Geoheritage

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The deterioration of geoheritage in the Central Spanish Volcanic Region by open-pit mining

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Abstract

The geoheritage of the Central Spanish Volcanic Region (Ciudad Real) has been severely affected by open pit mining since the beginning of the 20th century until 2017. Field work, photointerpretation of aerial images, and consultation of the Mining Cadaster of the Spanish Geological Survey (IGME), have been used to characterize the impact that open-pit mining has on the geomorphology of this volcanic area. As a result of this intense mining activity, uninterrupted over the course of a century, 18,76 million tons of basalt and more than 16,11 million tons of scoriaceous.deposits (considered as industrial minerals) have been extracted, which has caused irreversible damage to the region's geoheritage. Some thirty volcanoes have been destroyed, with cinder cones and exogenous domes being particularly affected. Currently, the validity of this mining exploitation system represents a serious threat to the conservation of the rich volcanic heritage of the area. Therefore, urgent measures are needed to rationalize the management of natural resources, namely, to make their use and preservation compatible for the future generations.

Keywords: Central Spanish Volcanic Region**,** geoheritage, open-pit mining, volcanic landforms, environmental impact.

Introduction

The versatility of volcanic products explains why since time immemorial, at least since the Paleolithic and the Neolithic, they have been used by man for the manufacture of tools (Mallarach and Riera 1981; Hunold and Schaaf 2010; Poblete et al. 2014), or as rock shelters in the case of the large basaltic columns and necks of the High Loire (France) (Richet 2000). Later, during the Roman Empire the exploitation of such resources was generalized, especially from the year 15 BCE, as described by Vitrubio in his work *De architectura* the fabrication of concrete or *opus caementicium*, by means of the mixture of sand, lime, and pozzolans (so called volcanic tuffs when extracted from Pozzuoli, in the Italian region of Campania). From then on, the extraction of pyroclastic rocks and lavas for the manufacture of ashlars and concrete had accelerated, thus facilitating the expansion of the Roman Empire—that is, the growth of cities, towns, and infrastructures that connected the territory, such as roads, bridges, aqueducts, etc. (Fisher et al. 1997). Basalts were also an important early tool making source as well as ritual aspect of life in various stages of the societal development of the Incas, Maya, Toltec, Maori, Rapa Nui, etc. (Hunt 1990; Baker 1993; Wozniak 1999; Németh and Cronin 2009; Ceruti 2010; Gravis et al. 2017).

Modern industrial exploitation began in the late nineteenth and early twentieth centuries with the opening of large quarries and the use of heavy machinery in the main volcanic areas of the world, such as the United States, Chile, Japan, Europe (Eifel, Auvergne, Italy, Western Hungary, Northern Bohemia, Catalonia), New Zealand, and Australia. From such quarries bentonite, perlite, pumice, cinder (scoria), etc. (Dehn and McNutt 2000) are massively extracted to cope with the growing demand from the chemical and cement industry, construction, and infrastructure, which represents a serious threat to the preservation of volcanic landscapes and volcanic heritage (Gray 2008). In response there is increasing awareness of both scientists and society, demanding protection and conservation measures for volcanoes and volcanic terrains. As a result, in many countries, initiatives aimed at the rational regulation of such mining activities have been taken and the first projects that allow the creation of volcanic natural parks have been launched (Mallarach and Riera 1981; Hunold and Schaaf 2010). In spite of everything, at the present time there are still numerous important volcanic zones without protection (Németh et al. 2017). One of them is the Central Spanish Volcanic Region (CSVR), whose geoheritage is poorly known internationally.

The CSVR is located in the Castilla-La Mancha region, in the center of Spain (Fig. 1), and offers one of the most peculiar volcanic landscapes of the Iberian Peninsula. In addition to its high number (around 257) of volcanoes and location in the middle of the Spanish Southern Plateau, its uniqueness—derived from the wide range of eruptive dynamics, types of volcanoes, and diversity of volcanic landforms—is remarkable. A large diversity of cinder cones, extrusive domes, small lava volcanoes, and an abundance of maars can be recognized there. Other outstanding elements of its volcanic heritage are the paleontological deposits of Plio-Quaternary age that are located in the interior of maars of older age, the petrological outcrops of olivinic leucitites (unique in Spain), as well as an extensive network of thermal ferruginous springs, known as “hervideros” (bubbling) by the exhalation of abundant CO_2, which have been exploited since the late nineteenth and early twentieth centuries as spas (Fuensanta in Pozuelo de Calatrava, Baños of Villar del Pozo, etc.) (Fig. 2).

Research on the degradation and impact of open-pit mining on the geological heritage of the CSVR is very scarce. One of the first studies was by López (1983), who in a brief report sent to the General Administration of Fine Arts of Madrid denounced the deterioration suffered by the Cerro de los Molinos volcano in Almodóvar del Campo (see Fig. 4) due to the extraction of pyroclastic materials, and proposed its declaration as a National Monument as a way to preserve it. Later, Romero et al. (1986) in a study on the volcanoes of Spain indicated the serious problem confronting the conservation of some volcanoes in the Campo de Calatrava, especially the Cabezo Segura, subjected to exploitation by large open-pit quarries. Subsequently, Poblete (1991) studied the geomorphological characteristics of Campo de Calatrava volcanism and analyzed the state of conservation of its volcanic landforms, pointing out the irreparable landscape impact produced by open-pit exploitations of several volcanoes. Other investigations that addressed the state of the volcanoes of Ciudad Real in-depth were those of González (1991) and Gosálvez et al. (2010), which revealed the protective role played by local urban legislation in defense of volcanoes, but also the agonizingly defenseless situation of these volcanoes in the face of the mining exploitations, due to the ambiguous environmental policy of the Autonomous Government of Castilla-La Mancha. It is also worth mentioning the works carried out by Becerra (2013), Poblete et al. (2014), Beato et al. (2018) and Escobar (2016), dedicated to the study of the volcanic geoheritage and the industrial use of volcanic materials, respectively.

In this work we analyze the process of degradation of the volcanic heritage of the CSVR as a consequence of the mining activity, through the application of an historical retrospective and the quantification of the morphological impacts on the volcanoes. It begins with the study of the traditional use of volcanic products and extends into the phases of modern industrial exploitation from the beginning of the 20th century, as shown in the initial results that can be consulted in Poblete et al. (2014).

Open-pit mining greatly intrudes into the landscape, without any regulation in the CSVR. This is why we recognize the affected volcanoes, emphasizing the recently granted mining concessions, which endanger the conservation of a still poorly known heritage of great geomorphological value. Finally, we also analyze the effectiveness of the protection figures applied so far by the Regional Government of Castilla-La Mancha and the proposed measures for the preservation of this important geoheritage for future generations.

Geological setting

The CSVR, located in the center of the Iberian Peninsula (Ciudad Real Province), shelters around 257 volcanoes scattered over an approximate area of 3,500 km^2 (Fig. 1). The CSVR, together with the Catalan volcanic zone (CVZ), comprise the Quaternary alkaline volcanic regions belonging to the European Cenozoic Rift System (Wilson and Downes 1992; Ziegler 1992).

From a geological point of view, the CSVR is located in the southeastern end of the Central-Iberian Zone of the Hesperian Massif, near the external sectors of the Alpine-Baetic Mountain Range, forming a slight tectonic depression that was generated at the end of the Cenozoic, between the reliefs of the Montes de Toledo, to the north, and the Sierra Morena, to the south (Poblete 1995, 2003). The Paleozoic basement, which is composed mostly of Armorican quartzites (Lower Ordovician), sandstones (Middle-Upper Ordovician), and slates (Silurian), is articulated around a series of large folded structures oriented from NW-SE to E-W and NE-SW, which were affected by two phases of the Variscan orogeny (between Devonian and Permian) (Roiz 1979). This substrate is unconformably covered by siliciclastic fluvial and limestones and marls of Mio-Pliocene age as well as Quaternary fluvial deposits (Fig. 3).

