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Characterization and Geotourist Resources of the Campo de Calatrava Volcanic Region (Ciudad Real, Castilla-La Mancha, Spain) to Develop a UNESCO Global Geopark Project

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Abstract: The Campo de Calatrava Volcanic Region is located in Central Spain (Ciudad Real province, Castilla-La Mancha) where some eruptions of different intensity and spatial location took place throughout a period of more than 8 million years. As a result, more than 360 volcanic edifices spread over 5000 km^2. Eruptions of this volcanic system were derived from alkaline magmas with events of low explosivity (Hawaiian and Strombolian). These events are characterized by three different manifestations: the emission of pyroclasts (cinder and spatter cones) and lava flows; some hydromagmatic events, which lead to the formation of wide craters (maars) and pyroclastic flows; and remnant volcanic activity related to gas emission (CO_2), hot springs (hervideros) and carbonic water fountains (fuentes agrias). The methods used for this study are based on analytical studies of geography, geomorphology and geoheritage to identify volcanoes and their resources and attractions linked to the historical-cultural heritage. These volcanoes are a potential economic resource and attraction for the promotion of volcano tourism (geotourism), and they are the basis for achieving a UNESCO Global Geopark Project, as a sustainable territorial and economic management model, to be part of the international networks of conservation and protection of nature and, especially, that of volcanoes.

Keywords: Campo de Calatrava; geoheritage; geopark project; geotourism; Spain; volcanoes

1. Introduction

The Campo de Calatrava Volcanic Region (CCVR) is located in the center of the Ciudad Real province (Castilla-La Mancha) in Central Spain (Figure 1). The aims of his paper are twofold. The first aim is to characterize this volcanic area from a geological and geographical perspective (genesis, chronology, eruptive dynamics and volcanic morphologies). The second objective is to review which resources are the most interesting that are present in this volcanic region in terms of its geoheritage, and to highlight the different activities that are currently being undertaken to promote geotourism and sustainable development. Both the geological and geographical characteristics as well as the geotourist resources will serve as the basis for developing a UNESCO Global Geopark Project in order to present its candidacy to the Spanish National Committee for UNESCO Global Geoparks.

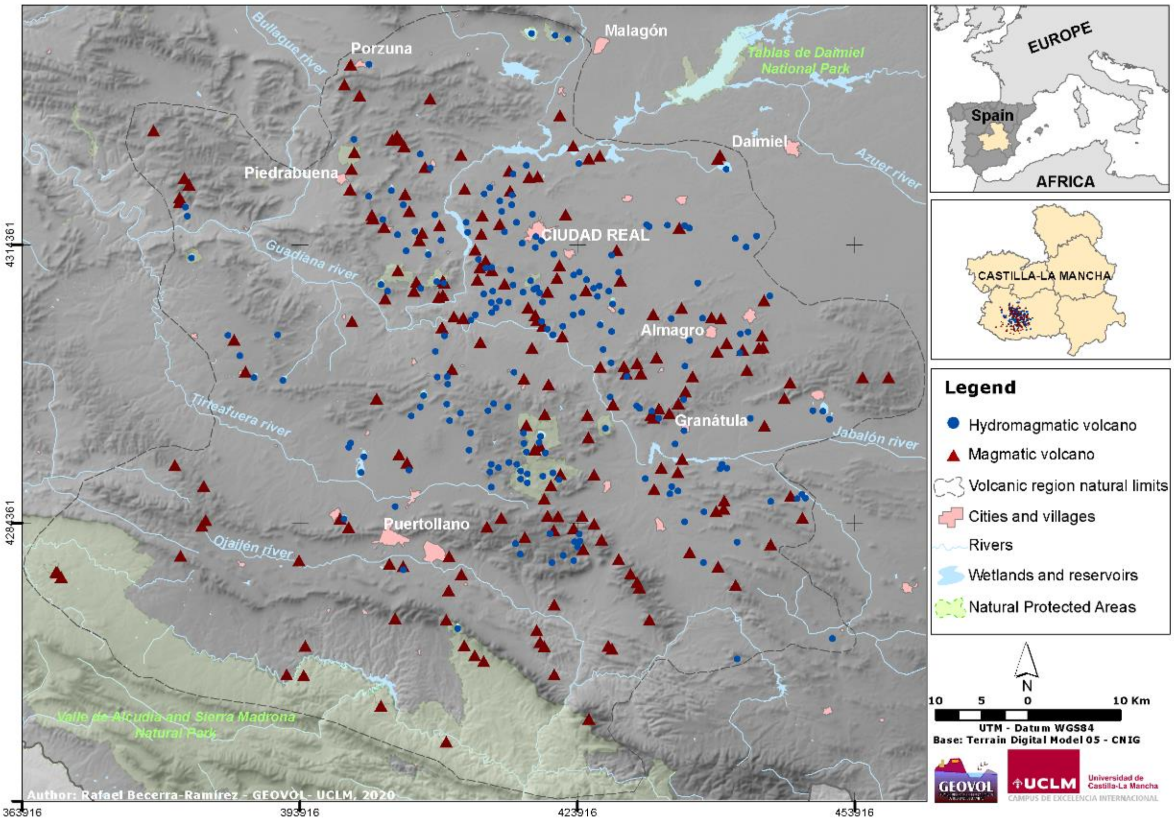

Figure 1. Study area and distribution of volcanoes in the Campo de Calatrava Volcanic Region (Ciudad Real province, Castilla-La Mancha, Spain).

In the first part of this paper, we want to highlight the great interest that this volcanic region has aroused from the 18th century to the present day. The first scientific reference interested in the existence of volcanoes in Campo de Calatrava can be attributed to the Irish naturalist William Bowles in his book *An Introduction to the Natural History and Physical Geography of Spain* (1775). Later studies developed between the 19th century and the end of the 20th century focused on petrological analysis [1–3] and the chronology of volcanoes [4–6]. From this period, the work by Francisco Hernández-Pacheco, *Study of the Volcanic Region in Central Spain* [7], has become the main source of reference for researchers of the CCVR, followed by the studies by Ancochea [8,9]. Other researchers in the 1990s and throughout the beginning of the 21st century have focused their work on the modeling and genesis of this volcanism [10–18]. From the year 2000 onward, studies turned towards a geomorphological aspect from the field of geography and reviewed the age of some volcanoes [19–34]. The latest studies are focused on highlighting the great geodiversity of the Calatrava volcanic region, its geoheritage and the link to other historical-cultural aspects and ecosystems, as well as the geoconservation and the promotion of volcano tourism (geotourism) [27,29,35–40].

Other noteworthy facets of the CCVR are its relative youth and the continuing volcanic activity, which will serve, in part, as the basis for justifying the UNESCO Global Geopark project proposal. Volcanic eruptions occurred in the area from the Miocene to the Holocene periods, spanning over 8.6 million years (My). The last eruptive event occurred 5500 years ago, so this region is considered to be an active volcanic area [22,23,29] and its current volcanic activity is manifested through continuous gas emissions, hot springs and carbonic water fountains (locally called hervideros and fuentes agrias).

The eruptions occurred in several well-defined stages, in which magmatic (effusive and Strombolian) and hydromagmatic (phreatic and phreatomagmatic) events took place. The final result was a wide variety of volcanic morphologies (cinder cones, spatter cones and maars) that, combined with other non-volcanic morphologies, developed a great geodiversity. This geodiversity is reflected in the Calatrava volcanic landscape, where natural aspects are interrelated with historical-cultural ones, both past and present, and as such will be one of the geotourist resources and attractions in the development of the geopark project.

Finally, we will focus on defining the wide variety of resources and attractions based on the region's geoheritage, thereby developing sustainable activities such as volcano tourism (geotourism). These resources and attractions are closely related to the geological and geographical characteristics of the volcanic region (landforms, gas emission, ecosystems and landscape). It is necessary for authorities and local population to begin using and revitalizing these resources in order to achieve a sustainable development of the territory designated for the geopark project.

2. Materials and Methods

The methods used are based on the analytical studies of geography and geomorphology, which aim to recognize landforms and deposits that can be observed in the landscape. A set of research techniques, ranging from a literature review to laboratory analyses, was implemented accordingly. Observation, sample collection (rocks, soils and paleosoils) and field data were also included.

Firstly, published works on the volcanism within the CCVR were reviewed. Later, the use of aerial photographs, satellite images, topographic maps and geological maps allowed for the identification of volcanoes and many of the tourist resources, such as hot springs and carbonic water fountains. Finally, by using geographic information systems (GIS), the volcanoes and tourist resources were placed on synthesis maps.

The different fieldwork performed helped us to delimit and characterize the geological setting as well as recognize the volcanic deposits and morphologies. This methodology has allowed us to classify the type of eruption and describe the morphologies associated with the monogenetic basaltic volcanoes using some morphogenetic and morphologic classifications [41–46]. The fieldwork has also made it easier to recognize the tourist resources and attractions that this volcanic region offers.

The biotic elements associated with shallow lakes held in hydromagmatic craters (maars) and other ethnocultural elements were also recognized. These are part of the historical-cultural heritage linked to the use of volcanoes throughout history and, presently, to their geoconservation and protection as stated in the regional law of nature conservation.

3. Geographical and Geological Features in the Campo de Calatrava Volcanic Region

The Campo de Calatrava Volcanic Region is located in a mountainous territory (in the southern Spanish plateau) where heights barely exceed 1100 m above sea level (La Atalaya volcano at 1118 m). The average height is over 650 m, while the average heights at the bottom of the valleys reach approximately 500 and 600 m.

This volcanic region is delimited in the north by the southern alignments of the Variscan folding reliefs of the Montes de Toledo; in the west by the area of mountains and glacis (rañas) where the Guadiana and Bullaque rivers flow, called the Montes de Ciudad Real; and in the south by the Alcudia valley, Sierra Madrona and Ojailén-Fresnedas valleys. These three natural boundaries in the north, south and west are not clear and precise boundaries as they are intertwined with each other. Even García [20] considers these three areas as a natural macroregion with very similar geomorphological, climatic and biogeographical characteristics. However, the delimitation in the east is more precise. Topographically, it moves from the mountainous landscape to the wide plains of La Mancha where the Variscan plinth and volcanic outcrops disappear completely, resulting in a totally different and anthropic landscape. Looking to the southeast, the region is delimited by Campo de Mudela [20] or the Alto Jabalón valley [21].

