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## *Geotourism with Augmented Reality in the Volcanic Area of Campo de Calatrava (Ciudad Real, Spain)\**

### I. INTRODUCTION

Geotourism is a relatively recent concept within the tourism industry, which took shape in 2002 in the United States, thanks to the actions of the Travel Industry Association and the National Geographic Traveler Magazine. Subsequently, on July 5, 2008, five U.S. government agencies and the National Geographic Society formally adopted the principles of geotourism based on environmental sustainability. Indeed, they define geotourism as a type of tourism that helps to sustain or enhance the geographic character of a place, its environment, culture, aesthetics, heritage, and the well-being of its residents (MOFFET AND MOODY, 2008). It is, in short, sustainable tourism that preserves the natural and geomorphological heritage for future generations.

In the last two decades, there has been a notable increase in interest in geotourism, including scientific tourism, based not only on the knowledge of geological and geomorphological heritage, but also of other natural and cultural resources, as well as on the enjoyment of beauty and participation in its conservation (DOWLING and NEWSOME, 2018). Such an impulse is due, among other reasons, to the fact that geotourism has become a fundamental resource for the sustainable development of economically depressed territories and/or affected by de-

population. In particular, there is an abundant academic literature analysing geotourism as a strategy for sustainable development (EAGLES and others, 2002; HIWASAKI, 2003; DOWLING and NEWSOME, 2006; DOWLING, 2009; HOSE, 2007; PANIZZA and PIACENTE, 2008; BURLANDO and others, 2011; FARSANI and others, 2011; DUARTE and others, 2020), as well as the role that georoutes and itineraries play in the dissemination and understanding of the contents in an enjoyable and didactic way (GÓMEZ ORTIZ, 1985; SÁNCHEZ, 1995; GARCÍA DE LA VEGA, 2004; BEATO and others, 2020; MARINO and others, 2021a, 2021b).

The lines of research focused on the analysis of volcanic heritage, that is, on the valuation and diagnosis of volcanic geosites is quite recent (HEGGIE, 2009; JOYCE, 2009; COSTA, 2011; REOLID and others, 2013; BECERRA-RAMÍREZ, 2013; HENRIQUES and NETO, 2015; MARTÍ and PLANAGUMÀ, 2016; NÉMETH and others, 2017; PLANAGUMÀ and MARTÍ, 2018; PLANAGUMÀ and MARTÍ, 2020; DÓNIZ-PÁEZ and others, 2020; BECERRA-RAMÍREZ and others, 2020), as well as works that address geotourism in volcanic areas by designing georoutes that encourage exploration of such territories (DÓNIZ-PÁEZ and others, 2011, 2019; ARMIERO and others, 2011; GALAS and others, 2018; PÉREZ-UMAÑA and others, 2019). Inactive volcanic areas can play a fundamental role because, due to the lack of potential risks on the integrity and health of people, they facilitate the didactic teaching of the fundamental keys of the origin and dynamics of such landscapes. This arouses public interest in learning about and visiting volcanoes, which have increased in popularity

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thanks to the creation of volcanic geoparks (NÉMETH and others, 2017). Moreover, augmented reality, based on the combination of real and virtual elements using mobile and computing devices, is an essential support tool for didactics and dissemination in both tourism and educational and scientific fields (DEL MORAL and VILLALUSTRE, 2013; LEIVA and MORENO, 2015; CÓZAR and others, 2015; DEL MORAL and others, 2016).

The main objective of this work is to show the geomorphological singularities and the attractive landscape of the volcanic area of Campo de Calatrava, especially the variety of forms and deposits of both magmatic and phreatomagmatic origin. For this purpose, an interesting georoute is proposed, based on both educational and training criteria, in which augmented reality plays a fundamental role as an interpretative tool. This not only stimulates scientific learning and cooperation in the maintenance of the natural heritage, but also promotes geotourism as a resource for the sustainable development of this region and lays the foundations for the Unesco World Geopark project of the “Calatrava-Ciudad Real Volcanoes”, whose application is being prepared by the Provincial Council of Ciudad Real with the supervision of a large group of scientists.