The CSVR is characterized by intraplate volcanism that is basic and monogenetic in nature formed by one continuous or discontinuous small eruptions that produce small-volume volcanoes with a wide range of eruptive styles and landforms (Németh and Kereszturi 2015). It consists of numerous small cinder cones and maars, articulated around structural lines that are mainly oriented WNW-ESE to NW-SE, with secondary orientations from ENE-WSW to NE-SW (Poblete 1995; Poblete et al. 2016). These structures follow fractures of a regional order that affect the Variscan basement (Ancochea 1983; Cebriá 1992; López-Ruiz et al. 1993; Cebriá et al. 2011). From a petrological point of view, the volcanic rocks are very homogeneous, their chemical composition being basic-ultrabasic (Ancochea 1983; Cebriá 1992; López-Ruiz et al. 1993; Cebriá et al. 2011). The most singular feature of this lithology is that it adopts a peculiar spatial distribution, as the basalts and basanites are located in the center according to a band arranged in a NNW-SSE direction, while nephelinites and melilitites occupy the external and marginal areas, respectively (Hernández-Pacheco 1932; Ancochea 1983, 2004). This distribution of rock compositions reflects the disposition and intensity of the thermal anomaly of the mantle, which is highly accentuated in the interior of the volcanic zone and attenuated in the external zone (Ancochea 1983). Also noteworthy is the presence of ultra-alkaline rocks, specifically olivine leucitites that are the only ones present in all of

Spain (Ancochea 2004). The origin of this volcanism is still under debate and different hypotheses, including a hot spot, an aborted rift, a transform fault, or lithospheric mantle anomalies, have been proposed (Ancochea 1983, 2004; Bergamín 1986; Bergamín and Carbo 1986; Doblas et al. 1991; López-Ruiz et al. 1993; Vegas and Rincon-Calero 1995).

Concerning the age of the volcanic activity, whose development over time is discontinuous, two major stages have been distinguished by radiometric K-Ar dating and from paleomagnetism on lava flows: the first and least important volumetrically began in the Upper Miocene (from 8.7 to 6.4 Ma) and had an ultrapotassium character; the second, with a much larger representation, extends from the Lower Pliocene (3.7 Ma) to about 0.7 Ma (Brunhes) (Ancochea and Giuliani 1979; Ancochea 1983; Bonnadona and Villa 1986; Gallardo-Millán et al. 2002; Gallardo-Millán 2004). However, some volcanoes are younger, in particular the Cuelgaperros maar (Poblete et al. 2018b) and the volcanoes of Cuevas and Columba, whose last eruption occurred between 14 and 6.2 ka ago (Poblete et al. 2019) although González et al. (2007, 2010) dated the Columba volcano as Holocene.

Methodology

The methodology used in this study included the identification of the open-pit quarries on the volcanoes by means of the photointerpretation of different sets of aerial images, corresponding to the 1956–57 American Military Service (B series) and National flights of 1980–1986, and the digital orthophotos of the National Plan of Aerial Orthophotography (PNOA) with 0.25 m resolution, from the photogrammetric flight carried out by the Spanish Geographic Institute (IGN) in 2009, as well as exhaustive fieldwork with a double objective: on the one hand, to prepare a complete catalog of the affected volcanoes, and on the other, to know both the scope of the impacts and the temporal evolution of the quarries.

Moreover, consultation with the Spanish Mining Cadaster (Ministry for the Ecological Transition) permitted to find out the type of exploitations, the size, the location (with geographic coordinates) of the perimeter of the concessions, the situation of mining rights, and also the business names of the extraction companies. From these data, the aforementioned orthophotographs, and the digital cartography of the area at a scale of 1:25,000 and 1:200,000, in addition to using a GIS system, we calculated the extent of mining operations.

Other documentary sources used were the yearbooks of the Spanish Mining Statistics, which since 1860 provides information about mineral substances and extraction of mining products, their uses and destinations, as well as the employment and economic value of mining production. Through them we ascertained the initial opening date of the basalt open-pit quarries in the province of Ciudad Real and calculated the amount of basalts and pyroclastic materials extracted over more than a century, from 1911 to 2017.

Finally, hemerographic sources are of great importance in the study of mining in the past, since they offer a daily vision of the socioeconomic activity that took place in the country. For this reason, we also consulted and systematically examined various official journals such as the Boletín Oficial de la Provincial de Ciudad Real (from 1836 to the present day) and the Gaceta de Madrid (1697–1936), as well as several newspapers in the national press (El Mundo, La Tribuna, La Correspondencia de España, etc.) and local (El Labriego, El Pueblo Manchego, La Voz, La Región Extremeña, etc.) of the late nineteenth and early twentieth century. This helped to identify the use and destination of the Ciudad Real basalts. All these publications are now available in the digital databases of the Biblioteca Digital Hispánica and the Biblioteca Virtual de Prensa Histórica.

Ancient use of volcanic materials

In the CSVR, as in other volcanic areas of Europe and the world, basaltic lavas have been used since the Neolithic to construct hunting and farming tools (Rosenberg et al. 2008; Tomo Ishimura 2014). In the study area the remains of these tools have been found along the valley bottoms of the Guadiana and Jabalón rivers, especially around Valdarachas, Aldea del Rey, and Granátula de Calatrava (Poblete et al. 2014) (Fig. 4). Moreover, abundant hand mills made of more vacuolar and spongy Neolithic basalts have been found in the surroundings of Villar del Pozo, Ballesteros and Cañada de Calatrava (Fig. 5). Warrior stelae corresponding to the Late Bronze Tartessians recorded on basalt were also discovered in Aldea del Rey and Bienvenida (Valiente and Prado 1977; Zarzalejos et al. 2012) (see Fig. 4).

The first opencast quarries of volcanoes in this region were carried out by the Romans for the exogenous domes of Castillejos de Bienvenida, in the Valle de Alcudia (see Fig. 4), to build the ancient city of Sisapo (cited by Plinio NH, III, 14). Sisapo was the mining capital that managed the resources of cinnabar and silver of Sierra Morena. The extraction of basalt to make the ashlars and masonry necessary to build the defensive walls is still visible in the easternmost exogenous dome (Zarzalejos et al. 2011). According to Poblete et al. (2014) due to this massive extraction of basalt, the exogenous dome located inside the enclosure of the wall, known as Castillejo I, was completely peeled off. In addition, the demand for building materials was so great that it was also necessary to use the rocks obtained from the so-called Sacred Hole, and to open more quarries in Castillejos II and III in order to build the houses of the Roman fortress (Fig. 6).

The Romans discovered the manufacture of concrete or *opus caementicium* (cement) in the year 15 BCE, by mixing sand, lime, and pozzolans (volcanic tuffs found by the Romans in Pozzuoli located in the Italian region of Campania, hence the name pozzolan), that the use of basalts for pavements, ashlars, and masonry was widespread in this area with the construction of a large number of villas, roads, bridges, etc. These materials can still be observed in the factory of the Roman bridges built on the banks of the Jabalón River, from which it is important to remark on those of the Alguacil, Molino de Parra, and especially that of Baebio (see Fig. 4). The latter was built in the 2nd century CE near the site of Oretum and Zuqueca (see Fig. 4) (occupied from the 4th century BCE to the 12th century CE), where there is also evidence of buildings made with volcanic masonry from the 6th century CE (Poblete et al. 2014).

In the Middle Ages it is curious how the Castle of Calatrava la Nueva (13th century) (see Fig. 3) was mainly constructed with blocks of quartzite, using only “aa” lavas of reddish color that contain enclaves of Paleozoic quartzites and quartz as an ornamental stone (Poblete et al. 2014).

This is visible for example, in the pillars and the ribs of the vaults of the Sacro Convento (Fig. 7). These lavas come from the quarries of the neighboring volcano of Salvatierra (see Fig. 4), exploited initially by the Muslims, to build the homonymous fortress during the 10–11th centuries. Conversely, the old Castillo del Comendador (12th century) or the Mortara Castle, built in the village of Piedrabuena on the lava flows of the Arzollosa volcano (see Fig. 4), was built exclusively with basaltic lava blocks. Today, it is preserved as a bullring after the ruins of the castle were sold by the Counts of Lences in 1901 to a bullfighting society (Fig. 8).

From the Middle Ages to practically the beginning of the 20th century, basaltic lavas and pyroclastic materials have traditionally been used to build the mud walls of houses and other constructions, as well as to pave the rural roads and the streets of the villages. In short, volcanic rocks have been used constantly over time for personal use from small artisanal extractions (Escobar et al., 2010; Poblete et al. 2014).

The industrial exploitation of volcanoes: open-pit mining

At the beginning of the last century mining operations dedicated to the extraction of basalts and pozzolans in the Ciudad Real district, were very scarce and of a small size (Spanish Mining Statistics, 1907). However, since the first decade of the twentieth century, the massive open-pit industrial exploitation of the Ciudad Real volcanoes began for fundamental reasons: 1) the knowledge of the existence of volcanoes revealed by the mining engineers after a long exploration period started in the mid-nineteenth century and that was reflected in geological maps (Poblete and Beato 2016); and, 2) in order to satisfy the need for resistant materials to pave the roads that Madrid demands due to its urban growth. The first official record of the opening of the opencast basalt quarry for industrial purposes in the CSVR dates back to 1911, when the operations at Aldea del Rey and Cerrillo Moreno (Almagro) began (see Fig. 4). Four years later there were 15 mining concessions already exploited to full capacity by the main construction companies of that time (Spanish Mining Statistics, 1915) (Table 1).