The rocks of this territory consist of quartzite, sandstone and slate (Paleozoic), limestone and marlstone (Neogene) and Quaternary sediments (alluvial—limestone, sand and gravel—and colluvial deposits). The landforms associated with eruptions in the CCVR are typical of effusive, Strombolian and hydromagmatic events that built 360 volcanoes [7,27,29,37,38,40]. Therefore, the landscape of the CCVR is settled into an extended basin framed by quartzitic mountains dissected by significant fracturing processes (Figure 2).

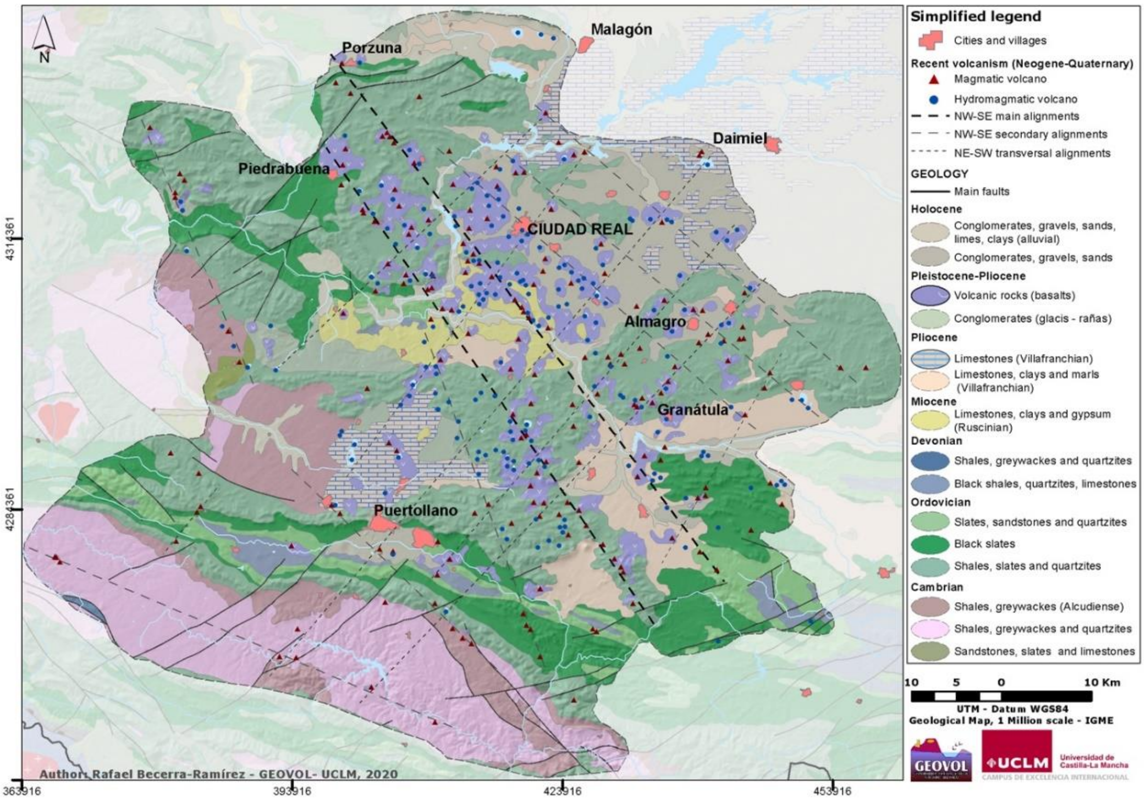

Figure 2. Geological map (1 million scale, IGME) [47], distribution of volcanoes and main volcanic alignments [9,11,12,21,29].

The distribution of the emission centers responds to tectonic patterns aligned in a NW to SE direction axial band accompanied by secondary parallel alignments running in the same direction. These are crossed by others that run in an ENE–WSW direction [9,11,12] (Figure 2). Furthermore, this volcanism is characterized by the presence of mafic and ultramafic rocks, coming from alkaline magmas very rich in CO_2, with a silica content lower than 45%, and is classified as a carbonate volcanism [18]. The result is the development of magmatic eruptions (Hawaiian and Strombolian), and the magma–water interaction has led to phreatic and phreatomagmatic eruptions [48,49]. Vulcanian explosive events may have also occurred, linked to the cooling of eruptive dykes and to the large amount of gas in this volcanic system [7,21]. In addition, the existence of a degassing vent (La Sima) can be attributed to a phreatic-type eruption [28,29,50].

3.1. Previous Studies

The first scientific reference of the existence of volcanoes in the CCVR can be attributed to the Irish naturalist William Bowles in 1775, who observed the presence of volcanic rocks between Almagro and Corral de Calatrava, close to the Jabalón river. In the 19th century, authors such as Maestre or Ezquerra del Bayo [1–3] studied basalt rocks in the plains of La Mancha (Central Spain), and Calderón, Quiroga and Cortázar [4–6] established the chronology for the first eruptive events in the Miocene.

In the 20th century, the work by Hernández-Pacheco [7] described the volcanic region, establishing the eruptive centers that were previously known up to that point as well as others that he himself had identified. As a result, he mapped out the spatial distribution of these centers, describing their petrology, deposits and eruptions, and established the age of the volcanism based on geomorphologic criteria.

At the end of the 1970s and the beginning of the 1980s, the studies focused on establishing the age of the eruptions through absolute dating techniques (K-Ar) [8]. In 1983, Ancochea [9] studied the volcanic rocks in order to establish the age of the Calatrava volcanism and analyzed the distribution of the eruptive centers and the geostructural patterns through the main faults in the volcanic region.

Other researchers continued to study the CCVR from both a geophysical and geochemical perspective [10–13], by using new methodologies. This has led to a better understanding of the origin of this volcanic region. López-Ruiz et al. [14] used a geodynamic model, established by Downes [15] and Hoernle et al. [16], to study the Calatrava region in relation with the intracontinental European volcanism.

In the early 21st century, a study by Gallardo [17], which has become another point of reference, proposed a new hypothesis on the origin of the volcanism and used new radiometric dating through the paleomagnetic polarities of volcanic rocks. He also studied the dynamics of the Neogene sedimentary basins of the Calatrava volcanic region and their connection to volcanism. Later, Bailey and Kearns [18] stated that carbonate volcanism is extensive and voluminous throughout the Calatrava region and that it is the most SW expression of intracontinental carbonatite–melilite volcanism in mainland Europe.

Geomorphological studies represent another line of work coming from the field of geography, which has focused on the geomorphological and morphometric analysis of volcanoes as well as a review of the age of this volcanism by means of absolute and relative dating. The most cited studies are the ones by García [19,20], Poblete [21–23], González [24,25], Gosálvez [26,27], Becerra-Ramírez [28,29], Carracedo et al. [30], Herrero-Hernández et al. [31] and Sarrionandia-Ibarra et al. [32–34].

The latest geographical studies, such as those by Gosálvez [27], Becerra-Ramírez [29] and Escobar [39], are related to the assessment of the geodiversity in the CCVR, its geoheritage, the ecosystems developed in the volcanic shallow lakes and the use of volcanic materials throughout history. Finally, current studies on the Calatrava volcanic region are focusing on the geoconservation of volcanoes and the promotion of volcano tourism (geotourism) [29,35–38,40].

3.2. Different Hypotheses on the Genesis of the Calatrava Volcanism

The interpretation of the genesis of the Calatrava volcanism has been studied by different authors and from different points of view (Table 1). Cadavid [51] interpreted its origin as an aborted rifting process due to a cortical elevation and a lithosphere thinning. Ancochea [9] raised the possibility of a hotspot that causes crustal rising and lithosphere thinning, and the existence of a rifting process that did not evolve very much or completely stopped.

The gravimetric analysis carried out in the CCVR confirms the hypothesis of the presence of a relative anomaly of Bouguer of −20 milligals along 100 km [52] and the existence of a positive thermal anomaly 40 km long and 6 km thick. Bergamín and Carbó [52] established a crust-thinning model, placing the Mohorovicic discontinuity at a 31 km depth under the center of the volcanic region. López-Ruiz et al. [14] inferred that, under the CCVR, a weak area in the crust has developed due to the compression from southern tectonic forces (Baetic Mountains). This process caused crust doming and the rise of ultramafic and alkaline rocks to the surface. The chemistry of the volcanic rocks in the CCVR confirms the hypothesis of the rifting process in the origin of this volcanism and in the rest of the European Cenozoic volcanism [53].

Vegas and Rincón [13] and Rincón [54] proposed another model to explain the origin of this volcanism based on a flexural process of the lithosphere in a low compression regime. For these authors, the asthenospheric mantle could have risen, decompressed and partially melted.

Gallardo [17,55] interpreted a process of an oblique rifting, based on a movement of blocks according to the patterns of paleomagnetism, which would indicate that there is no magnetic oscillation when the Calatrava volcanism formed after the orogenic movements of the Baetic Mountain range.

Finally, Cebriá and López Ruiz [56] proposed that the Calatrava volcanism is related to the magmatic reservoir of the Central Atlantic Plume, following the petrogenetic model of Oyarzum et al. [57], which links the volcanic regions of Campo de Calatrava, the Catalonian Volcanic Zone (NE Spain), the French Massif Central, Eifel and Vogelsberg (Germany) and the Bohemian Massif volcanism.

Table 1. Different hypotheses on the genesis of the Campo de Calatrava Volcanic Region. Modified from González et al. [58] and Becerra-Ramírez [36].