## II. STUDY AREA

The Campo de Calatrava is, together with Montes de Toledo, Montes de Ciudad Real, La Mancha, Valle del Ojalén and Valle de Alcudia, one of the six natural areas or regions that make up the so-called Central Volcanic Region of Spain (CVRS), a name first used by Eduardo Hernández-Pacheco in 1927 and later by his son Francisco in 1932 to refer to the entire eruptive complex located in the province of Ciudad Real. Specifically, the Campo de Calatrava has the largest number of volcanoes, around 200, and is also, due to the diversity of types of volcanic edifices and the variety of structural forms and volcanic deposits, the most important and interesting volcanic area in the whole of the CVRS.

The Campo de Calatrava, located in the centre of the province of Ciudad Real, between the Montes de Toledo to the north, the Ojalén Valley to the south and the Montes de Ciudad Real and La Mancha, to the west and east respectively, has an area of approximately 2,500 km<sup>2</sup> and is characterised by a landscape of great beauty and simple orography that is resolved by the alternation of small sedimentary plains of Tertiary age, where traditional crops of olives, vines and cereals still prevail, and

the Paleozoic quartzite hills that rise above them, which are home to the few patches of Mediterranean vegetation formed mainly by thickets of holm-oaks. Finally, the volcanoes, the most singular and emblematic forms of relief in the region, are located above both the small Tertiary plains and the quartzite mountain ranges, forming a post relief that enriches and interferes with both structural units, and whose origin is evidently more recent.

The scientific exploration of this volcanic territory, after its discovery by the enlightened Irishman William Bowles in 1775, hardly aroused interest among foreign geologists and naturalists, so the exploration was carried out exclusively by Spaniards, specifically, by the engineers of the Royal Academy of Almaden and the Commission of the Geological Map, standing out the works of Felipe Naranjo, Francisco de Luxán and Daniel de Cortázar (POBLETE and BEATO, 2016; POBLETE and others, 2018a). Finally, the most exhaustive and in-depth research, revealing the volcanological features, was the work of three geologists from the University of Madrid, namely Francisco Quiroga, author of the first doctoral thesis on the area, Eduardo Hernández-Pacheco and, especially, his son Francisco, architect of the most modern and detailed cartographic representation of the first half of the 20th century.

## III. VOLCANOLOGICAL AND GEOMORPHOLOGICAL SETTING

From the geological point of view, the Campo de Calatrava is in the south-eastern end of the Central-Iberian Zone of the Hesperian Massif, near the outer sectors of the Alpine Betic Cordillera, forming a slight tectonic depression formed at the end of the Cenozoic, between the pseudo-Appalachian reliefs of the Montes de Toledo, to the north, and Sierra Morena, to the south (POBLETE, 1994, 2003). The Paleozoic basement, composed mainly of Armorican quartzites (Lower Ordovician), sandstones (Middle-Upper Ordovician) and shales (Silurian), is articulated around a series of large folded structures oriented NW-SE to E-W and NE-SW, having been affected by two phases of the Variscan orogeny (ROIZ, 1979). This Paleozoic substrate is discordantly covered by carbonate lacustrine sediments and siliciclastic alluvial fan deposits of the Mio-Pliocene age, as well as by Quaternary fluvial deposits. In addition, dilute lava flows and PDC (pyroclastic density currents) deposits were intercalated with alluvial fans and lacustrine sediments of the distension basins (Late Miocene-Quaternary), leading to the forma-

tion of a very complete set of depositional sedimentary environments (HERRERO-HERNÁNDEZ and others, 2012, 2015), which occurred after the Serravaliense-Tortonian Betic compression.

The Campo de Calatrava, together with the Catalan Volcanic Zone (ZVC), is one of the Quaternary alkaline volcanic regions of Spain belonging to the European Cenozoic Rift System. It is characterised by an intraplate volcanism of basic and monogenic nature, although with evidence of polycyclic behaviour of some volcanoes (Mesa del Villar and Columba) (POBLETE, 2002; BECERRA-RAMÍREZ, 2013) articulated around structural lines from WNW-ESE to NW-SE direction, the main ones, and from ENE-WEST to NE-WEST, the secondary ones; following, in short, fractures of regional order that skew the Hercynian basement (ANCOCHEA and BRÄNDLE, 1982; ANCOCHEA, 1983; CEBRIÁ, 1992; LÓPEZ-RUIZ and others, 1993; CEBRIÁ and others, 2011).

