Universitat de Girona

LA CONSERVACIÓN DEL PATRIMONIO NATURAL GEOLÓGICO EN CAMPOS VOLCÁNICOS, UNA HERRAMIENTA PARA LA GESTIÓN SOSTENIBLE DEL TERRITORIO. EL CASO DE LA ZONA VOLCÁNICA DE LA GARROTXA

Llorenç Planagumà i Guàrdia

Universitat de Girona

TESI DOCTORAL

La conservación del patrimonio natural geológico en campos volcánicos: una herramienta para la gestión sostenible del territorio

El caso de la zona volcánica de la Garrotxa

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PROGRAMA DE DOCTORAT

Dirigida per: Josep Vila-Subirós
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El Dr. Josep Vila-Subirós, de la Universitat de Girona y el la Dr Joan Martí i Molist, del Instituto de Ciencias de la Tierra "Jaume Almera" (CSIC)

DECLARAMOS:

Que el trabajo titulado *La conservación del patrimonio natural geológico en campos volcánicos, una herramienta para la gestión sostenible del territorio. El caso de la zona volcánica de la Garrotxa,* que presenta Llorenç Planagumà i Guàrdia para la obtención del título de doctora, ha sido realizado bajo nuestra dirección.

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1) Planagumà, L.; Martí, J. Geotourism at the Natural Park of La Garrotxa Volcanic Zone (Catalonia, Spain): Impact, Viability, and Sustainability. Geosciences 2018, 8, 295. https://doi.org/10.3390/geosciences8080295

2) Planagumà, L., Martí, J. Identification, cataloguing and preservation of outcrops of geological interest in monogenetic volcanic fields: the case of La Garrotxa Volcanic Zone Natural Park. Geoheritage 12, 84 (2020).
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3) Planagumà, L.; Martí, J.; Vila, J. Evaluation of the conservation of the geological heritage of volcanic fields: the case of la Garrotxa Volcanic Zone Natural Park 20 years after the approval of its geoconservation strategy. Geoheritage 14, 39 (2022).
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Dr. Josep Vila-Subirós

Dr Joan Martí i Molist

Girona, 4 de julio de 2022

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PNZVG	- Parque Natural de la Zona Volcánica de la Garrotxa.
ZVG	- Zona Volcánica de la Garrotxa.
CVG	- Campo volcánico de la Garrotxa.
AIG	- Afloramiento de interés geológico.
ODS	- Objetivos de desarrollo sostenible 2030.
UNESCO	- Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura
Ma	- Millones de años
PDC	- Corrientes de densidad piroclástica.
UTM	- Proyección Universal Transversa de Mercator.
ETRS	- Sistema de referencia europeo.
UICN	- Unión Internacional de conservación de la Naturaleza.
PEIN	- Plan de Espacios de Interés Natural de Catalunya.
ICGC	- Institut Cartogràfic i Geològic de Catalunya

A totes les anònimes de la història que han permès que també les humils puguin estudiar i investigar, en definitiva pensar.

AGRADECIMIENTOS / AGRAIMENTS

Si bé la tesis doctoral està escrita en castellà i anglès per tal que companys i companyes que conec de Mèxic, Costa Rica, Argentina, Itàlia, Estats Units, Islàndia, Madrid, Portugal, i altres encara per conèixer puguin comprendre millor el debat científic que proposo, he decidit que els agraïments, que aporten sentiments contraposats a la racionalitat de la ciència, fer-la en la meva llengua materna, la llengua dels meus pares, avis i la que he parlat sempre a les meves filles i la dels parlars de joventut entre alguns carrers sense asfaltar en el barris de la perifèria del centre d'Olot. Si bé és ben cert que l'idioma en ciència és l'anglès crec fermament que la ciència també ha de tenir espais en altres idiomes per tal de poder socialitzar el coneixement per tal que no es quedi només en mans de científics o de les elits. La ciència geològica cal que també arribi a qui viu i conviu amb els volcans ja que la socialització de la ciència és un dels pilars de la democràcia, un pas més a construir-nos com a societat pels reptes no gens fàcils que tenim i tindrem.