Authors	Year	Interpretation	Observations
Cadavid Ancochea	1977 [51] 1983 [9]	Aborted rifting process. Hot spot?	Cortical elevation and lithosphere thinning. Mantellic thermic anomaly
Bergamín and Carbó	1986 [52]	Little evolved Rift	Relative Bouguer anomaly (−20 mg). Local rise in temperature. Crust thinning (31 km).
López Ruiz et al.	1993 [14]	Cortical weakness due to Baetic compressive thrusts	Crust bulging/doming. Basaltic magma ascent (diapirs): 2 stages: diapiric and distensive
Vegas and Rincón Rincón	1996 [13] 1999 [54]	Flexural process: rise of the asthenospheric mantle, decompression and partial fusion (Fields of compressive stresses: Baetic and Iberian ranges)	Deformation of the Baetic basin. Crust buckling. Reactivation and creation of directional faults. Development of faults in the Hercynian basement.
Gallardo	2005 [17] 2006 [55]	Oblique rifting. Paleomagnetism: block movement.	No magnetic oscillation. Calatrava volcanism after the Baetic orogenic movements.
Cebriá and López Ruiz	2010 [56]	Petrogenetic model base on the EAR (Oyarzun et al. [57]: metasomatism of the lithospheric mantle in the European volcanic regions.	The European Cenozoic volcanism reservoir comes from the Central Atlantic Plume.

3.3. Chronology of the Volcanism

The first studies that tried to give an explanation of the age of volcanism in the Calatrava region date from the late 19th century [4,5], and suggest that the eruptive phenomenon occurred in the Miocene. This timeframe was corrected by Hernández-Pacheco [7], who established the age between the Upper Pliocene and Middle Pleistocene, based on stratigraphy. Years later, Molina [59] proposed three stages: The Intra-Miocene, Lower Pliocene and Upper Pliocene–Lower Pleistocene (Table 2).

Ancochea [8,9], by means of absolute dating (K-Ar) applied to 12 volcanoes, established two periods in the volcanic activity of the CCVR. The first one was from 8.7 million years to 6.4 My (Early Miocene), and the second one from the Pliocene (4.5 My) to the Lower Pleistocene (1.5 My), with a period of inactivity of about two million years between them.

Gallardo and Gallardo et al. proposed two different stages [17,55,60]. The first one in the Miocene period with the eruption of the Morrón de Villamayor volcano (6.4 My), and a second stage, where most eruptions occurred, from 4.7 My to 1.75 My. These authors extend the last eruptions to the Upper Pleistocene (0.7 My) in a later work [61].

Table 2. Different interpretations of the chronology of the Campo de Calatrava Volcanic Region. Modified from González et al. [58] and Becerra-Ramírez [36].

Authors	Year	Chronology	Observations
Quiroga Cortázar	1880 [4] 1880 [5]	Miocene	
Hernández-Pacheco	1932 [7]	Upper Pliocene Middle Pleistocene	
Molina	1975 [59]	3 stages: 1. Intra-Miocene 2. Lower Pliocene 3. Upper Pliocene-Lower Pleistocene	Depending on the arrangement of volcanic materials with respect to sedimentary basin deposits.
Ancochea	1979 [8] 1983 [9]	2 stages: 1. 8.7 My to 6.4 My (Upper Miocene) 2. 4.5 My (Pliocene) to 1.5 My (Lower Pleistocene)	Petrological, geochemical and analysis of magnetic polarity and *K-Ar* absolute dating.
Poblete	1995 [21]	3 volcanic stages: EV1. Upper Miocene–Lower Pliocene EV2. Lower–Upper Pliocene EV3. Lower-Middle Villafranchian	Depending on the positions of the volcanic products with respect to the Ruscinian limestones.
Poblete and Ruiz	2002 [22] 2007 [62]	EV4? Pleistocene–Holocene? End of Upper Pleistocene to Middle Holocene (<10,000 years)	For the Ojailén and Jabalón basins. Relative data according to the disposition of volcanic products with respect to the sedimentation of the basin.
González González et al.	1996 [24] 2004 [63] 2006 [64] 2007 [65]	Last eruptions: End of Upper Pleistocene to Middle Holocene. Eruption related to Columba volcano: Middle Holocene (<6000 years)	Absolute dating from plant remains found in a paleosoil fossilized by hydromagmatic deposits. Radiocarbon analysis (^{14}C).
Gallardo Gallardo et al.	2005 [17] 2006 [55] 1998 [60] 2002 [61]	2 stages: Neogene (6.4 My) Pliocene–Pleistocene (4.7–1.75 My) and Upper Pleistocene (0.7 My)	Paleomagnetism
Poblete et al.	2019 [23]	Las Cuevas volcano (±75,000 years)–Columba volcano, last eruption between 14,000 and 6200 years (Upper Pleistocene–Holocene)	Absolute radiocarbon dating of river terrace deposits and the paleosoil of Columba volcano.

Poblete [21] established the existence of three eruptive stages by using relative dating. The first one (EV1) started in the Early Miocene and continued until the Lower Pliocene (the Ruscinian limestones present in the area are prior to this first stage). The second one (EV2) would have developed between the Lower and the Early Pliocene, and the third one (EV3) would have started around the Lower and Middle Pleistocene. For this author, this last stage would have ranged between the Pleistocene and the beginning of the Holocene.

González et al. [64,65] established the last eruptive activity in the Middle Holocene of the Columba volcano through radiocarbon absolute dating (^{14}C). The analysis was applied to organic matter contained in a paleosoil fossilized by deposits of pyroclastic flows (Figure 3) (Table 2). The radiocarbon analyses were carried out by the Ångstrom Laboratory at Uppsala University (Sweden), showing a calibrated age of 5510–5551 years BP (charcoal and vegetable molds). This dating was later confirmed by

Poblete et al. [23] and coincides with the latest eruptions in the Ojailén and Jabalón valleys [22] and the basin of Moral-Calzada–Santa Cruz de Mudela, at the end of the Upper Pleistocene–Holocene [62,63].

Figure 3. (**a**) Pyroclastic flow deposits on the Columba volcano; (**b**) detail of the deposits of pyroclastic density currents (base surges), paleosoil and vegetable molds.

The relative and absolute dating that has been carried out in the last years in the CCVR prove the existence of eruptive activity in the Holocene. The last eruptions occurred in the Upper Pleistocene–Middle Holocene, and currently the eruptive activity remains dormant due to the intense process of magma degassing [29,58,66,67].

The dating and manifestations of volcanic origin (gas emission, thermal anomalies and the sudden increase in temperature in some wells from the area) have prompted the Smithsonian Institution (National Museum of Natural History—USA) to recognize and include the Campo de Calatrava Volcanic Region in the list of active volcanic zones within its Global Volcanism Program (Volcano No. 210040) [29,68]. This latent activity would be another of the most interesting characteristics of the Calatrava volcanic region for development of a geopark project. The relative youth of the region and the gas emission processes that the dormant activity shows are the basis for some of the tourist resources that will be part of the geopark project, such as hot springs, carbonic water fountains and gas-water fountains (jets).

4. Interpretation of Eruptive Dynamics and Volcanic Morphologies in the Campo de Calatrava Volcanic Region

4.1. Eruptive Dynamics

The eruptive manifestations of this volcanic region, given its alkaline nature and its location in an intracontinental platform area, fall within monogenetic and polycyclic basaltic volcanism [29]. The interpretation of these types of eruptions has been based on the study of volcanic deposits and the landforms they developed, suggesting two main types of eruptions: magmatics (effusive and Strombolian) and hydromagmatic (phreatic and phreatomagmatic). Of the total number of volcanoes that have been accounted for to date in the volcanic region (about 360), 51% would correspond to magmatic eruptions and the remaining 49% to hydromagmatic eruptions.

The effusive eruptions in the CCVR were characterized by the emission of abundant lava flows and the development of lava fountains in the eruptive centers, generating very specific deposits: agglutinated scoria or spatter. These deposits were able to form small volcanic edifices, known as spatter cones. These are rarely found in the region, as they are very small and easily erodible morphologies.

Strombolian eruptions in the Calatrava region emitted large quantities of pyroclasts: lapilli, scoria and bombs. These built the typical cinder/scoria cones that also erupted on occasion, forming lava flows.

The presence of water outside the volcanic system (aquifers or superficial water), allows for the development of highly explosive phreatic and phreatomagmatic eruptions. These eruptions dramatically changed the landscape by creating deep and wide depressions, hydromagmatic explosion craters or maars. These hydromagmatic craters are able to hold water and develop a unique wetland complex in the Iberian Peninsula and even in the Western Europe volcanism [26,27,49]. The volcanic-origin shallow lakes of the CCVR are another of the most notable characteristics from the geomorphological and ecosystem perspective. These also play an important role in the overall landscape of the region and as a potential tourist attraction for the geopark project.

4.2. *Volcanic Morphologies*

Following the classifications outlined in the work of Thouret [41], the Encyclopedia of Volcanoes [42] and the morphogenetic classification by Kereszturi and Németh [43] for monogenetic basaltic volcanoes, the resulting morphologies based on their genesis and subsequent modeling in Campo de Calatrava would correspond to the following types: spatter cones, spatter-dominated scoria cones, ash-dominated scoria cones, cinder/scoria cones, maar-diatremes and some eruptive complexes where maar/scoria cones and maar-tuff ring/scoria cones were built [27,29].

The wide variety of morphologies resulting from volcanic eruptions, in combination with other non-volcanic landforms, has created a wealth of geodiversity, which will be another key in justifying the geoheritage values of this territory for the development of the geopark project.

4.2.1. Spatter Cones

These volcanic morphologies are the result of short effusive events generated throughout effusive fissure eruptions in the Campo de Calatrava Volcanic Region. They are mainly located in the Paleozoic mountains (although they are occasionally found in the center of the basins) and have formed small piles of scoriaceous material and highly welded and agglutinated spatter between them. These eruptive fissures have emitted short and thick lava flows that travel down along the mountain flanks, which sometimes stop in the middle of the hillside or fill in pre-eruptive paleo-gullies. The resultant morphology is represented by small agglutinated scoria cones or spatter cones, hornitos and even rootless hornitos. A morphological analysis was applied to 23 spatter cones in the CCVR (out of more than 30 counted), and the mean diameter of the cones is 312 m and the mean height is 11 m [29]. Because of their fragility, these small volcanic morphologies are quite eroded and only the lava flows are preserved. With respect to hornitos, rootless hornitos and some spatter cones, these have disappeared almost completely [29]. Some significant examples of these spatter cones, which opened on Paleozoic mountain flanks, are La Sima, Casas de Fuentillejo or Cerro Negro (Figure 4) [28].