From the petrological point of view, the volcanic rocks are very homogeneous, being their chemical composition of basic and ultrabasic nature. The most singular characteristic of this lithology is that it adopts a peculiar spatial distribution, as basalts and basanites are in the centre according to a band arranged in NNW-SSE direction, while olivine nephelinites and melilitites occupy external and marginal areas respectively (HÉRNANDEZ-PACHECO, 1932; ANCOCHEA, 1983, 2004). This distribution of the rocky terrain faithfully reflects the disposition and intensity of the thermal anomaly of the mantle, very accentuated in the interior of the eruptive zone and attenuated in the exterior (ANCOCHEA, 1983). It is also worth mentioning the presence of ultra-alkaline rocks, specifically olivine leucites, which, although a minority, are the only ones existing in all of Europe (ANCOCHEA, 2004). Most of the rocks of the Calatrava basaltic series come from primary magmas, little evolved, formed from the different degree of partial melting of the same enriched and uniform asthenospheric source (ANCOCHEA, 1983; CEBRIÁ and LÓPEZ-RUIZ, 1995), whose isotopic homogeneity is like those of the European asthenospheric mantle (WILSON and DOWNES, 1991). However, recently, the possible carbonate nature of the Calatrava magma has been inferred from the analysis of pyroclastic deposits, mantle xenoliths and, especially, volcanic tuffs with abundant carbonate matrix (BAILEY and others, 2005; HUMPHREYS and others, 2010; STOPPA and others, 2012).

From the geomorphological point of view, we distinguish in Calatrava 6 types of volcanoes following the classifications proposed by Poblete (1995) and Poblete et al. (2018b): maars with diatreme and pericrateric vol-

canotectonic subsidence, maars embedded in quartzites without annular rim, maars with annular rim, cinder cones, small lava volcanoes and dome-shaped lava accumulations. The first three types of volcanoes are of phreatomagmatic origin with very explosive eruptions produced by the contact between water and magma. The morphological result of such eruptions are maar-type volcanoes. Maars are volcanic forms consisting of a crater depression excavated below the pre-eruptive topographic surface, resulting from phreatic and/or phreatomagmatic explosions. The shapes and dimensions of such depressions or hollows are very diverse, i.e., circular, semicircular, elliptical, or horseshoe-shaped, with flat or funnelled bottoms, from several tens to several hundreds of kilometres in diameter and from tens to several hundreds of kilometres deep. The other three types of volcanoes are the result of magmatic volcanic eruptions, although sometimes small phreatomagmatic explosive phases without morphological configuration may occur.

#### IV. METHODOLOGY

The methodology used is basically based on that used in the educational itineraries and georoutes with augmented reality by Beato et al. (2020) and Marino et al. (2021a, 2021b). In these works, the methodology is based on three phases: the first consists of the analysis and selection of the most interesting and unique places or geosites; the second focuses on the design of the itinerary indicating the stops with the best conditions for observation and accessibility; finally, in the third phase, all the scientific information is elaborated, the geographic interpretation is carried out and the materials are incorporated into the augmented reality tool.

The first phase of the work consisted of the geographical study of volcanic forms, morphoeruptive sequences and geomorphological mapping, focused on the selection of the geosites, in this case, volcanic edifices and thermal springs of greatest interest and representativeness. The analyses carried out also included an extensive literature review and were based on recent contributions from the works of Poblete (2016) and Poblete et al. (2016a, 2019a, 2019b, 2019b, 2021). Twenty volcanoes integrated by cinder cones, maars and exogenous lava domes located in the centre and eastern edge of the volcanic zone of Campo de Calatrava were obtained, from which a total of 8 and 2 thermal springs were finally selected, based not only on scientific criteria (volcanic forms, eruptive style, morphoeruptive sequence, resulting products) but also on cul-

tural (landscape and aesthetic value, pedagogical interest, etc. ) and of use and management (accessibility, observation conditions, services and facilities, tourism potential, etc.) following the scientific valuation proposals applied in the area (BECERRA-RAMÍREZ, 2013; BEATO and others, 2018b). Specifically, of the 8 volcanoes selected (Yezosa, Cerro Gordo, Barondillo, Columba, Hoya de Cervera, Cuelgaperros, Corchuelos and La Posadilla-El Portillo) two are protected under the figure of Natural Monument and another is musealised, which enhances even more, if possible, the interest and value not only natural but also didactic of these geosites. The second phase consisted of an exhaustive fieldwork in which roads, asphalted tracks and paths were covered to ensure the accessibility of the stops. In this way, basic and precise information was available for the design of the route, choosing the attractive and touristic town of Almagro as the starting point and the small village of Valverde (Ciudad Real) as the end of the route. Road access was always prioritised, although sometimes there are also tracks and trails.