The rapid proliferation of basalt quarries in Ciudad Real was due to the urban transformation experienced by Madrid throughout the first third of the 20th century, which would turn the old town into a metropolis. During this period Madrid doubled its population, going from 540,000 inhabitants in 1900, reaching one million in 1930 (Rueda 1993). Great advances were also made at that time in construction techniques and materials, with the massive use of cement and reinforced concrete in public and residential buildings.

In this context of social-economic modernization and urban growth in Madrid there was the need to replace the old street pavement (which was obsolete and unsuitable for mechanical traction) with a new stronger one mainly made of basalt and other rocks of similar resistance (Ruiz 1945). The reformed surface, including roads and sidewalks, has reached a total area of 1.5 million m^2 and a total length of more than 163 km. To achieve this massive work, basalt paving stones from the province of Ciudad Real were used, among other reasons due to its proximity and rapid transportation via the Madrid-Badajoz railway line.

According to Poblete et al. (2014) during the time that the paving operations of Madrid lasted, about 47,423 m^3 of volcanic rocks were extracted from the quarries of Ciudad Real. Considering that each paving block has an approximate volume of 4,752 cm^3, almost 10 million were manufactured, of which 7.5 million were transported to Madrid and the rest were used in nearby towns. The most productive quarries were: Coria (Aldea del Rey) from the basalt quarries of La Mancha, from which 20,603 m^3 were extracted, followed by Miró with 7,850 m^3, while 3,000 m^3 were extracted from the Morrón de Villamayor volcano (Spanish Mining Statistics 1920–1932) (Fig. 9). From 1934, there was a sharp decline in the extraction of basalt, which lasted until the mid-twentieth century, when the exploitation for local consumption was reactivated due to the paving of the main towns of the Castilla-La Mancha region, such as Puertollano, Daimiel, Almagro, Manzanares, Ciudad Real, Aldea del Rey, etc. (see Fig. 4).

In fact, the production of basalt quarries has always been very irregular, with numerous oscillations, as it is highly conditioned by the demand for infrastructure projects, increasing considerably when large-scale works were started, and vice versa. For this reason, the largest quantities were extracted in the last third of the twentieth century during the construction of the Madrid-Seville high-speed railroad, between 1988 and 1991, with an annual production close to one million tons for ballast. Recently, between 2004 and 2007, annual figures of around one million tons were also obtained as a result of the construction of the Central Airport of Ciudad Real, the A-41 (Puertollano-Ciudad Real), A-43, and the Regional Highway IV Centenary (Poblete et al. 2014).

In contrast, the industrial exploitation of pyroclastic materials (known as pozzolans) is more recent. Specifically, it began in 1962 with the initial extractions from the Cabeza del Rey volcano (Poblete) and the Yezosa volcano (Almagro) (see Fig. 4). The first official figures of the production of these quarries correspond to the year 1965 with an amount of 51,351 metric tons, destined mostly to the production of pozzolanic cements in the factories of La Sagra in Toledo. Although the industrial exploitation of pyroclastics is late, their production has remained very stable over time, extracting around 340,000 metric tons, becoming the third most important mineral in the province, after mercury and coal by the year 1967. The reason lies in its greater versatility compared to basalt, because although at first they were used almost exclusively to manufacture cement and aggregates for concrete, subsequently their use has been diversified being used both in industry (as an abrasive, natural filter, encapsulant, etc.) and in construction (insulating material), and agriculture (inert substrate, aerating, mulching, etc.). However, the highest production was reached in 1991, with 7,865,245 metric tons, also thanks to the construction of the Madrid-Seville high-speed railway line (Poblete et al. 2014).

Impact of open-pit mining on volcanic geoheritage

The current Mining Law 22/1973, of the 21st of July, amended by Law 54/1980 for energy minerals, together with the R.D. 2994/1982, of the 15th of October, on the restoration of the natural areas affected by mining activities, and the Order of the 20th of November, 1984, have tried to harmonize the interests of mining operations with the protection of the environment—advancing several years to the regulations of the Environmental Impact Assessment (EIA), force all extractive activities to carry out restoration work. However, the reality has been very different since in practice the application of these new laws has been minimal, at least with regard to quarries of pozzolans and basalts, due in part to the fact that they were not retroactive, and also due to the lack of control by the Administration towards the adequate achievement of these measures.

Thus, for entrepreneurs open-pit mining has been and still is a very productive and profitable activity, especially when the rules that regulate the obligation to restore quarries are violated or ignored, hence causing irreparable damage to the morphology of volcanoes, because the extraction of basalts and pozzolans sometimes generate the partial removal of the volcanic structures (cones, lava flows, exogenous domes), or even their total disappearance. In all cases, the quarries produce remarkable changes in the physiognomy of the volcanic landscapes, always opening permanent holes, because the materials are transported away from the extractions for further transformation, and that barely enough sterile material is generated, in order to fill the cavities. Although these could be completely covered by the use of other materials, it would be impossible to reconstruct the old topography, that is, to model the old silhouette of the volcanic edifice as it was before the exploitation began. In short, it is impossible to extract basalts and pozzolans in the open without causing disturbances to the morphology of the volcanoes and damaging fertile soils. These types of mining operations always degrade the landscape and cause the destruction of the vegetation cover, as well as causing irreversible geomorphological and hydrological sequelae (Fig. 10).

Moreover, the functional changes must be considered, as they go from having an agricultural use consistent with the environment, to occasionally becoming illegal landfills after the abandonment of the quarries—either for debris from construction or even garbage from urban areas, causing further degradation. This is what happened for example in the La Atalaya (see Fig. 4) in the 1990s (which became the dump of Ballesteros de Calatrava); or in the case of the Yezosa volcano, on the former Banderas quarry (see Fig. 4) where a waste recycling plant for urban solids has been installed; or in the Palo volcano in Ciudad Real (see Fig. 4) where there is also a waste treatment plant; or in San Isidro (Herrerías quarries) (see Fig. 4) where a waste treatment and elimination center, with an extent of 40 ha and a capacity of 7 million m^3, has been built (Poblete et al., 2014).

The restoration of volcanoes is very complex and expensive. In fact, there are very few examples in the world, highlighting the Mt Elephant volcano (the largest scoria cone in the Newer Volcanic province) and the Hornsby maar in Australia. Much more frequent is the use of such volcanic quarries as museums and geoparks. Such is the case of the volcano-museum of Cerro Gordo in CSVR (Calatrava) inaugurated in 2016, Vulkanpark Osteifel (situated between the Eifel and the Rhin, Germany), Puy de Lemtégy (Chaîne des Puys, France), Kemenes Vulkánpark (Ság Hill, Hungary), etc., in which various walking trails are promoted to know the geoheritage and visit the interior of volcanoes. As a particular example of the successful use of protected volcanic quarries as a way to show and explain volcanic landscape is offered by the Natural Park of La Garrotxa Volcanoes (Catalonia, Spain), where the stop of mining activities and conversion of the area into a Natural Park allowed the transformation of a poorly known territory into one of the best known and most visited geosites of the region (Planagumà and Martí, 2018)

According to the Spanish Mining Statistics (1911–2017) the extraction of basalts in Ciudad Real over a century is on the order of 18,764,264 tons, while the rate of pyroclastic or pozzolan production has been even higher, since in just 53 years they have obtained on the order of 16,109,797 tons (data available from 1965 to 2017). The result of this intense mining activity has been the degradation of the volcanic landscape at Campo de Calatrava, which has been more impacted compared to other areas such as the Valle de Alcudia, the Montes de Ciudad Real, Montes de Toledo, etc. This is due to the greater number of volcanic edifices, which in most cases have an easy access and are located close to the main population centers, having excellent transportation routes (rail, national roads, etc.), which allow the transfer of materials and their rapid implementation to the market (Fig. 11).

In summary, the number of volcanic edifices whose morphology has deteriorated rises to a total of 31, of which those from El Arzollar (Ciudad Real), La Balona, Cerro Moreno (Almagro) (see Fig. 4) have been practically completely destroyed, while those of Cabezo Segura II, Negrizal de Villafranca or Enebrillo, La Atalaya (Ballesteros), Cabeza Parda (Ciudad Real), Cerro de las Higueras (Encomienda), Cerro de los Molinos, Yezosa (Fig. 12), Cerro Gordo, Cabeza Mesada, Tiñosas, Palomarejo, etc. (see Fig. 4) have been severely damaged.