Figure 4. Some examples of spatter cones: (**a**) La Sima (Granátula de Calatrava); (**b**) Peñas Negras (Piedrabuena); (**c**) Peñón de Ciruela (Ciudad Real); (**d**) Pozo Blanco (Moral de Calatrava).

These small morphologies, which are not very prominent topographically, receive the local name of *castillejos*, because of their current morphology that has been significantly modified by erosive agents. These morphologies resemble the towers and ruins of a castle [7,21,29,39,40].

4.2.2. Cinder/Scoria Cones

These are volcanic edifices formed by Strombolian or violent Strombolian eruptions with the emission of pyroclastic materials (ashes, lapilli, scoria, bombs and blocks). These have a variable welding degree, which build a truncated cone shape around the center of the emission (Figure 5). In the CCVR, these eruptions have generally developed lava fountains, pahoehoe and aa lava flows, and many spatter deposits that generated piles flowing down the slopes of some cones. For example, in the southeastern flank of the Cerro Gordo volcano, these spatter deposits have been attributed to lava fountains emitted from the main crater, and they have formed overlapping lobes with steep fronts about 4 m thick [69]. The mean diameter for the base of the cinder cones in the CCVR is 680 m and their heights rarely exceed 100 m [29].

The analysis conducted by Becerra-Ramírez [28,29] confirms the existence of different morphology types of the cinder cones in the CCVR. This characterization has been applied to 111 cones (of more than 160 cones counted) and is based on the morphological classification of monogenetic basaltic volcanoes [44–46], which establishes different morphologies: ring-shaped cones, horseshoe-shaped cones, multiple volcanoes and volcanoes without a crater. In the CCVR, 14% of the total cones analyzed are ring-shaped cones, 17% are horseshoe-shaped cones, 9% are multiple volcanoes and 60% correspond to volcanoes without a crater [29]. In turn, volcanoes without a crater were divided into pyroclastic mountains (40% of those analyzed) and spatter-lava mountains (20%), following a morphogenetic classification [43] for spatter-dominated scoria cones and ash-dominated scoria cones, depending on the predominance of scoria or lapilli and spatter, respectively [29].

These morphologies in the volcanic region are given the local name of *cabezos*, *cabezas* (translated literally as "heads") or *cerros*, for their morphology which has been flattened and softened by the intense erosion. The lava flows are also colloquially referred to as *negrizales* ("blackish"), due to their blackish-brown color [7,21,29,39,40].

Figure 5. Some examples of cinder cones: (**a**) La Yezosa (Almagro); (**b**) Cerro Gordo (Granátula-Valenzuela de Calatrava); (**c**) Cabeza del Rey (Poblete); (**d**) La Arzollosa (Alcolea de Calatrava).

4.2.3. Maars and Diatremes

In the Campo de Calatrava Volcanic Region, landforms derived from the hydromagmatic activity are affected by the location of water, its interaction with the magma and the breaking of the rocky substratum in the explosion [25]. The resultant morphology is a hydromagmatic crater or maar. Types of volcanic edifices vary depending on several factors, such as the strength of the paroxysms, the resistance and nature of the rocky substratum, the magma–water interaction and the depth of the resulting crater caused by the explosion. With respect to the CCVR, three types of hydromagmatic edifices can be distinguished: maar-diatremes sensu stricto, maars with well-developed tuff rings and maars without tuff rings.

Maars are the most widespread morphologies in the CCVR. They are characterized by the presence of an explosive depression opened under the pre-eruptive topographic surface (Figure 6). In the hard and soft rocks at the Variscan substratum, the craters present very craggy and rough internal walls, with depths of up to 150 m. They usually lack a tuff ring and, if they have it, this is not fully formed. The craters developed in sedimentary basins are subcircular or subelliptic with well-defined tuff rings surrounding them, provided that the erosion has not been too intensive.

Figure 6. Some examples of maar-diatremes with shallow lakes: (**a**) Las Carboneras (Argamasilla de Calatrava); (**b**) Hoya de Cervera Natural Monument (Almagro); (**c**) Laguna del Acebuche, Calatrava Massif Natural Monument (Almagro).

The research carried out by some authors [9,25–27,70,71] establishes a morphological classification for distinguishing different types of hydro-magmatic explosion craters, which differentiates four main morphological types: isolated explosion craters, clustered explosion craters, intersected explosion craters and those associated with a cinder cone.

This morphological classification has been applied to 43 maars (out of a total of 180 maars) located in the central part of the volcanic region of Campo de Calatrava [40]. It has been concluded that these are predominantly clustered explosion craters (20 craters), located mostly in sedimentary basins; followed by isolated explosion craters (14 craters), most of which are also located in sedimentary basins, while only two simple craters appear in plains. Seven centers can be found attached to the cinder cones (maar/scoria cones) and only one corresponds to an intersecting explosion crater, the Las Longueras maar. However, this is something very common in other regions of intracontinental volcanism (Auvergne, Eifel, and La Garrotxa) or in volcanism associated with a subduction process (the region of Lazio and Campania, Carpathians, Mexican Neovolcanic Axis, etc.). The maar–scoria cone association is due to alternations between the hydromagmatic and purely magmatic phases, something that has been observed relatively frequently in Campo de Calatrava (Hoyas del Palo, Parral, Peral or Las Higueruelas, among others) [27].

The analyzed maars have a mean diameter of 900 m at their culminating point and at the bottom of the crater they have a mean diameter of 630 m. The maximum depth varies between 2 and 143 m, with a mean depth of 25.72 m. With respect to the area, the maars have a mean area of 0.73 km^2, with minimum and maximum values of between 0.07 km^2 and 2.38 km^2, respectively [27].

Similar to the magmatic volcanoes and lava flows in the volcanic region, the maars are called *hoyas*, *navas* or *navazos* ("hollows") because of their shallow depressed topography and their capacity to hold water [27,40].

4.3. Other Manifestations and Volcanic Structures Related to a Mantle Degassing Origin

This volcanic system presents the largest diffuse emissions of CO_2 of all the recent volcanism in Western Europe with visible surface manifestations (hot beds and gas outlets). These results showed the existence of magmatic masses in a degassing process and greater energy from the volcanic-hydrothermal system, as well as semi-active tectonic fissures that facilitate the rise of gases (mainly CO_2, CO and Rn) to the surface [66,72–74]. As mentioned above, perhaps this is another of the most interesting geological features that supports the UNESCO Global Geopark proposal and project.

The presence of such high concentrations of CO_2, and to a lesser extent He and Rn, is directly related to recent tectonics and volcanism. It should be noted that this flux of CO_2 and other gases always follows the structural alignments, although its presence on the surface is rare and only through thermal springs [21,66,73,74].

In 2007, a field study was undertaken to assess the diffuse emissions of CO_2 in Western European volcanic systems by the Instituto Tecnológico y de Energías Renovables (ITER, Cabildo de Tenerife) studying the Calatrava volcanic region [66] with the collaboration of the GEOVOL research group (Universidad de Castilla-La Mancha—UCLM). The main result obtained was that this volcanic system had the highest peak or abnormal (P) value of CO_2 among all of the Western European volcanic systems studied, with the resulting data of 119,993. This was followed by Lake Laach in Germany.

According to information provided by Calvo et al. [66], Vaselli et al. [73] and Elío et al. [74], one can speak of the existence of at least two sources of CO_2. The first one stemming from a deep degassing of the mantle where the carbon dioxide reach the surface as a diffuse gas throughout the soil or dissolved in superficial aquifers. A second superficial source that has its origin in biogenic activity.

The highest CO_2 flux values are associated with hot springs and a case of CO_2 output without water, La Sima (Granátula de Calatrava), all of which present an aligned distribution following the tectonic patterns (NW–SE axial band) and a spatial attenuation of the CO_2 signal from the center to the outskirts of the volcanic region. These data are characteristic of aligned conduits in tectonic accidents controlled by fracturing and the fluid flows (water and gas) ascend through these semi-active tectonic structures [74].

4.3.1. Hot Springs and Natural Spas

The existing springs in this region are related to the hydrothermal activity linked to the degassing of mantellic-origin under the CCVR, and they are mentioned in *Relaciones Topográficas de Felipe II* (16th century). These hot springs are located along the volcanic system alignments with the dominant directions NW–SE, NNW–SSE and ENE–WSW [21]. The chemical analysis of the water in these hot springs reveals the presence of calcium and magnesium bicarbonates, sodium and calcium bicarbonate and sodium–magnesium sulphates, with an abundant presence of cobalt, manganese, quartz, iron, calcite, dolomite and manganese siderite. Mineralogical analyses of the water residue reveal that the main component is the iron that is deposited in the hot springs as $Fe(OH)_2$ in the form of goethite [21].

The large amount of CO_2 emerging from the water and forming the bubbling characteristic of these hot springs must be highlighted. The average temperatures fluctuate between 15 and 28 °C [21]. Some representative hot springs (locally called hervideros and fuentes agrias) in the CCVR (Figure 7) are El Chorrillo (Pozuelo de Calatrava), La Sacristanía (Calzada de Calatrava), El Barranco (Aldea del Rey) and Villafranca (Ballesteros de Calatrava).

Figure 7. Examples of hot springs and natural spas: (**a**) Baños del Emperador—women's bath (Miguelturra); (**b**) Baños del Emperador—men's bath (Miguelturra); (**c**) El Barranco baths (Aldea del Rey); (**d**) Boiling waters in El Barranco (Aldea del Rey); (**e**) El Chorrillo bath (Pozuelo de Calatrava).

4.3.2. La Sima Degassing Vent

Related to the existence of hot springs, a degassing vent called La Sima has been identified (Figure 8). Its origin is attributed to a phreatic-type eruption, made easier by the existence of a 300 m fracture running in a WNW–ESE direction located at the SW flank of the Paleozoic mountain of Valenzuela-Granátula. The existence of this vent is mentioned for the first time in *Relaciones Topográficas de Felipe II* (16th century).