Finally, in the third phase we proceeded to the explanation and interpretation of each of the stops, in this case, of the selected volcanoes, specifically, of the most characteristic morphological features, eruptive styles, dynamic evolution and products expelled, always in a pleasant and didactic way. To promote and motivate learning and even make it more interactive, complementary documentation (photographic and cartographic) was developed and displayed through the application of the augmented reality tool. In this way, the materials developed are openly available to all users on the Internet portal of the Territory Observatory of the Department of Geography of the University of Oviedo ([www.observatoriodelterritorio.es/rarv/calatrava/calatrava.html](http://www.observatoriodelterritorio.es/rarv/calatrava/calatrava.html)).

In fact, the contents are easily available online through any device with internet access. It consists mainly of graphic and multimedia material, i.e., three-dimensional models, videos, photographs, and old geological maps, as well as recent geomorphological cartography, accompanied by their corresponding interpretative texts. To this information we must add other interactive resources such as digital elevation models (DEM) or surface models (DSM) built from IGN LIDAR data, elaborated using QGIS, and available on the Sketchfab platform. Therefore, there are two ways to access the interactive contents:

- On the one hand, through the hyperlink that gives access to the web [www.observatoriodelterritorio.es/rarv/calatrava/calatrava.html](http://www.observatoriodelterritorio.es/rarv/calatrava/calatrava.html), where the interactive contents are located.

- On the other hand, the virtual resources of this article can be visualised by means of augmented reality techniques, these contents will be superimposed on the images of the article itself that work as markers or activators.

To do so, it is necessary to access the following weblink <https://studio.onirix.com/exp/ID51dL> or scan the following QR (Quick Response) code with a mobile device.



Once the mobile application is opened, the device's camera will be activated and the user will only have to focus on the figures with the following logo for the Augmented Reality to be activated. It is also possible to visualise these contents through weblinks that have been incorporated at the foot of the figures.



Access to all this extended information can be done in two different ways. The first is done through markers (tracking images), through hyperlinks that are activated with QR (Quick Response) codes or with images or 3D objects detected by a sensor (camera) that link to the web page where they are hosted the content. The second uses sensors integrated in mobile devices (mainly GPS) for its activation. The great advantage of this system is that it enables self-guidance through open air spaces, while offering additional information based on the user's position. In any case, in the explanatory texts of each of the stops on the itinerary the link to all the virtual resources generated has been inserted, so they are also at the service of the review's readers.

## V. RESULTS

The georoute starts in the town of Almagro, seat since the 13th century of the Order of Calatrava, and nowadays capital of the region. In this Renaissance town of great tourist attraction (where the Corral de Comedias, the oldest theatre in Europe built in 1628, is still active) we will take the CM-412 towards Moral de Calatrava, to undertake the route of the most representative volcanoes of the volcanic area of Calatrava. In fact, the georoute has a total length of 60.5 km and consists of 7 stops that coincide with the volcanic buildings that we have selected, according to the criteria indicated above in the methodology. Specifically, the visit begins at the Yezosa volcano, then

passes through Cerro Gordo, Barondillo, Columba, Hoya de Cervera, Cuelgaperros, Corchuelos and ends at La Posadilla-El Portillo, that is, in the Sierra de Medias Lunas.

### 1. YEZOSA VOLCANO

Yezosa is a cinder cone formed from a strombolian eruptive activity, in which at least two phases can be distinguished: an initial explosive phase, which builds the pyroclastic cone, and a terminal effusive phase characterised by the emission of lava flows. These very fluid lava flows, formed by olivine melilites, were emitted from the horseshoe crater, 500 m in diameter, located in the southwestern end of the cone. From this crater, several lava flows have been emitted, which bifurcated into two branches: one to the west -called Cuesta de Banderas-retained by the quartzite ridges; and another to the south, called Cuesta de los Gatos, which overflows the quartzite sill and expands in the form of a fan towards the Graná-tula de Calatrava basin.