The environmental policy of the Regional Government of Castilla-La Mancha

The environmental measures applied by the Regional Government of Castilla-La Mancha to protect the volcanoes of the CSVR began very late (in 1999) when a large number of volcanoes had already been partially or totally destroyed. In addition, to stop the interventions of open-pit mining, they used the figure for the lowest range of protection, which is that of Natural Monuments, under which only the most singular or relevant volcanoes are protected individually or in small groups. As a result, from 1999, to date only 11 Natural Monuments have been declared, protecting 23 volcanoes, which cover an area of only 63,87 km^2 (Fig. 13), whereas the number of volcanoes is 257 and extends to an area of more than 3,500 km^2 (Poblete et al., 2014). Therefore, it is evident that the environmental policy of Castilla-La Mancha in terms of geo-volcanic heritage protection is clearly insufficient, since priority criteria for conservation have also not been taken into account. For example, there is a specific regulation to protect maar-type volcanic edifices, of which there is great scientific interest and which constitute one of the main volcanological and geological values in the area, but that do not face any type of threat, since they have little industrial or mining utility. However, the main pyroclastic or cinder cones have been left unprotected, despite the fact that they are very much desired by the mining industry, because they have a large quantity of basalts and pozzolans in their facies, such as those from Yezosa, Columba, Cerro Gordo, etc. (see Fig. 4).

It is worth mentioning that there are several measures in the Spanish regulations aimed at protecting natural landscapes. For example, there is a wide prevailing legal regulation of a protectionist nature included in the Castilla-La Mancha Government Council Agreement of November 6, 1998, declaring several areas of high natural value that cannot be registered for the purpose of mining legislation. Also, the Law 4/2007, of the 8th of March, on Environmental Assessment, which in relation to the extraction industry states that exploitations with affected land exceeding 0.25 km^2 and those that have a land displacement exceeding 200,000 m^3 must be submitted to the EIA. Moreover, the RD 975/2009, of the 12th of June, regulated the management of waste from the extraction industries as well as protection and rehabilitation for the area affected by mining activities. However, despite all these protectionist measures, the Ministry of Industry has granted mining companies with another 17 mining concessions, 12 of which are pozzolans, 2 are basalts, and 3 of mixed concessions (Table 2). The extractions granted cover an area of 53.13 km^2, the most active of which are those of Alemana II in the Yezosa volcano, La Encomienda in the Cerro de la Higueras volcano, San Fernando in La Atalaya (Ballesteros de Calatrava), Siempreviva in Negrizal de Villafranca, Herrerías II in San Isidro, and San Carlos in Cerro Gordo (Fig. 13). These concessions endanger the integrity of 18 other volcanoes of great geomorphological interest such as Cuevas Negras, Loma del Negrizal, Cerrajón de La Puebla, Las Cabezas,, Cabeza del Rey, Cerro Pelado, Montecillo, San Marcos, El Cabezuelo, etc. (see Fig. 4).

In order to stop the destruction of geoheritage, urgent measures are needed to rationalize the management of natural resources, which makes it possible to combine their use and conservation, since at present, the extraction process is not sustainable. Among other measures, it would be sufficient for the Castilla-La Mancha Regional Government to at least protect the volcanic area of greatest value, that is, the Campo de Calatrava, with the declaration of a Natural Park, similar to the volcanic zones of La Garrotxa and Cabo de Gata, protected as natural parks, since 1982 and 1996, respectively.

Conclusions

As in other European volcanic areas, the use of volcanic materials in the Central Volcanic Region of Spain dates back to the Paleolithic period. These materials were traditionally used with an artisanal character and in small proportions without supposing any threat to the patrimony. Initially they were used to manufacture hunting and farming tools and later became an essential element in the construction of fortifications, housing, and basic infrastructure (bridges, roads, and villas). However, by the second decade of the 20th century its exploitation reached industrial levels, with the opening of open-pit mines, in particular quarries of basaltic lava for the paving of the roads of Madrid and other cities. Additionally, starting in the 1960s, and continuing to the present day, massive exploitation of quarries of pyroclastic material are carried out, whose products are particularly used as an additive for the manufacture of pozzolanic cements. As a result of this uninterrupted mining activity over the course of more than a century, 18,76 million metric tons of basalts and more than 16 million of pyroclastics have been extracted, causing irreversible geomorphological damage to the geoheritage—in particular, the destruction of some thirty volcanic edifices. Taking into account that the reconstruction of the volcanic landforms is very expensive, this supposes a serious loss of geoheritage. On the other hand, the most frequent uses of such volcanic quarries are as landfills or as museums for geotourism.

From 2010 to 2017 there has been a decreasing trend in the amount of rocks extracted, both basaltic lava flows and pyroclastic deposits, because the economic crisis. However, the granting of another 17 mining operations again represents a serious threat to the integrity of this volcanic heritage, so urgent measures are needed to rationalize the management of natural resources, trying to square their use with their conservation. The best and simplest solution to ensure the conservation of the Campo de Calatrava volcanic area would be to declare it a Natural Park. It has been done for other volcanic zones of Spain, where exploitation and conservation of natural resources can now coexist sustainably.

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Fig. 3 Geological map of the CSVR (modified after Poblete et al. 2016). CSVR is a slight tectonic depression formed at the end of the Cenozoic in the southeastern end of the Central-Iberian Zone of the Hesperian Massif, near the external sectors of the Alpine-Baetic Mountain Range

Fig. 4 Location map indicating the situation of the main localities and outcrops mentioned in the text. 1. Valdarachas; 2. Aldea del Rey; 3. Granátula de Calatrava; 4. Villar del Pozo; 5. Ballesteros de Calatrava, La Atalaya; 6. Cañada de Calatrava; 7. Bienvenida, Sisapo; 8. Alguacil, Molino de Parra, and Baebio; 9. Oreto and Zuqueca; 10. Castle de Calatrava la Nueva; 11. Salvatierra; 12. Piedrabuena; 13. Arzollosa; 14. Valenzuela de Calatrava; 15. Almagro, Cerrillo Moreno; 16. Puertollano; 17. Daimiel; 18. Manzanares; 19. Cabeza del Rey; 20. Yezosa, Banderas; 21. Palo; 22. Herrerías; 23. Arzollar; 24. La Balona; 25. Cabezo Segurra II; 26. Enebrillo; 27. Cabeza Parda; 28. Cerro de las Higueras; 29. Los Molinos; 30. Cerro Gordo; 31. Cabeza Mesada; 32. Tiñosas; 33. Palomarejo; 34. Columba; 35. Estrella; 36. Cabeza Galiana; 37. Zurriaga; 38. Cabeza del Hierro; 39. Cerro Pelado; 40. Cabeza de la Plata; 41. Cabeza de los Pescadores

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Fig. 12 Quarries in the volcano of Yezosa (Almagro). It is s a cinder cone of olivinic melilite composition