This morphology consists of a small cone of detrital material (mainly heterometric and angular blocks of quartzite) and two morphologically different depressions (craters). The small cone-shaped formation is built up by breccia deposits, composed of heterometric lithics derived from the pre-existing rocks (mainly quartzite), where a phreatic explosion opened the craters. These deposits (without any new volcanic material) are encrusted in a muddy matrix and are similar to those described by Barberi et al. [75] for typical phreatic eruptions.

The cone base has a sub-elliptical shape and its nature is the result of a phreatic fissure explosion. Its mean diameter is 27 m and its surface diameter is 770 m^2. The maximum height of the detrital cone is barely 4 m, which may indicate that there is an important asymmetry between the NE flank, where the height of the cone is at ground level, and the SW flank, where the largest slope is measured. The total volume calculated for this small cone is around 1173 m^3. The main crater has a sub-elliptical floor with a mean diameter of 9.3 m and a depth of 3.5 m. The second crater has a mean diameter of 7.1 m and a depth of 1.2 m [50].

The gases emitted by this degassing vent when measured are CO_2 (diffuse flux of 324 kg $m^{-2}d^{-1}$ and air concentrations higher than 50%), H_2S (around 1 ppm), CO, CH_4 and Radon (180,000–270,000 Bq/m^3) according to Calvo et al. [66] and others [74]. All of these gases are very dangerous for the organisms living in the environment since numerous wild animals (birds, small mammals and reptiles) and even sheep [67] die every year because of them (Figure 8c). Up to now, neither similar morphologies linked to volcanic areas in the Iberian Peninsula have been reported, nor has been the danger associated with those gases [50].

Figure 8. (**a**) La Sima degassing vent main crater; (**b**) volcanic gas monitoring station; (**c**) dead owl inside the main crater; (**d**) degassing points without vegetation.

Given the importance of this gas emission and the danger it poses to living organisms, the first volcanic monitoring network in the Iberian Peninsula was installed in 2009 (Figure 8b) and a microseismic network was recently installed by the Instituto Geográfico Nacional—IGN (Spanish Government). This geological feature gives credence to the classification of this territory as an active volcanic area, which then gives the scientific committee more weight when presenting the CCVR's candidacy for becoming a UNESCO Global Geopark.

4.3.3. Gas-Water Fountains

Since the year 2000, different gaseous upwellings, known locally as *chorros* (literally, jets), have been documented, particularly in the eastern part of the volcanic region (Figure 9). These are water outlets forced up by the sudden depressurization of CO_2, contained in a confined aquifer, that forms a trap for carbon dioxide migration. In almost all documented cases to date, the driving force behind this process is the degassing of CO_2 as a consequence of an increase in human pressure on the underground aquifers for agricultural purposes in Campo de Calatrava. This action affects the aquifers with a high carbon dioxide content [76–78]. The presence of such high concentrations is directly related to the volcanism resulting in the emission of CO_2 either diffusely [66] or through hervideros and fuentes agrias.

Since 2000, several such phenomena have occurred, such as the 60 m high Chorro de Granátula that was active for 6 months (Figure 9a); the Chorro de Bolaños in March 2011, which flooded a hydromagmatic crater (Figure 9b); and those that occurred in other wells in the Bolaños and Almagro area in 2012, 2013, 2014 and 2018, with the last occurrence between November 2019 and May 2020 (Figure 9c,d) [76–85].

With respect to the Chorro de Bolaños, March 2011 (Figure 9c), INVOLCAN and GEOVOL-UCLM [72,82] were able to assess the gases emitted by this upwelling, concluding that they were mostly comprised of CO_2 (concentration levels above 90%) and an unquantifiable presence of H_2S and mercury vapor (Hg^0), both very characteristic of active volcanic–hydrothermal systems. The origin of the

CO_2 was determined by geochemical analysis (evaluation of isotopes $^{13}C/^{12}C$, $^{3}He/^{4}He$ and the molar ratios $CO_2/^{3}He$ and CO_2/He), resulting in 99% of the CO_2 emitted in Bolaños coming directly from the mantle. In this case, it was estimated that the location of the hydrothermal system would be at about a depth of 640 m (at 63 bar pressure) and at a low temperature (118 °C), from where the CO_2 would rise by exsolution to more superficial positions through faults or trapped in confined aquifers in sedimentary basins.

Figure 9. (**a**) Chorro de Granátula, years 2000–2001; (**b**) Chorro de Bolaños and flood, year 2011; (**c**) Chorro de Almagro and flood, years 2019–2020; (**d**) Chorro de Almagro, year 2013.

5. Volcanic Resources to Implement a UNESCO Global Geopark Project in Campo de Calatrava Volcanic Region

The Calatrava Volcanic Region presents a great geodiversity, having very interesting geological and geographical characteristics, as previously mentioned. When taking into consideration those ecosystems present in the maar lakes (biodiversity) in conjunction with the overall landscape of the area and its historical-cultural elements, the importance of having a profound understanding of the nature of volcanoes becomes that much more apparent. Through this understanding, a clearer picture of how to best manage the volcanoes and its landscape can be obtained. This is of great importance to its geoheritage and for its potential of becoming an economic resource for the area.

Volcanic landforms, as part of the geoheritage (included in the natural heritage) of any territory, require comprehensive knowledge and characterization through scientific study, inventory and its evaluation for further research. Once this has been done, it is necessary to promote the area as a resource, either as a natural, scientific, cultural and/or didactic one. Additionally, a management scheme must be put into place for the conservation and protection of the area as well as the development of sustainable activities, such as volcano tourism (geotourism) [29,36,37,86–88].

Under these premises, the Provincial Council of Ciudad Real has taken the reins to promote a geopark project that will have its geological base at the volcanoes of the Calatrava region. This has come about after several years of debate among the regional scientific community represented by geographers from the GEOVOL-UCLM research group, different developmental associations and the public administration [37,89–94].

According to the UNESCO Global Geopark Network [95], a geopark is a well-managed, unique and unified geographic area where "sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development". In addition, geoparks use their "geological heritage, in connection with all other aspects of the area's natural and cultural heritage, to enhance awareness and understanding of key issues facing society in the context of the dynamic planet we all live on, mitigating the effects of climate change and reducing the impact of natural disasters".

The geopark designation would have a vision far beyond being purely geological. It would be a broader and more integrative management model and much more geographical. This can be explained by the fact that both the elements of the natural environment (geology, landforms, climate, hydrology, fauna and flora) as well as those of the human environment, their social behavior (past and present) and their cultural and ideological expressions, are embodied in the territory and, of course, on the volcanoes. Moreover, UNESCO's own definition of a geopark states that [95] "raising awareness of the importance of the area's geological heritage in history and society today, UNESCO Global Geoparks give local people a sense of pride in their region and strengthen their identification with the area".

The UNESCO Global Geopark Project "Volcanes de Calatrava. Ciudad Real" is in the process of being drafted by different figureheads from the public and private sectors of this territory (scientists, city halls, development associations, commonwealths, associations of companies, etc.). This is being done in order to publicize the interest of the project and the economic benefit that it could have for the municipalities if the area received this distinction [38]. In July 2020, a scientific committee composed of 26 members from different disciplines (geographers, geologists, mine engineers, biologists, ecologists, historians, art historians and high school and university teachers) was established. This committee is responsible for the delimitation of the area indicated in the project and the inventory of the most relevant geosites, geozones and georoutes for the presentation of the project's candidacy to the Spanish National Committee of the UNESCO Global Geoparks [38,93].

5.1. Geotourist Resources

Volcanoes present themselves as an exceptional heritage, an element to be valued for science and an unquestionable social resource (soils, geothermal processes, rocks, tourism, etc.), as well as offering many attractions (eruptions, hot springs, beautiful landscapes, etc.). Therefore, the reasons why they are visited are many and quite varied. The main resources that volcanoes offer are related to geonatural factors (their relief, hot springs, vegetation, wildlife, etc.) and geocultural factors (historical, archaeological, religion, etc.). Thus, one of the main economic resources they offer worldwide is tourism [86,87,96,97].

Volcano tourism consists of visiting active, dormant or extinct volcanoes for the purpose of studying and exploring them, provided that they have a geological and geomorphological heritage interesting enough to attract visitors [87,96–100]. Research, such as that carried out by Sigurdsson and Lopes-Gautier [96] and Dóniz-Páez [87], groups the touristic attraction of volcanoes into 8 categories: 1. The landscape and beauty of the volcanic geography; 2. The spectacle of volcanic activity (eruptions, geysers, fumaroles …); 3. Hot springs and natural spas; 4. The practice of extreme and adventure sports; 5. Eco/geo-tourist and nature activities; 6. Volcanic sand beaches (black, green, red); 7. Archaeology on volcanic areas; 8. Volcanoes and religion.

It is therefore necessary to take advantage of the resources offered by volcanoes in order to offer a broader range of tourist attractions, beyond the other traditional activities that promote gastronomy tourism, local festivals, visits to monuments and historical buildings or to the National Parks (Cabañeros and Tablas de Daimiel) or Natural Parks (Lagunas de Ruidera and Valle de Alcudia-Sierra Madrona) in the province of Ciudad Real [37]. It is also necessary to consider what is attractive about the CCVR volcanoes for the tourists who visit them, as is done in other volcanic areas around the world [101,102]. The main attractions of the volcanoes in this region are the volcanic deposits (ash, lapilli, lava flows, pyroclastic flows, spatter, etc.) and the resulting morphologies (constructive and destructive), the ecosystems developed within them, the ethno-cultural elements present and, ultimately, the volcanic landscape of Calatrava.