Yezosa volcano is subject to intense mining, in particular, pyroclasts are extracted in several quarries still active today for the manufacture of pozzolanic cements (POBLETE et al., 2019b), which endanger the conservation of the cone shape and, in particular, of the horseshoe crater about to be destroyed.

### 2. CERRO GORDO VOLCANO AND BARONDILLO MAAR

Cerro Gordo volcano has originated as a result of strombolian and phreatomagmatic eruptive phases. During the first phase of strombolian activity, a cinder cone was formed, from the base of which two lava flows of olivine nephelinites were emitted, which moved northwest about 1.5 km. Subsequently, once the cinder cone was built, a small lava flow of only 700 m in length was emitted again, this time from the top of the volcano downhill, opening a small channel to the southwest of the cone. Almost at the same time, an intense lava fountain activity is triggered in a small circular crater, 140 m in diameter, located at the southeastern end of the summit (38°49'55.85"- 3°44'30.87W), originating an accumulation of densely welded spatter layers on the southeastern slope of the cone (BECERRA-RAMÍREZ, 2013; SARRION-ANDIA and others, 2019). It is, therefore, the accumulation of lava spatter formed from a typically Hawaiian lava source. Finally, the volcanic dynamics undergoes an abrupt change when concluding with an intense ex-

plosive activity of phreatomagmatic type, in which two explosive phases have been distinguished (GONZÁLEZ and others, 2008), which originates the formation of the Barondillo maar, excavated on the quartzite mountain range of La Sima and the southeastern base of the Cerro Gordo cinder cone. It is, in particular, a crater depression 560 m in diameter and 50 m deep, with a completely flat bottom. Dilute PDC deposits and laharic facies up to 4 m thick extend mainly to the north, overlying the pyroclastic deposits initially emitted (GONZÁLEZ and others, 2008). Such deposits were exploited by open-pit quarrying by the French company Lafarge for the manufacture of pozzolanic cements (ESCOBAR, 2016).

### 3. COLUMBA VOLCANO

Columba is a strombolian volcano consisting of a small pyroclastic cone or cinder cone of 100 m relative height, crowned by a circular crater 200 m in diameter, from which several very fluid lava flows of basaltic nature came out. It is of enormous volcanological interest because it is the most recent volcano in Campo de Calatrava, whose last eruption took place between 14 cal ka and 6.2 ka BP (POBLETE and others, 2019a) and according to González et al. (2007, 2010) around 5.5 cal ka BP. Another relevant singularity is that it is one of the few monogenic volcanoes that has had a polycyclic eruptive behaviour (BECERRA-RAMÍREZ, 2013). Indeed, despite its modest dimensions and morphological simplicity, it is a building with polycyclic dynamics, as it originated as a result of two clearly differentiated eruptive cycles. The first eruptive cycle took place around  $33.9 \pm 2.36$  ka BP and the second, after a period of inactivity of more than 20,000 years, lies between a maximum age of 14-13.5 cal ka BP and a minimum of  $6.27 \pm 4.28$  ka BP, i.e., between the Upper Pleistocene - Holocene (MIS 1) (POBLETE and others, 2019a).

### 4. HOYA DE CERVERA MAAR

The peculiarity of the maar Hoya de Cervera lies in the fact that it is excavated on the Paleozoic rock of the Calatrava Massif, specifically, in the Arzollar armorican quartzite mountain range, separating the tertiary sub-basins of Ciudad Real, Almagro and Moral de Calatrava. It consists of a maar of large dimensions and of a remarkable beauty, very well preserved as it is protected by the Junta de Comunidades de Castilla-La Mancha since

October 1999 under the figure of Natural Monument. It consists of a depression of elliptical shape of 1.3 km of major axis and 790 m of minor diameter and a depth of 147 m. The bottom of the crater is completely flat and is filled with materials expelled during the phreatomagmatic eruption.