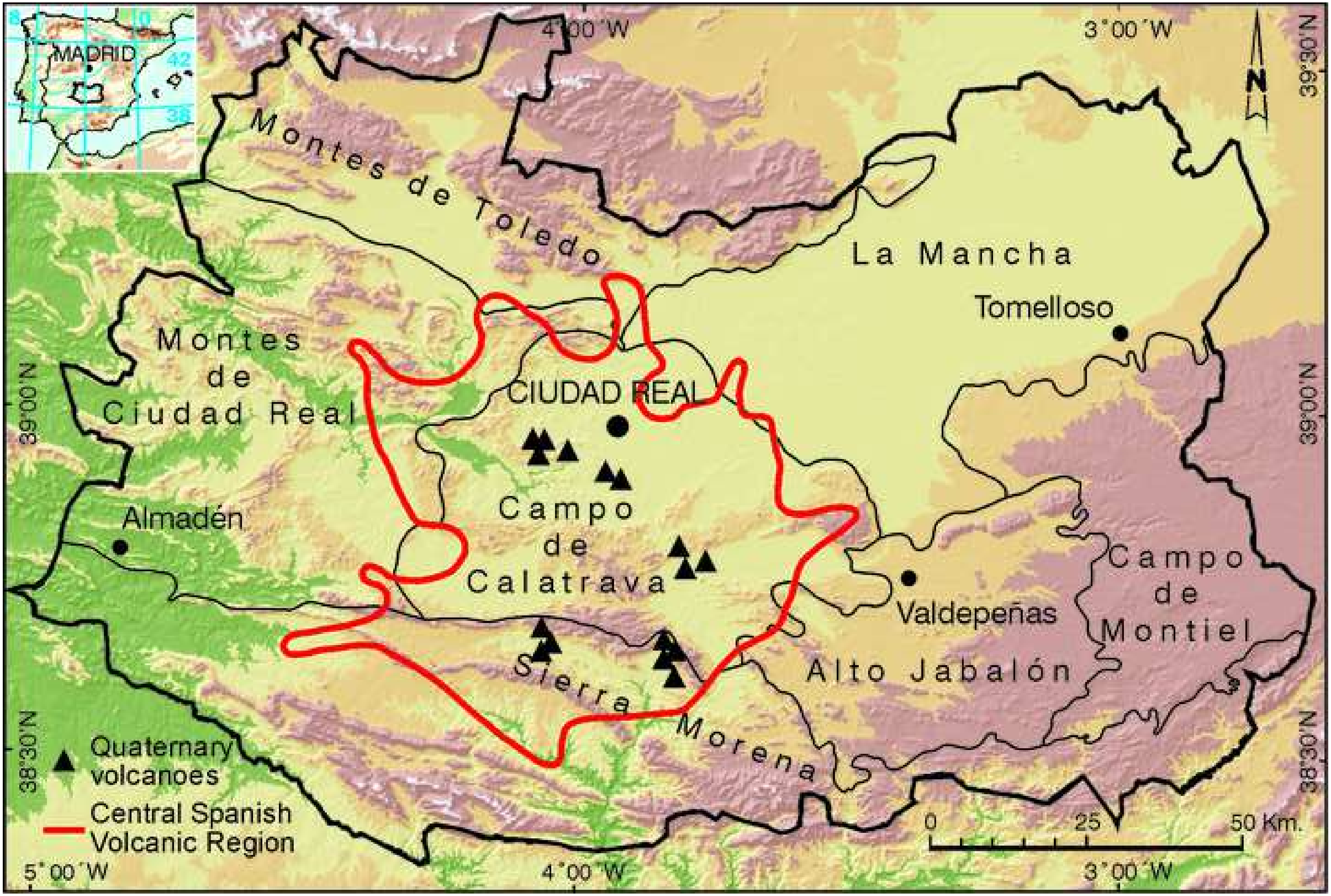
Fig. 13 Location of current granted pozzolan and basalt mining concessions and volcanoes of the CSVR protected under the denomination of Natural Monument

Table 1 Active basalt quarries in the Central Spanish Volcanic Region between 1911 and 1915 (Spanish Mining Statistics: 1911–1915)

Table 2 Current granted mining concessions of pozzolans and basalts (Spanish Mining Cadaster)

Figure

Click here to access/download;Figure;Figure 1_Study area.JPG



Figure

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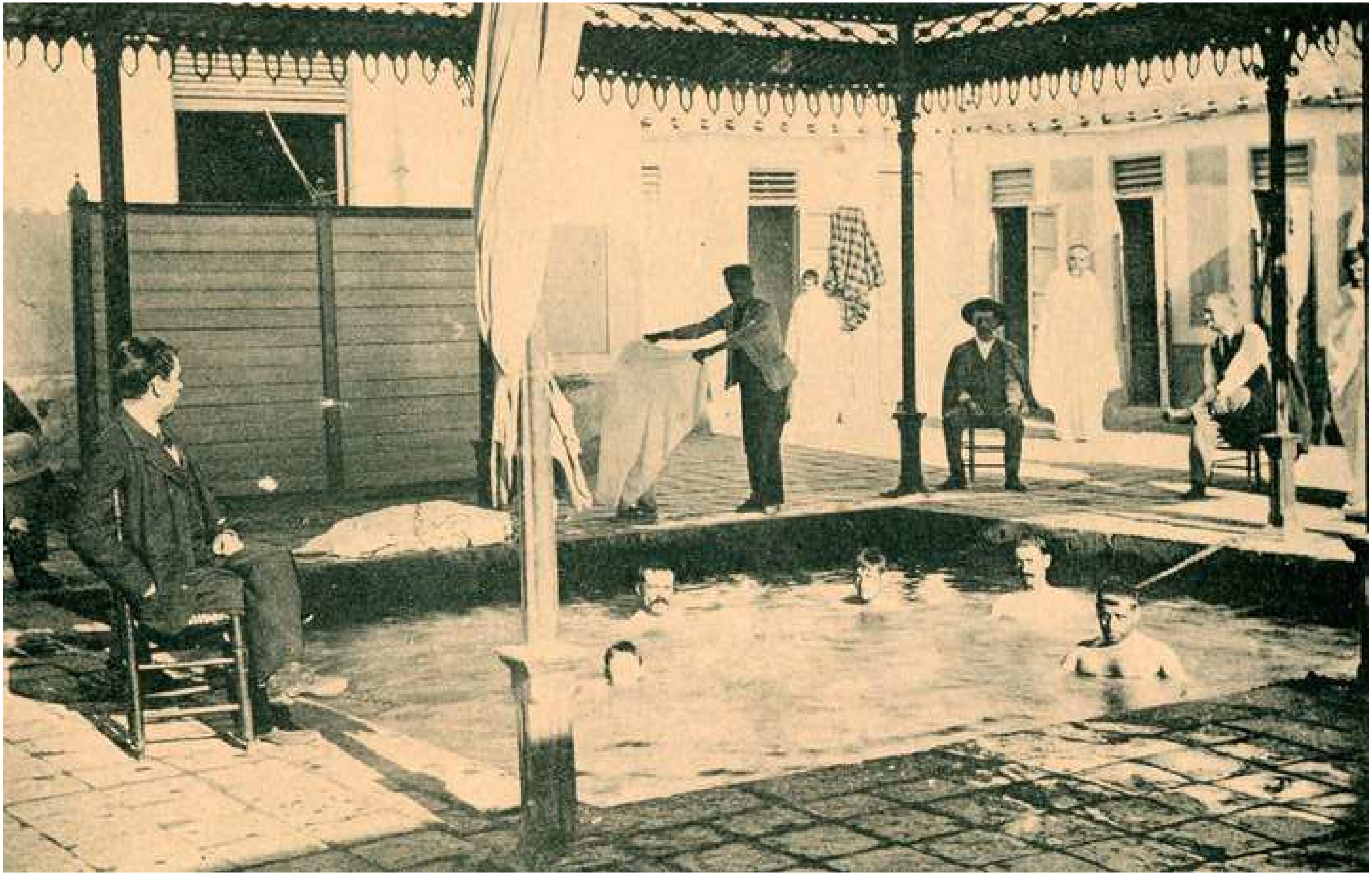

Figure

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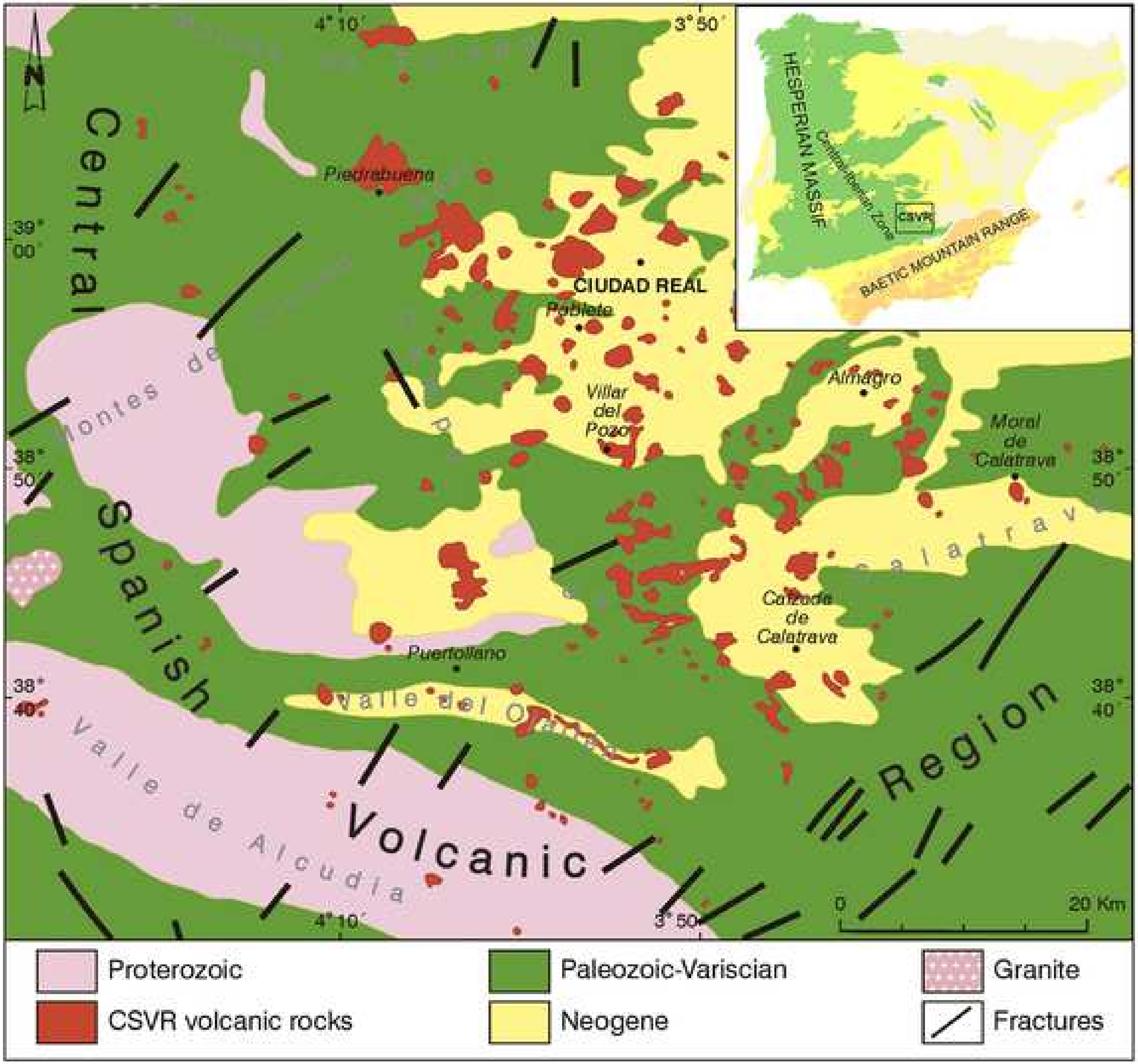