Almost all of the 8 categories of volcanic attractions mentioned above appear in this territory, with the exception of the volcanic sandy beaches and the spectacle of eruptive activity. Logically, this is because of the intracontinental location of the volcanic region and the fact that the volcanism is dormant or latent, except for the aforementioned gas-water fountains that occasionally take place in the area [36,37]. Some tourist attractions grouped by categories would be the following:

- The scenery and volcanic landscape of Campo de Calatrava: The volcanic landforms have significantly changed the previous morphology and topography in the Neogenous plains and Paleozoic mountains on which they were built as a "postiche" relief. The *castillejos* (spatter cones) appear mainly on the slopes of Paleozoic mountains, the *cabezos* or *cabezas* (cinder cones) stand out topographically on flats and sierras forming their highest point, and the *hoyas* or *navas* (maars) generate deep depressions capable of temporarily holding shallow lakes. With regard to the ecosystem, the volcanoes also generate a radical change in the patterns of flora and fauna, especially the shallow lakes of the maars, where the ecosystem adapts to the temporary conditions of flooding and drying. In addition to the volcanic morphologies, the Mediterranean forest must also be considered as a valuable asset to the overall landscape. It is reasonably preserved in the mountain areas, but quite altered and anthropized in the flat areas. Hence, this markedly contrasting landscape that enriches the beauty of the CCVR (Figure 12).
- The spectacle of ongoing volcanic activity: These are not eruptions, but the continuation of volcanic activity is manifested in the form of a diffuse gas emission. This emission is presented both in the hydrothermal waters of the region, fountains and hot springs, and also in the sudden and ephemeral appearance of jets—gas-water fountains or chorros (similar to a geyser) as mentioned in Section 4.3.3. These jets are quite appealing to the local population, even though the duration of these phenomena is short (Figure 9).
- Fountains, hot springs and natural spas: Related to the above attraction, there are many fountains of carbonic water charged with CO_2 [21,39,103], known as fuentes agrias ("sour water fountains"), and hot springs or hervideros ("boilers", due to the characteristic bubbling of the gas escaping through the water) with temperatures ranging from 15–17 °C to 28–35 °C. Many of these fountains and springs have been used and well-kept since ancient times as thermal baths or natural spas, or even as mineral-medicinal waters used for curing gastrointestinal and skin diseases, among others [21,39,103]. Among these uses, there are pools, bath houses and fountains spread throughout the volcanic region (Figure 13), most notably the baths of Villar del Pozo, El Emperador (Miguelturra), El Barranco and La Sacristanía (Aldea del Rey) and El Hervidero (Carrión de Calatrava); and fountains such as Valenzuela de Calatrava, Puertollano or Piedrabuena.
- Practice of extreme and adventure sports (Figure 10): Volcanoes in the CCVR lend themselves to the development of sports activities, such as climbing the rocky escarpments of the maars or along the border of some lava flows (Columba volcano). In addition, the territory is crossed by one of the most outstanding historical-cultural elements of medieval times, such as the *Cañadas Reales* (translated literally as "the royal cattle paths"—glens) that have been turned into official hiking trails and cross many of these volcanoes and volcanic shallow lakes. The glens, as well as other public roads converted into tourist routes, are used for hiking and biking [104]. Additionally, big game hunting is practiced throughout the territory, especially in the large ranges located in mountain areas, and where some of the most beautiful and emblematic volcanoes of the region are located (maars de Las Carboneras-Las Pilas, El Acebuche, etc.).
- Eco-tourist activities, geotourism and scientific tourism (Figure 10): The study and understanding of volcanic rocks and mineralization present in the area, as well as the resulting morphologies, has led to many national and international conferences in the volcanic region. Additionally, different universities and national and international research groups use this region to carry out internships and fieldwork, and so the CCVR is becoming increasingly important and piquing scientific interest. Some notable conferences centered around the volcanic phenomenon of the region were the Workshop of Physical Geography (1996), Meeting of the Spanish Volcanology Network (2007), Spanish Geographers Congress (2009) and the Spanish Congress of Biogeography (2018). These are not only scientific meetings, but they also highlight other eco-tourism activities, such as listening to deer bellowing in the mountain areas or birdwatching in volcanic shallow

lakes, or in the extensive cereal fields that play host to an interesting community of steppe birds. The most notable are the great bustard (Otis tarda), the little bustard (Tetrax tetrax), the black-bellied sandgrouse (Pterocles orientalis), pin-tailed sandgrouse (Pterocles alchata) and the Eurasian stone-curlew (Burhinus oedicnemus). The central area of this region is declared an SPA—Special Protection Area—called the Steppe Area of Campo de Calatrava, within the framework of the European Natura 2000 Network.

- Archaeology and Cultural Parks: This volcanic territory has been occupied since ancient times as evidenced by a multitude of archaeological sites from different historical periods, ranging from the Paleolithic and Bronze Ages to the times of the Romans, Muslims and the medieval period. People have mainly used the volcanic resources for the development of their activity and the construction of their settlements or cities. In this sense, we can highlight some archaeological sites: the ancient city of Sisapo (occupied from 7th century BC to 7th century AD by Tartessian, Iberian, Visigothic and especially Roman cultures), where the Romans built their temples high in the Castillejos de La Bienvenida volcano (Almodóvar del Campo) and used the volcanic rock for ashlar and masonry; the Visigode and Muslim of Oreto-Zuqueca (Granátula de Calatrava); Alarcos of Iberian, medieval Christian and Muslim origin (Ciudad Real-Poblete); and the Sacro Castle-Convent of Calatrava La Nueva (from 1217 to 1804). Above all, the use of volcanic rock (Figure 11) in ornamental elements, covers, arches, tombstones or even some burial sites on the slopes of the volcanoes like Columba (Granátula) and Cerro de la Cruz (Alcolea) is of significant note [39]. There is also Calatrava Cultural Park in the region, which promotes the cultural and tourist activities of this territory [105].
- Volcanoes and Religion: As mentioned above, the CCVR volcanoes are located at the top of many Paleozoic mountains and stand out topographically on the region's Neogene plains. This location makes them strategic points for the control of the territory and as prominent places of religious worship, where the most emblematic buildings of the different cultures were placed by the people that have inhabited this territory throughout its history. It is not surprising, therefore, that many hermitages appear at the top of volcanoes, including archaeological sites and ancient temples of Roman deities (Figure 11d–f). Most notably, the hermitages of Santa Cruz on the Cerro de la Cruz volcano (Alcolea de Calatrava), the hermitage of San Isidro on the Cabezo del Rey volcano (Poblete) or the hermitage of Jesus Nazareno on the Cerro Santo volcano (Porzuna) [39].

Figure 10. (**a**) Scientists studying pyroclastic flows in the La Encina maar; (**b**) university students in a workshop; (**c**) official hiking guide course in the El Acebuche maar, Calatrava Massif Natural Monument; (**d**) Biking and trekking in the Peñarroya maar.

Figure 11. (**a**) Archaeological Roman site of Sisapo on the Los Castillejos volcano natural monument (La Bienvenida, Almodóvar del Campo); (**b**) archaeological Bronze Age site of La Encantada and detail of arrowheads found in the nearest volcanic complex of Cerro Gordo-Varondillo; (**c**) doorway of the Calatrava La Nueva castle made of volcanic rocks (Aldea del Rey); (**d**) Santa Cruz hermitage (Alcolea de Calatrava); (**e**) San Isidro hermitage (Poblete); (**f**) Jesús Nazareno hermitage (Porzuna).

Figure 12. (**a**) Cerro Pelado volcano in the Calatrava massif surrounded by Mediterranean forest and meadows; (**b**) Peñarroya volcano Natural Monument in Sierra de Las Medias Lunas after a snowfall; (**c**) Cerro Prieto volcano at the top of Sierra de Calatrava; (**d**) rural landscape at the Cuevas Negras volcano.

Figure 13. (**a**) Villar del Pozo Bath; (**b**) El Hervidero Bath and detail of the pool (Carrión de Calatrava); (**c**) carbonic sour water fountain (Valenzuela de Calatrava); (**d**) carbonic sour water fountain (Pozuelo de Calatrava); (**e**) Fuente Agria (Puertollano); (**f**) carbonic sour water fountain (Piedrabuena).

5.2. Volcanic Shallow Lakes in the Campo de Calatrava Volcanic Region: A Unique Environmental Resource in Europe

In addition to the previously mentioned tourist attractions, we could add an eighth characteristic for the CCVR; this being mainly an environmental feature, such as the capacity of the maars to hold water, depending on the climatic characteristics of this territory, and the subsequent rich ecosystem they develop. This has led to some of them being listed as nature reserves, microreserves and wildlife refuges [106] (Figures 6 and 14). This environmental resource is also the basis for the development of tourist attractions such as exploring the volcanic landscape and doing other ecotourism activities.

Hernández-Pacheco [7] was the first author to link the presence of shallow lakes in Campo de Calatrava with volcanic activity. However, Ancochea [9] conducted the first detailed study of the CCVR's maars, identifying 46 shallow lakes and depressions with this origin, giving great importance to the maars as a very characteristic structure of this volcanic region. Since the 1990s, the research of several geographers [21,24,26,27,63,70,71,107,108] has focused on the genesis of these manifestations and has added many more that had not been described up until that time. The hydromagmatic activity has been the eruptive mechanism with the greatest geo-ecological impact in the CCVR, in the form of temporary water puddles (or shallow lakes) that appear at the bottom of the maars.

Of the 180 maars identified in Campo de Calatrava, there are up to 65 that hold water in their interior [27], generally temporal shallow lakes and wetlands (a depth of <2 m). These make Calatrava the volcanic field with the largest number of volcanic lakes in continental Europe [49].

The water balance of the volcanic shallow lakes indicates that variations in the surface of the water sheet and the volume of its basin are related to the amount of precipitation it receives: in dry years, the shallow lakes will lose the water sheet in summer, and in very dry years, they will not even be replenished in winter or spring [27]. Surface runoff constitutes the main water source for these shallow lakes, which has very important implications for the management of the ecosystems. Any intervention or modification of land use in the area of these small watersheds will have negative consequences on their future evolution, with respect to an increase in erosion and the clogging of maar beds. Infiltration and evapotranspiration are the main causes of water loss from the shallow lakes. The lack of underground water sources, resulting from overexploitation of underground water by human activity, plays a significant role in water loss within the shallow lakes system. This loss occurs through infiltration to nearby areas (piedmont and sedimentary basin shallow lakes), to compensate for the extraction of irrigation water [27].

Figure 14. Examples of volcanic shallow lakes in Calatrava: (**a**) Volcano and Laguna de La Posadilla Natural Monument (Ciudad Real); (**b**) Laguna del Prado Natural Reserve (Pozuelo de Calatrava) and lots of flamingos; (**c**) Los Lomillos, Calatrava Massif Natural Monument (Argamasilla de Calatrava).