The origin of the maar of Hoya de Cervera is associated with a very violent explosion of hydromagmatic origin, produced by the contact between water and magma, in which the resulting pyroclastic flow was channelled in a northerly direction, adopting a directed shape. The materials expelled during the phreatomagmatic eruption are made up of diluted PDC deposits that extend throughout the Encomienda de Cervera estate, where the maar is located. At present, most of these PDC deposits, consisting mainly of pulverised quartzite, are covered by accumulation glaciis and colluvium formed after the eruption, so they do not appear directly on the surface. However, some outcrops of the PDC deposits expelled from the Hoya de Cervera maar can be recognised on the left bank of the Jabalón river valley, specifically at km 18+450 of the CM-4111 road.

#### 5. CUELGAPERROS MAAR

The Cuelgaperros maar originates as a result of two hydromagmatic explosive phases. A first phase of lesser magnitude and intensity, produces the opening of the volcanic diatreme, emitting a large amount of quartzite and schist explosion breccias from the Paleozoic substratum. This first phase is simultaneous with the formation of a calcareous crust at the southern end of the maar, inferring a lacustrine environment. This initial phreatomagmatic explosive phase is followed by a period of calm, in which sedimentation occurs, on the southern calcareous crust, of a fluviolacustrine terrace deposit corresponding to the +15-20 m level of the Jabalón River, whose age is  $34.7 \pm 2.5$  ka (POBLETE and others, 2016b). Subsequently, explosive activity resumes with a second very energetic phreatomagmatic phase, in which the Cuelgaperros crater is excavated. It is, in fact, a very intense explosion due to the great water-magma interaction that causes the destruction and fragmentation of the Paleozoic substratum and a large part of the calcareous crust and the fluvial terrace +15-20 m. In addition, the phreatomagmatic explosion triggers the formation of an eruptive cloud base, which does not adopt the typical annular shape, but rather expands in a fan oriented to the northeast and southeast. For this reason, the tuffaceous rim adopts a semi-ellipti-

cal shape and is not annular as it is more usual and frequent in this type of hydromagmatic explosive manifestations. On the other hand, this tuffaceous rim fossilises the +15-20 m fluvial terrace level of the Jabalón River, from which it is deduced that the second phreatomagmatic phase has a maximum age of  $34.7 \pm 2.5$  ka, while the first phase has a minimum age of  $34.7 \pm 2.5$  ka (POBLETE and others, 2016b).

#### 6. CORCHUELOS MAAR

The formation of this large crater depression in the Despeñadero anticline is linked to a powerful phreatomagmatic eruption, which took place due to the presence of a NE-SW fracture that crosses this alignment. This fracture, which cuts the Paleozoic basement, allowed both the ascent of magma and the seepage and confinement of water, resulting in a phreatomagmatic eruption from the contact and interaction between the two. The explosion was so violent and intense that it destroyed and split in half the anticlinal vault of the Despeñadero, excavating a crater depression 80 m deep (POBLETE, 1994).

During the phreatomagmatic explosion, a pyroclastic flow moved northward. In fact, the diluted and wet PDC deposits formed during the eruption are accumulated in the northern area, covering a distance of 2 km without interruption until reaching km 301 of the CN-420, in the section between Ciudad Real and Valverde.

The interior of the crater has a flat shape because it is filled with quartzite explosion breccias of heterometric size and very angular shapes, as well as cauliflower bombs with abundant xenoliths of small quartzite. The explosion breccias and cauliflower bombs were emitted ballistically during the initial phase of the eruption, when the opening of the volcanic diatreme took place.

#### 7. LA POSADILLA AND EL PORTILLO MAAR

The Posadilla maar has a crateric depression, circular in shape and with a flat bottom, approximately 1 km in diameter, excavated in the northern slope of Medias Lunas, which is why it exhibits a marked dissymmetry between the northern and southern edges, the former presenting a gentle escarpment, with a drop of only 40 m, and the latter a more accentuated and vertical 140 m.

The origin of this maar is inescapably linked to a rift fracture of E-W direction, about 12 km long, which cuts the Sierra de Medias Lunas, and in which a set of five maars

is articulated: La Posadilla, El Portillo, El Paso, Medias Lunas, Laguna de las Maestras or Peñarroya (POBLETE, 1993, 1994). Of all of them, the La Posadilla-El Portillo tandem is the most relevant, both morphologically and volcanologically, due to the changes experienced during the eruptive dynamics and the resulting forms.