Figure

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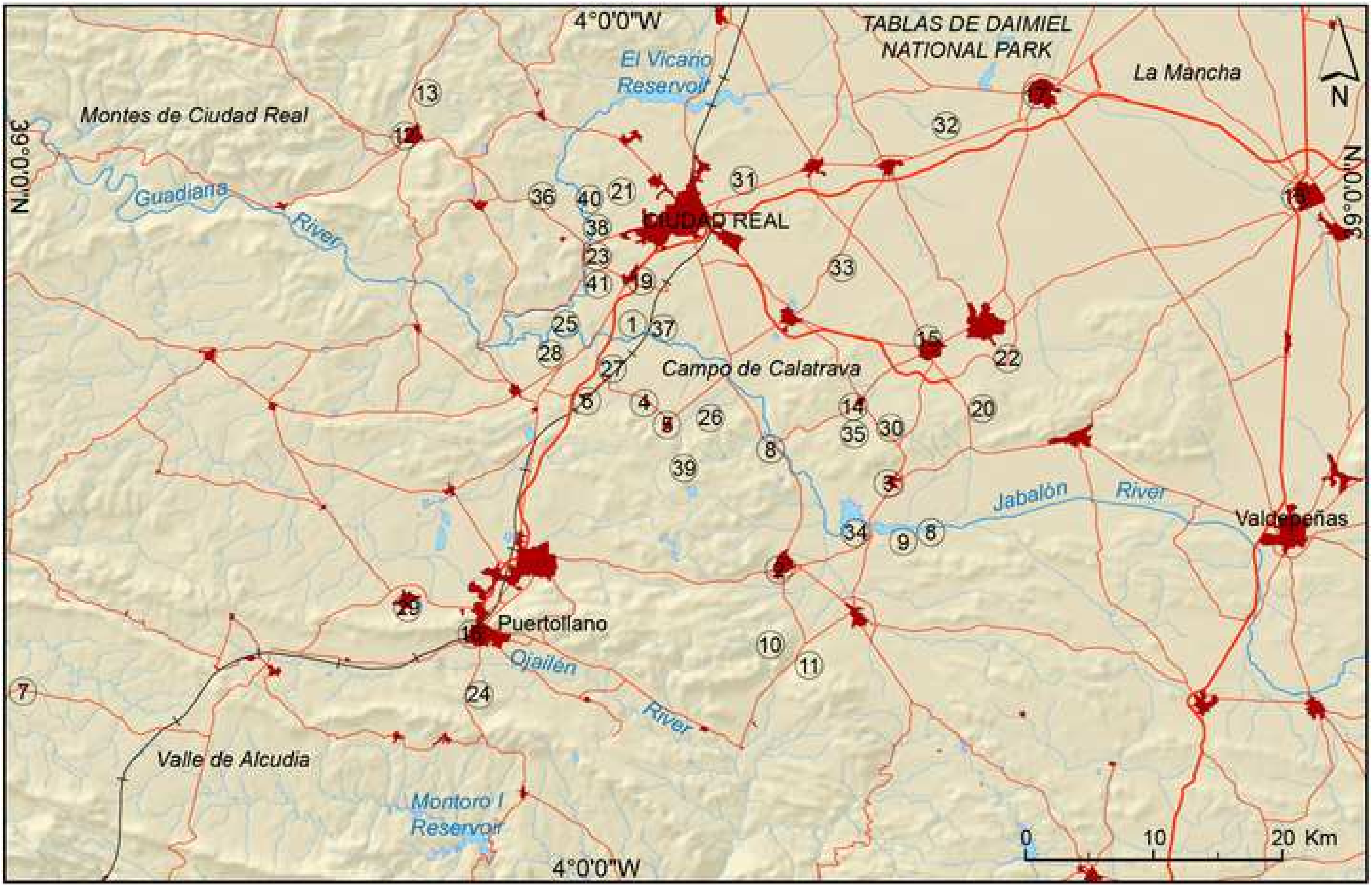

Figure

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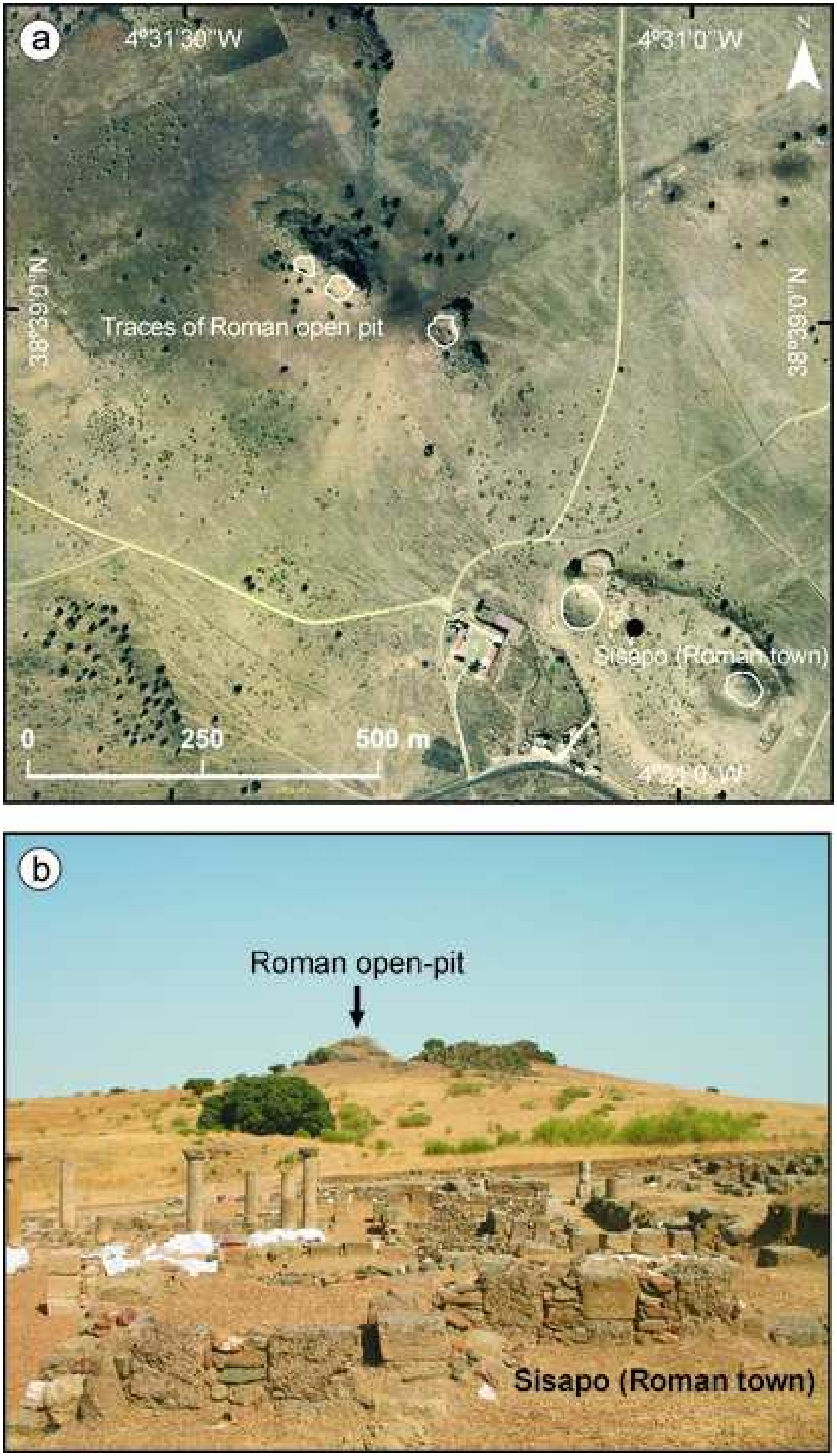
Figure