From a hydrochemical perspective, these shallow lakes are characterized by storing mostly fresh or brackish water (electrical conductivity between 82 and 2500 μS/cm), with an average pH of more than 8 (alkaline or very alkaline waters), medium and high levels of oxygenation (dissolved oxygen >8 ppm), relatively high levels of sulfates (>150 ppm) and, in general, low concentration levels of nitrates, nitrites and phosphates [27].

With regards to floristic factors, the provisional catalogue of flora linked to volcanic shallow lakes basins has been established, amounting to 130 specific taxa, which are spatially grouped into sixteen plant formations within five major categories, according to floristic and structural factors: aquatic macrophytes, large helophytes, pioneer amphibious plants, meadows and lake-surrounding halophile creeping shrubs and tamarisk trees. The predominance of amphibious and helophytic pioneer vegetation, with a floristic composition based on various species of Cyperaceae, Juncaceae and Charophyta, mark the physiognomy of the shallow lakes. Their origin lies in the irregularity of precipitation and the intense anthropic modification of these geosystems, which has fostered the emergence and extension of taxa and formations adapted to successional advances and regressions, a consequence of the fluctuating functioning of the ecosystem.

Finally, with respect to fauna, there exists a catalogue of vertebrate fauna linked to the Calatrava shallow lakes and their surrounding environment [27], which amounts to 11 species of amphibians, 12 reptiles and 115 birds (Figure 14b), as well as the presence of the Eurasian otter (*Lutra lutra*) in several volcanic lakes (Caracuel, Doña Elvira, La Dehesa, etc.). Additionally, 160 planktonic and 13 benthic taxa have been catalogued. Likewise, the presence of microbial mats, a unique benthic community typical of extreme saline environments, has been recognized. These have been observed in Laguna Blanca (Argamasilla de Calatrava) and in La Saladilla and Los Almeros (Villamayor de Calatrava).

5.3. Current Activities to Promote Volcano Tourism (Geotourism): The Seed for a Geopark Project

Given the attractive features of the region as a result of the Calatrava volcanism, geotourism activities are currently being developed, although very incipiently, by development associations, hikers, hostelry and active tourism companies and city halls. An example of this type of exploitation in a volcanic area of the Iberian Peninsula is in the La Garrotxa volcanic field (Girona, Catalonia) [109,110]. Additional examples can be seen in other volcanic geoparks around the world, such as El Hierro (Canary Islands, Spain), Colca-Andagua (Perú) or Azores (Portugal) [86,102,111]. The very important heritage linked to the volcanoes, and the actions that involve the accumulation of knowledge, the dissemination of that knowledge and the promotion of geotourism, have been the seed for the development of the UNESCO Global Geopark Project "Volcanes de Calatrava. Ciudad Real", promoted by the Ciudad Real Provincial Council [28,93]. Activities that promote volcano tourism, although today still in its infancy, are gaining more strength and piquing more interest in society, businesses and local governments, in order to drive sustainable economic development and meet the challenge of achieving the Sustainable Development Goals that the UN is promoting for 2030 [112]. In order to achieve these goals and obtain the UNESCO Global Geopark endorsement, the following activities should be promoted in the CCVR [36,37]:

- Education and Training: The values of volcanism in the CCVR need to be disseminated to local society through a series of conferences, exhibitions, drawing contests, photography contests, employment workshops for nature guides, etc. (Figure 15), which encourage the participation of the population and highlight the value of the volcanoes as part of the natural heritage and landscape that they inhabit. A good example has been the scientific and informative event *Volcanoes' Night* (in the framework of European Researchers' Night, 2014) and *the European Volcanoes' Night* (from 2015 to 2019) [113,114], organized by INVOLCAN and the GEOVOL-UCLM research group, in which more than 3000 people participated, especially schoolchildren. Another similar event would be *Geoloday*, organized by the Instituto Geológico y Minero de España (IGME). However, other avenues of education may also can be used, such as monographic publications, leaflets, brochures, magazines, web pages, or the creation of volcano interpretation centers, so as to inform people of the natural and cultural value of the environment and create social awareness among the local population of their geoheritage [91].

Figure 15. (**a**,**b**). *Volcanoes' Night* and *European Volcanoes' Night* events; (**c**) Campo de Calatrava volcanoes website [115]; (**d**,**e**) Campo de Calatrava volcanoes guides (2005, 2013) [58,116]; (**f**–**i**) other publications about Calatrava volcanism [36,40].

- Volcanism interpretation centers: There are currently two centers for interpreting the natural and cultural value of Calatrava volcanism, both inaugurated in April 2016 (Figure 16). The first is the *Centro de Interpretación del Agua Volcánica La Inesperada* (Pozuelo de Calatrava), which highlights the value of the biology and ecosystem of the volcanic shallow lake of La Inesperada. There is also the *Centro de Interpretación de Cerro Gordo* (Granátula de Calatrava), which is a museum-like space inside an open quarry in the Cerro Gordo volcano, where they explain Calatrava volcanism and the most interesting characteristics of the eruptive area [117]. Both centers have information leaflets, but Cerro Gordo also has a smartphone application that explains the route and the contents of the center. In just three years since its opening, Cerro Gordo has had more than 30,000 visitors [118], and La Inesperada has an average annual visitation rate of 4500 visitors [119], a lower number due to the fact that it depends on the seasonal nature of the water mass and also that the center does not open during the summer. Other centers to be highlighted are the Mining Museum of Puertollano, which highlights the coal mining industry since the late 19th century [120]. Finally, the Almadén Mining Park, declared a UNESCO World Heritage "Mercury Heritage Almadén-Idrija", highlights the values of the world's oldest mining activity with more than 2000 years of activity [121].
- Design of itineraries and georoutes through the volcanic natural landscapes where trekking and geohiking are encouraged (Figure 10d), which take advantage of the basic infrastructure, such as the neighborhood public roads and the *Cañadas Reales* (Segoviana and Eastern Soriana), that cross this territory and through which runs the official network of trails of the Provincial Council of Ciudad Real; or different tourist routes like the Red Rocinante (Valle de Alcudia) and the Don Quijote Route (Castilla-La Mancha Government). These routes need to be improved for better access and equipped with information that explains the natural and cultural value of this territory (Figure 17) (leaflefts, QR-Bidi codes, information panels, interactive guides for smartphones, etc.).
- Restoration and reconditioning of the fuentes agrias and hervideros for the use and enjoyment of society. Many of these have been abandoned after being used for centuries as natural spas for therapeutic purposes [39] thanks to the mineral-medicinal properties of their waters (Ntra. Sra. del Prado Bath in Villar del Pozo, Fuensanta Bath in Pozuelo de Calatrava, El Emperador Bath in Miguelturra, Fuente Agria and Bath House in Puertollano, etc.). Others have recently been refurbished by the city halls, such as the El Barranco Baths (Aldea del Rey), El Chorrillo Bath and Fountain (Pozuelo de Calatrava) and El Hervidero Bath House (Carrión de Calatrava) (Figures 7c and 13b).
- Birdwatching in shallow lakes ecosystems (maars) or other species of fauna in nearby areas (Figure 14b). The great peculiarity of the CCVR maars is the existence of shallow lakes that host fauna and floristic communities, which, as previously mentioned, are unique ecosystems in the Iberian Peninsula and in Western Europe [27,49]. The proximity of these volcanic shallow lakes to all the municipalities of the region, constitute a natural and scenic appeal to all tourists and nature lovers [122]. To this is added the ornithological value of the SPA *Steppe Area of Campo de Calatrava* (European Natura 2000 Network).
- Visit to natural protected areas of volcanic origin: Some volcanoes are protected as a geological and landscape resource (natural monument) or deemed as an area of biotic importance, such as in the case of maars with a water sheet (natural reserve, microreserve or wildlife refuge) (Figure 12b, Figure 10c,d, Figures 11a, 14, 16b and 17). The proximity of the cities to these spaces protected by the Castilla-La Mancha Government [106], or others included in nearby spaces, such as the Valle de Alcudia and Sierra Madrona Natural Park, which has volcanic structures inside, lend themselves to being visited so as to know their natural elements and highlight the importance of these morphologies in spaces where other landforms predominate. All volcanic natural monuments have information on-site (e.g., panels and routes) and on the Castilla-La Mancha Government's website.

Figure 16. (**a**) Some images of the Centro de Interpretación de Cerro Gordo (Granátula de Calatrava); (**b**) some images of Centro de Interpretación del Agua Volcánica La Inesperada (Pozuelo de Calatrava).

Figure 17. Some examples of georoutes, itineraries and hiking trails through protected volcanoes: (**a**) La Conejera volcano; (**b**) Peñarroya maar; (**c**) signs to La Posadilla maar; (**d**) Morrón de Villamayor volcano and Don Quijote Route; (**e**–**g**) information panels and signs to some volcanic natural monuments.

- Promotion of local volcanic products: This entails using scientific terminology or volcanic words to refer to typical local products (e.g., wines, sweets, or cuisine), offering "volcanic menus", volcanic tapas in bars and restaurants and artisan products that refer to the names of nearby volcanoes, to give them more importance and offer products with the "volcano brand" in a similar way that has been done in the Canary Islands, La Garrotxa [87,99,102,109,110] and in other geoparks around the world [111,123,124]. The CCVR is already starting to become fashionable among local companies [36,37,91]: "volcanic wines", such as *Vulcanus*, *Maar de Cervera*, *Lahar de Calatrava*; olive oils, such as *Maar de La Posadilla* and *Vulcanus*; sweets, such as the *magmitos* ("little magmas") in Poblete; the offering of volcanic routes planned by active tourism companies, hotels and tour operators (4 × 4, horse trails and biking); and menus that include "volcanic tapas" (snacks) in order to differentiate themselves from similar products (Figure 18).

Figure 18. (**a**) Local active tourism companies' websites offering volcano tourism; (**b**) *Magmitos* ("little magmas"); (**c**) examples of local "volcanic" oils and wines.