For a correct interpretation of the morphoeruptive sequence of the La Posadilla maar, we must consider two basic aspects: on the one hand, the presence of powerful and extensive lava flows located on the southern slope of Medias Lunas, partly covered by a large amount of volcanic bombs and quartzite xenoliths; and, on the other hand, the dilute and dense PDC deposits that extend without interruption from the crater to Valverde. These are, in fact, dilute and dense PDC deposits that resemble lahar deposits, formed mostly by fragments of quartzite, slate and schist, and to a lesser extent volcanic materials, including dark-colored augite megacrystals. The dilute PDC deposits and lava flows are associated with different phases of the eruptive mechanism that originated this volcanic edifice.

According to Poblete (1993), the morphoeruptive dynamics of the La Posadilla maar includes at least four main phases: a first one of Strombolian style that builds the Malos Aires cinder; followed by a phreatomagmatic explosion that originates the La Posadilla maar. Finally, the El Portillo maar was formed as a result of a small phreatic pulsation that culminated in a phase of very effusive activity (POBLETE 1993, 1994). The volcanic activity began in Malos Aires, that is, at the top of the Sierra de Medias Lunas, through a Strombolian eruptive phase with an explosion that caused the formation of the eruptive mouth and the launching of many volcanic bombs and the effusion of lava flows. As a result, a small cinder cone was formed, from which two large lava flows were emitted that descended rapidly down the southern slope to stop at the basal part, near the right bank of the Guadiana River. The first lava flow is quite fluid, basaltic in nature, and forms a frontal escarpment of small dimensions and quite unwashed, which rests on Pliocene marls and limestones of Vahondo. It presents an external pahoehoe morphology and its main singularity is the large amount of quartzite xenoliths, between 1 and 4 cm in size and with angular edges. Such quartzite xenoliths are the result of the strombolian explosion that achieves the opening of the eruptive mouth, from which the ballistic projections of volcanic bombs and lava emissions will be produced later.

The second lava flow, disposed on top of the first, is composed of olivine nephelinites. This means that it

comes, after the evacuation of the first emission, from a deeper magma or hypomagma and that a certain period must have elapsed in the discharge between the two. This flow, like the previous one, is very fluid, with smooth and soft external surface forms, typical of pahoehoe lavas, although it also contains a large amount of quartzite xenoliths of centimetre size and angular edges. However, unlike the first flow, it has a great thickness that exceeds 20 m and forms two very abrupt fronts, with a spheroidal structure in the eastern section. Another characteristic feature of this lava flow is the presence of two distension fissures, through which the central part of the lava flow has collapsed, thanks to the settlement of these huge lava masses. Overlying this second lava flow is an abundance of spheroidal and pyriform bombs between 50 cm and 1 m in length, containing numerous quartz xenoliths. Therefore, it can be inferred that the Malos Aires volcano is the result of a Strombolian-style dynamic, which simultaneously emits lava flows and pyroclasts, and ceases its volcanic activity with a small explosive phase in which it projects ballistic materials in the form of volcanic bombs.

Once the Malos Aires strombolian volcano was formed, whose morphology would be very similar to that of the Peñarroya volcano located 4 km to the west on the Cerro de las Loberas, a change in its eruptive activity occurs, producing a phreatomagmatic explosion of great magnitude that destroys not only the cinder cone but also the Armorican quartzite ridges of the Sierra de Medias Lunas, carving a large crater depression on the northern slope. This phreatomagmatic explosion originates because of the contact of magma and water, through the rift that cuts the Sierra de Medias Lunas from west to east. It is a late interaction that occurs after the formation of Malos Aires, once the most superficial magma has been emptied, which leads to a deeper reaction and only after the decrease of the conduit pressure. Because of the powerful phreatomagmatic explosion, a directed pyroclastic flow was triggered, which did not adopt the usual annular disposition, but moved laterally channelled towards the north, since on the southern edge was the Medias Lunas range, on whose summit the Malos Aires volcano had formed (POBLETE, 1993, 1994). Specifically, the directed pyroclastic flow moved about 4 km, adapting to the Valverde valley floor until it reached the bank of the Guadiana River, fossilizing the alluvial terrace +6 m of this river. Thus, the Valverde valley floor is covered by dilute PDC deposits formed by a large amount of accidental and heretometric lithics of very angular and broken quartzites and slates, as well as reinforced and cauliflower-type

bombs and amphibole megacrystals. The fine matrix of the PDC deposits is composed of quartz sands and quartzites pulverised by the explosion of the Armorican quartzite banks of the Sierra de Medias Lunas.