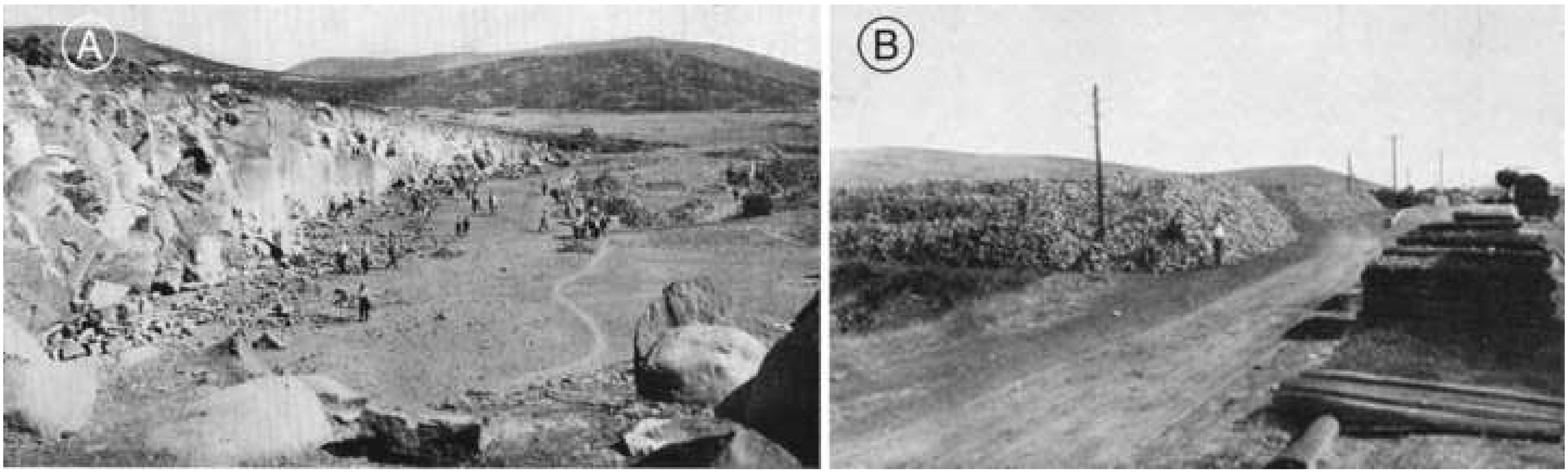

a
4°31'30"W
4°31'0"W
38°39'0"N
38°39'0"N
Traces of Roman open pit
Sisapo (Roman town)
0
250
500 m
b
Roman open-pit
Sisapo (Roman town)

Figure

Click here to access/download;Figure;Figure 7_Sacred Convent of Calatrava (New).jpg