6. Discussion: Conservation, Geotourism and the Geopark Project

Volcanoes in the Campo de Calatrava Volcanic Region have been largely forgotten from the perspective of geoconservation, escaping environmental awareness by public administrations focused more on assessing and protecting other natural areas, such as national and natural parks or La Mancha wetlands. Some of the most emblematic volcanic structures have been, or are being, completely dismantled through excavation, the expansion of road infrastructures and other negative urban actions. Therefore, the implementation of conservation measures for this unique natural resource is imperative [29,35,36,40,125]. Their protection and the sustainable economic use of their resources through volcanic tourism (geotourism), or even through sustainable management plans such as geoparks, are equally needed.

It is true that, in the last twenty years, actions aimed at promoting the conservation of natural heritage in Castilla-La Mancha (Spain), particularly that of the Calatrava volcanoes from the perspective of its ecosystems, geological and geomorphological characteristics and landscapes, have led to the declaration of some as protected natural areas [35], under Law 9/1999 of Nature Conservation of Castilla-La Mancha [106]. However, mining concessions continue to be given for the exploitation of volcanic rocks in quarries that threaten such emblematic and interesting volcanoes such as Cerro Gordo (Granátula-Valenzuela), Cabezo Segura (Poblete) or La Yezosa (Almagro), among others. Although this law generally protects eruptive morphologies, a broader and more specific protection designation that stops mining practices from the most threatened volcanoes would be desirable, such as the distinction of a "Natural Park". This has been done in the Canary Islands, in the La Garrotxa volcanic field (Catalonia, Spain) and in the Azores (Portugal) [109–111,126]. However, there are significant economic contrasts between rural and urban areas in the territory, as well as political and business interests that stand in conflict with the conservation of the natural heritage, including the expansion of mining concessions for the exploitation of volcanoes.

With regard to the conservation and protection of the Calatrava volcanoes, we must remember the first person who raised his voice in defense of them, the priest Candelo López Serrano. In 1978, he drafted a report on the value of the volcano of Almodóvar del Campo and demanded for its protection before the Directorate General of Fine Arts of the Spanish Ministry of Culture [35,127]. However, it was not until the late 1980s and beyond that geographers linked to the Universidad de Castilla-La Mancha warned about the deterioration of the Calatrava volcanic landscape and the need to establish conservation measures of such a unique geological entity [125]. Here, we refer to the team led by Dr. Elena González Cárdenas, the GEOVOL-UCLM research group.

The NGO *Ecologistas en Acción–Ciudad Real* has also played an important role, repeatedly calling for the need to protect the volcanoes most threatened by mining activity.

In an effort to disseminate information regarding volcanic value, the Association for the Development of Campo de Calatrava is playing a key role through its rural development programs, taking on the responsibility for publishing the first informative guide to the volcanoes of Campo de Calatrava [116]. It was recently reissued thanks to the multinational company Lafarge-Holcim [58]. In addition, the Association, in collaboration with GEOVOL-UCLM research group and Lafarge-Holcim, opened two volcanism interpretation centers in the region.

For all these reasons, and to start the process of developing these types of activities, conservation efforts, protection efforts and sustainable management, the first step that should be taken is to highlight the most outstanding aspects of the territory. It is necessary to carry out a fairly exhaustive inventory of volcanic formations, including their nexus with other geological elements or structures, their importance to the ecosystems that develop within them, and the social link and use they have had throughout time. This inventory is vital in order to prioritize which volcanoes require the most attention and need immediate intervention so that they do not lose their natural and cultural value [38,40].

Perhaps the most appropriate endorsement for the sustainable management of this territory is that of a UNESCO Global Geopark. As mentioned in Section 5, a geopark is a well-managed, unique and unified geographic area where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. They use their geoheritage in connection with all other aspects of the area's natural and cultural heritage [95]. This is the reason why the geopark designation would be a broader and more integrative management model, in which the elements of the natural environment, those of the human environment, their social behavior and the cultural and ideological expressions are embodied in the territory. UNESCO's own definition of a geopark states that the importance of the area's geological heritage in history and society today give local people a sense of pride in their region and strengthen their identification with the area [95]. This is a point that the people responsible for the geopark project must work on, so that through the education and training that we highlighted in the previous section, society becomes aware of the territory that it lives in and that the territory is backed by diversified and sustainable economic development.

The declaration of a geopark in the CCVR would also have a positive impact economically since [95] "the creation of innovative local enterprises, new jobs and high-quality training courses is stimulated as new sources of revenue are generated through sustainable geotourism, while the geological resources of the area are protected".

There are currently 15 UNESCO Global Geoparks in Spain [128]. Three of them have volcanic origins, such as Cabo de Gata (2006) and, in the Canary Islands, El Hierro (2014) and Lanzarote-Chinijo Archipelago (2014). As a result, Spain has the largest number of geoparks in all of Europe and is second in the world behind China. The challenge that the bid of the geopark project "Volcanes de Calatrava. Ciudad Real" will have is to be seen as a reference point for the Tertiary and Quaternary volcanism of the Iberian Peninsula. The main feature of this volcanism is the hydrovolcanism represented by maars and the very high number of shallow lakes within them, which makes the area unique in Spain and, without a doubt, in Western Europe [27,36,37,49]. Of the 180 maars recorded, 65 currently have seasonal shallow lakes, but there are records that show so many others that held fairly deep lakes where very rich ecosystems were once generated with respect to the fauna. An example of one these maars that lost their shallow lake is Las Higueruelas (Alcolea-Ciudad Real), where the remains of fauna from 3.5 million years ago were found on ancient lake deposits of the maar [129].

Alongside these aspects, the CCVR has several Geological Interest Sites (in Spanish LIG—*Lugares de Interés Geológico*) listed in the Spanish Inventory of LIG (Instituto Geológico y Minero de España—IGME). Among them is the extremely important paleontological site of Las Higueruelas maar, which, in turn, is also part of the Spanish inventory of geosites within the Global Geosites Program (International Union of Geological Sciences—IUGS) [130].

One feature that stands out in the territorial scope of the geopark project throughout its geological evolution is that the volcanism is much more varied and extensive (temporally and spatially) than previously thought [17], as was explained in Section 3. Volcanic manifestations have been a recurring process throughout the geological history, from the Cambrian to the Holocene. The oldest eruptive manifestations of the alkaline and tholeiitic character occurred during the Silurian, extending to the Late Devonian in the Almadén area, and correspond to pyroclasts stratified under subaerial and subaquatic conditions [17].

Subsequently, during the filling of the Puertollano Carboniferous basin, volcanism intensely reappears, this time, having a rhydacytic composition [131]. It remained active at the same time that the basin was filled, leaving thin levels of ash interstratified between the layers of coal (from the Stephanian stage).

Finally, the most recent volcanic period extends from the Miocene to the Holocene, which is what the Campo de Calatrava Volcanic Region is best known for. As a result, this region has not only shown Neogene–Quaternary igneous activity, but it has also been repeated many times throughout its geological history, with most cases having an alkaline composition and a highly explosive character.

Concerning the territorial delimitation of the geopark project, the industrial mining area of Almadén must also be included. This area has already been recognized as a World Heritage Site by UNESCO under the name *El Patrimonio del Mercurio, Almadén e Idrija* since 2012 [121], and is also part of the Global Geosites Program. In addition to the presence of underground and surface mining infrastructures associated with mercury extraction that occurred ever since Roman times, this area features volcanoclastic and paleovolcanic deposits from the Devonian period. This is a testament to the remote and eruptive past of this territory and a historical economic and commercial link to the Campo de Calatrava region. Furthermore, it also includes the Puertollano Carboniferous basin [120], where there are other geological and mineralogical processes of international interest as well as industrial mining infrastructures, open pit mines and underground tunnels from the mining of coal and bituminous slate mining for the manufacturing of fossil fuels.

In short, all these are the ingredients that the Campo de Calatrava Volcanic Region has that, from our point of view and that of the Ciudad Real Provincial Council, serve as the basis for a geopark project with the goal of presenting it to UNESCO. It is also the means for recognizing the geological and geographical importance of this territory, and the close bond that the local population has and has had in harnessing the resources it offers. The development of the geopark project will place the Calatrava volcanic region in international networks that strive for the conservation and protection of nature and, in particular, that of its volcanoes.

7. Conclusions

The large number of volcanoes (more than 360) and the extent of the eruptive phenomena (more than 5000 km^2) makes the Campo de Calatrava Volcanic Region the most extensive and most important area of active volcanism within the Iberian Peninsula. To this we must add the great geodiversity and geoheritage of this region, especially the high number of maars and the current volcanic manifestations, such as hervideros (hot springs), fuentes agrias (carbonic "sour" water fountains) and chorros (jets, gas-water fountains); it has very important historical-cultural heritage and the resulting landscape should not be overlooked. All these elements are resources that must be conserved and taken advantage of for sustainable economic development, in keeping with the UN Sustainable Developments Goals. The conservation and protection of this volcanic territory, the development of public outreach projects popularizing its geoheritage and the promotion of sustainable economic activities, such as volcano tourism (geotourism), are basic strategies that need to be developed in the CCVR and require the involvement of the local administration and the general population. It will be a way to foster and revive the economy of many localities within the volcanic region affected by a major economic recession, a result of depopulation and the recent crises with its restrictions. It is therefore a question of diversifying the economy (a rural economy in many small towns and a tertiary-administrative economy in the city of Ciudad Real) and, in particular, the touristic opportunities that can be offered based on the geology and geomorphology of the eruptive manifestations.

The need for the conservation and protection of these volcanoes is not only due to the fact that they are geological and/or geomorphological elements characteristic of this region, but that they are also essential elements to the current landscape, both historically and culturally. Furthermore, they are the hallmark of the society that inhabits them and that has used them from the first historical settlements to the present day. The resources and tourist attractions of these volcanoes should also serve as a means for obtaining some form of protective status for these eruptive morphologies, such as being designated a natural monument or a natural park, and even for fulfilling the sustainable strategies of territorial management, such as in geoparks.

Therefore, considering the challenge of developing a geopark project, there is a great need for the whole of society, businesses and public administration officials to work together with the common objective of achieving sustainable economic development and achieving the UNESCO Global Geopark declaration.

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