The maar of El Portillo is located on the summit of the Medias Lunas range, less than 50 m E of La Posadilla, right on the summit of the Medias Lunas. In fact, the summit of Medias Lunas is broken by a small cleft of only 100 m in diameter and 5 m deep, the result of a small phreatic explosion, that is, of low energy, which materialised in the launching of large explosion breccias. Therefore, this maar is not a crater depression as usual, but a simple perforated cleavage at the top of the quartzite crest. After this first phreatic explosion, there was a change in the behaviour of its eruptive dynamics, expelling two lava flows that slide to the north and south. Both are lava flows of smooth and soft external morphology that is, pahoehoe, and are composed of olivine nephelinites, highlighting the one located on the southern slope because it ends in a 20 m frontal escarpment. It is, therefore, a small maar whose sequence is inverse to that of La Posadilla, starting with a phreatic phase of low intensity that finally changes to an effusive activity of some consideration, if we consider the number of lavas emitted (POBLETE, 1993, 1994).

## VI. CONCLUSIONS

Geotourism promotes local economic development based on three basic foundations: the dissemination of scientific knowledge and landscape qualities of the territory (through the preparation of maps, guides, georoutes, itineraries, etc.), the commitment of local populations and the implementation by political authorities of management and planning measures aimed at the preservation of natural heritage, particularly geomorphological heritage.

This work focuses on the first of the pillars of geotourism, that is, the dissemination of volcanic contents because of extensive fieldwork and interpretation, which is embodied in the design of a georoute, that is, a fundamental scientific and educational resource to publicise and reveal the geomorphological characteristics of this volcanic area of Campo de Calatrava and for the enjoyment of visitors. Along a 60.5 km route and through 7 stops, reinforced using augmented reality, the reader is

given the keys to understand the wide range of eruptive styles and dynamics, variety of morphologies and types of volcanic devices. Among the most relevant details is the disclosure of the polycyclic nature of the Columba volcano and the recent age of its volcanic activity since it originated because of two clearly differentiated eruptive cycles. The first took place around  $33.9 \pm 2.36$  ka BP and the second, after a period of inactivity of more than 20,000 years, lies between a maximum age of 14-13.5 cal ka BP and a minimum of  $6.27 \pm 4.28$  ka BP, i.e., between the Upper Pleistocene - Holocene (MIS 1).

The second pillar of geotourism, namely the commitment of local populations, is projected in Calatrava in the Association for the Development of Campo de Calatrava, created in 2000 and made up of 15 municipalities of the territory, which brings together not only public institutions, but also social and economic agents of the territory. Among the aims of the association are: to energise and revalue the human resources of the region; to promote cultural identity; to recover the cultural, ethnographic and natural heritage values of Campo de Calatrava; to promote and encourage research; to elaborate, design and apply integral programs for the development of tourism.

The third pillar of geotourism is environmental policy, that is, planning and management measures aimed at protecting volcanoes. In this sense, we must point out that of the thirteen Natural Monuments of volcanic nature protected by the Junta de Comunidades de Castilla-La Mancha, twelve are in Ciudad Real and six of them are precisely in the Campo de Calatrava (La Posadilla, Hoya del Mortero, Hoya de Cervera, Macizo Volcanico de Calatrava, Volcán y Laguna de Peñarroya and Morrón de Villamayor). At present, the Diputación de Ciudad Real is processing, under the supervision of a group of scientists, the application for the declaration of the above-mentioned region as World Geopark of the Unesco of the "Volcanoes of Calatrava-Ciudad Real", whose concession can mean the accolade to turn it into one of the referents of the peninsular volcanism. For this reason, it is even more incomprehensible to understand that the Junta de Comunidades de Castilla-La Mancha has resisted to protect, since a long time ago, this relevant geomorphological heritage under the figure of Natural Park, which would have meant the paralysis of the mining exploitations that endanger its conservation and that began in 1911, more than a century ago.