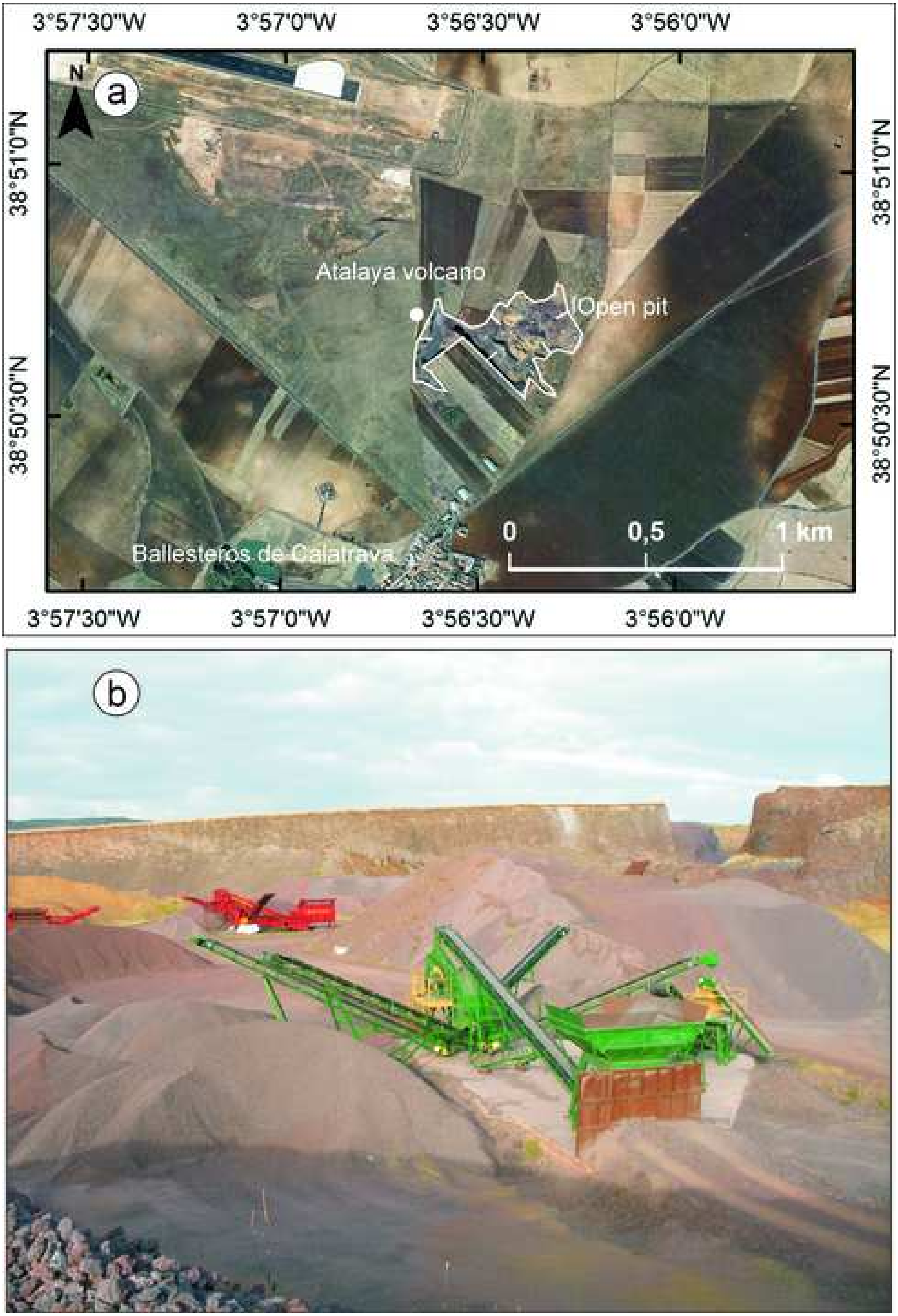
Figure

Click here to access/download;Figure;Figure 8_Ancient castle of Piedrabuena.jpg


A
B

Figure

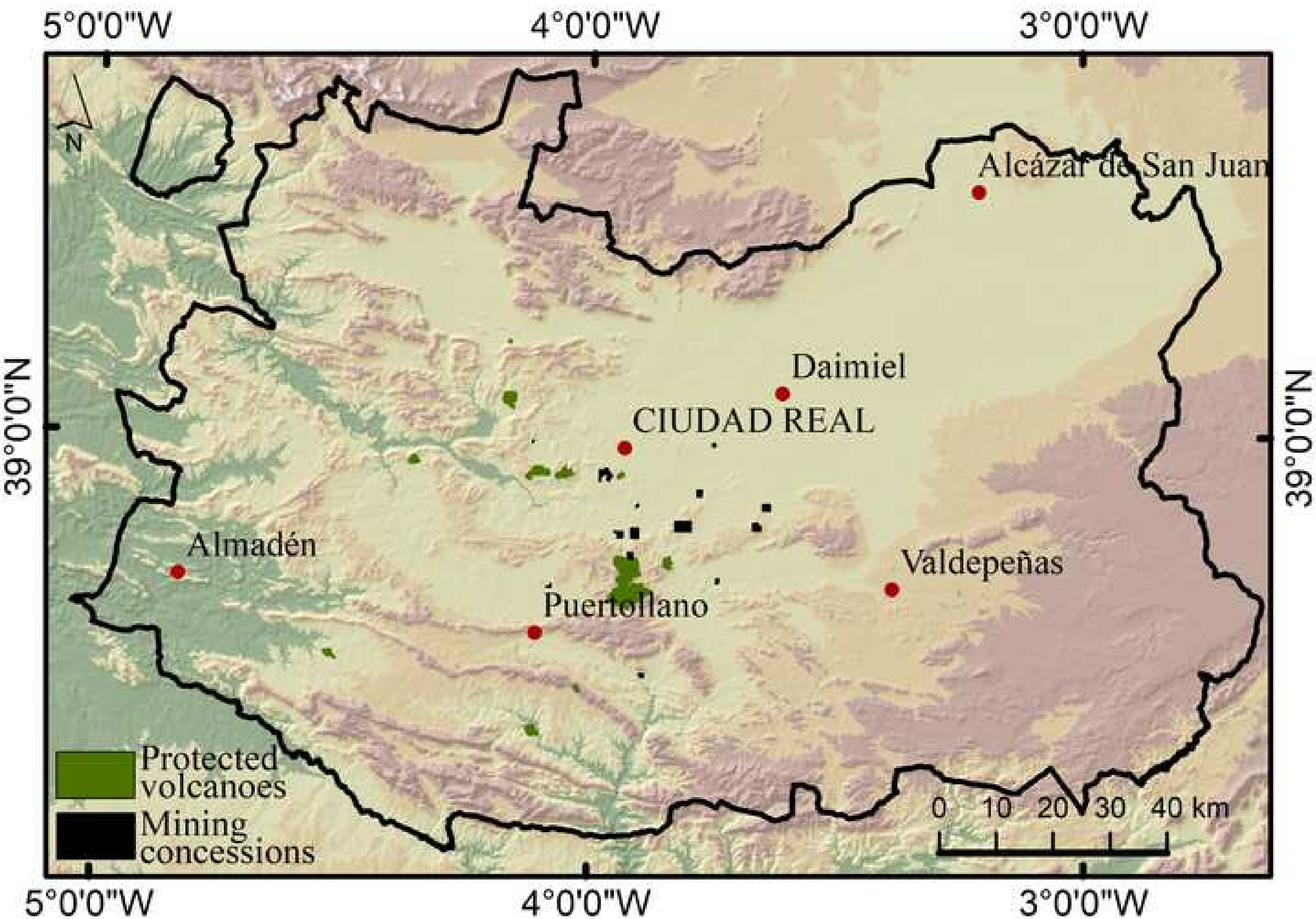
Click here to access/download;Figure;Figure 10_Quarries in Arzollar (New).jpg


3°57'30"W
3°57'0"W
3°56'30"W
3°56'0"W
38°51'0"N
38°50'30"N
N
a
Atalaya volcano
Open pit
Ballesteros de Calatrava
0
0,5
1 km
b

Figure

Click here to access/download;Figure;Figure 12_Quarries in Yezosa.JPG

Figure


5°0'0"W
4°0'0"W
3°0'0"W
39°0'0"N
N
Alcázar de San Juan
Daimiel
CIUDAD REAL
Almadén
Valdepeñas
Puertollano
Protected volcanoes
Mining concessions
0 10 20 30 40 km

Table

Table 1 Active basalt quarries in the Central Spanish Volcanic Region between 1911 and 1915 (Spanish Mining Statistics: 1911–1915)

Open-pit Name	Site	Municipality	Company	Date	Labourers	Production (Tm/m^3)
Miró	Juan Díaz	Aldea del Rey	Construcciones y Pavimentos S.A.	1911	23	
Unknown	Cerrillo Moreno	Almagro	Construcciones y Pavimentos S.A.	1911		
Mesetas	Cerro de la Cruz	Alcolea de Calatrava	Antonio Fernández Sánchez	1912		
María	Ardales	Aldea del Rey	Construcciones y Pavimentos S.A.	1912	58	2,000
Antonia	Juan Díaz	Aldea del Rey	Construcciones y Pavimentos S.A.	1912	20	400
Unknown	Cerrillo Moreno	Almagro	Construcciones y Pavimentos S.A.	1912		
Cerro Moreno	Arzollar	Ciudad Real	Fomento de Obras y Construcciones, S.A.	1912	11	
Castillejo de la Puente	Castillejo de la Puente	Puertollano	Antonio Fernández Sánchez	1912		
Morrón de la Valona	Morrón de la Valona	Puertollano	Antonio Fernández Sánchez	1912		
María Antonia	Ardales y Juan Díaz	Aldea del Rey	Construcciones y Pavimentos S.A.	1913	112	500
La Zorrera	Las Zorreras	Ciudad Real	Canteras Basálticas de La Mancha	1913	42	2,900
Las Zorreras	Casa de las Monjas	Ciudad Real	Canteras Basálticas de La Mancha	1914	380	2,000
La Balona	Valle de los Cañizares	Puertollano	Canteras Basálticas de La Mancha	1914	45	600
El Retamar	Morra de los Negrizales	Almodóvar del Campo	Canteras Basálticas de La Mancha	1914	60	1,200
Unknown	Palancares y Morrón	Villamayor de Calatrava	Fomento de Obras y Construcciones, S.A.	1914	74	200,000 cobblestones
Unknown	Hontanares	Piedrabuena	Construcciones y Pavimentos S.A.	1915	43	8,400

Table

Table 2 Current granted mining concessions of pozzolans and basalts (Spanish Mining Cadaster, 2019)

Mining site	Volcano	Location		Extracted material	Ha
Amp La Alemana	Yezosa	3° 40' 1,363" W	38° 51' 28,592" N	Basalt, Pozzolans	70
Siempreviva	El Enebrillo o Viilafranca	3° 54' 30,718" W	38° 50' 44,781" N	Basalt, Pozzolans	400
Octubre	Montecillo?	3° 46' 39,966" W	38° 54' 39,975" N	Basalt	400
Herrerías II	Ermita de San Isidro	3° 38' 30,004" W	38° 53' 20,002" N	Basalt	600
Demasía a Siempreviva	El Enebrillo o Viilafranca	3° 54' 29,957" W	38° 50' 50,051" N	Basalt, Pozzolans	900
Alemana II	Yezosa	3° 39' 32,358" W	38° 51' 27,004" N	Pozzolans	125
1 Amp A Alemana	Cabeza del Rey	3° 58' 13,605" W	38° 56' 28,149" N	Pozzolans	257
2 Amp A Alemana	Cabeza del Rey	3° 57' 46,385" W	38° 55' 55,821" N	Pozzolans	26
Primavera	Cerro Pelado	3° 54' 59,943" W	38° 48' 40,022" N	Pozzolans	400
Oreto	De las Cuevas	3° 44' 26,646" W	38° 46' 20,826" N	Pozzolans	47
San José	San Marcos	3° 44' 56,249" W	38° 59' 15,073" N	Pozzolans	36
Fermina	Cerro de la Cruz	4° 6' 59,943" W	38° 59' 27,255" N	Pozzolans	10
Fortuna	El Cabezuelo	3° 53' 33,466" W	38° 37' 21,031" N	Pozzolans	58
Amp a El Rayo	Cabeza Parda	4° 4' 50,242" W	38° 45' 43,955" N	Pozzolans	26
San Felipe	Cuelgaperros	3° 54' 13,724" W	38° 53' 27,190" N	Pozzolans	20
San Fernando	La Atalaya	3° 56' 20,959" W	38° 50' 43,484" N	Pozzolans	138
El Negrizal	Cabezas, Cabeza and Hoyos	3° 48' 39,760" W	38° 51' 30,085" N	Pozzolans	1,800

Dear Kevin Page,

Please find enclosed the revision of the manuscript entitled *The deterioration of geoheritage in the Central Spanish Volcanic Region by open-pit mining* by M.A. Poblete Piedrabuena and coauthors, to be submitted for publication to Geoheritage. This revision has been undertaken considering all the changes suggested by referees. We also attach an annotated copy (added as supplementary material) in which all the changes made are indicated in red colour.

We hope you will find this revision suitable for being published in Geoheritage. Sincerely yours,

Miguel Ángel Poblete Piedrabuena