El perquè d'una tesis ara i no abans? Doncs suposo que aquesta pregunta l'hi hauria de fer a qui m'ha codirigit la tesis doctoral i m'ha ensenyat el que és el rigor científic. Sense els seus ànims no crec que m'hi hagués aventurat. Una tesis significa demostrar que tens capacitat d'anàlisis i saps desenvolupar el mètode científic i això només es pot fer amb temps. De jove no vaig tenir el temps de fer-la, sia per demèrit propi, sia per les circumstàncies del context socioeconòmic que m'envoltaven. Però llavors no m'adonava que també hi ha altres maneres de construir una tesis doctoral i és sembrant durant molts anys i deixant madurar el coneixement en el treball del dia a dia, entre afloraments efímers volcànics, atenent científics o divulgant la geologia... Una maduració que sense un entorn ben abonat no reeixiria a créixer, per això considero que gràcies a l'equip gestor del Parc Natural de la Zona Volcànica de la Garrotxa que m'ha donat la possibilitat de copsar lo complexa que és la conservació del patrimoni geològic en una zona tan bella com humanitzada com és la Garrotxa, a les companyes i companys del Centre per a la Sostenibilitat per oferir-me un marc de debat i terreny fèrtil per discutir idees de territori, als companys del Grup de Volcanologia de Barcelona del Institut de Geociències de Barcelona del CSIC que sempre han aportat coneixement de ciència vulcanològica a preguntes sobre el vulcanisme de la zona (algunes encara per respondre i que potser algunes mai les podrem saber) i finalment a TOSCA que m'ha donat el marc de coneixement en educació ambiental i programes educatius en els volcans, a tots ells i elles els hi dec aquest treball. Per això una tesis ara, malgrat disposar de poc temps en el dia a dia per fer-la però manllevant temps a experiències del passat he pogut construir unes conclusions de manera calmada, rigorosa, per demostrar allò que alguns cops s'intueix. I és que la ciència no es construeix a cop de sospites, s'ha de demostrar i això requereix temps, paciència i esforç. I, finalment, agrair a la Universitat de Girona i qui m'ha dirigit la tesis doctoral per la oportunitat de poder treballar en un marc acadèmic extraordinari.

No he posat noms en els agraïments, només col·lectius, per tal de no oblidar-me a ningú i perquè crec que la millor manera de construir pensament i de fer ciència és col·lectivament. Però tampoc voldria oblidar a els meus pares, fills de famílies pageses i obreres, ells i el context d'una educació pública i de qualitat em van donar la possibilitat en el seu moment d'estudiar geologia. Crec que una part també es deu a les meves filles, sense elles ser-ne conscients em van provocar un canvi en la manera de comprendre l'entorn que habitem i la responsabilitat de la constància. Molts són els amics, amigues i parelles que han influït en la construcció d'aquesta tesis, ja que som el que som gràcies als demés, no en tinc cap dubte. Però de tots els impulsos rebuts per afrontar la tesis i la seva finalització vull agrair especialment a qui fa uns anys m'acompanya, exemple de constància i profunditat de pensament en les accions que emprèn, sense ella seria difícil entendre com s'ha teixit dia a dia, o més ben dit cap de setmana a cap de setmana, aquesta tesis doctoral, ja que el mètode científic necessita temps i profunditat de pensament però també molt d'esforç i treball.

PUBLICACIONES DERIVADAS DE LA TESIS

Esta tesis doctoral se ha redactado con el formato tradicional. Aunque el apartado de resultados se ha escrito siguiendo el formato de tres artículos publicados en diferentes revistas internacionales. Los tres capítulos centrales han sido enviados, aceptados y publicados en dos revistas científicas, el primero en la revista *Geosciences* incluida en la base de datos Scopus d'Elselvier (SJR) y los dos siguientes artículos han sido enviados, aceptados y publicados en una revista indexada en la base de datos Journal Citation Report de Thompson Reuters (JCR), en concreto *Geoheritage*. A continuación se detalla el proceso de cada uno y su Factor de Impacto (FI).

El primer artículo (capitulo 6) analiza el impacto que ha tenido la gestión de la zona respecto el geoturismo en este campo volcánico, así como si este turismo se enmarca dentro de un turismo sostenible. El segundo artículo (capítulo 7) ya aborda cómo se pueden catalogar y conservar puntos de interés geológico en estos volcanes, metodología, líneas de gestión y investigación. Y para finalizar el tercer artículo (capitulo 8) evalúa 20 años de gestión en la zona volcánica respecto a la estrategia de conservación del patrimonio geológico para analizar si geoturismo y conservación están alineados y si la estrategia ha cumplido con sus propósitos.

Artículo 1

Planagumà, L.; Martí, J. Geotourism at the Natural Park of La Garrotxa Volcanic Zone (Catalonia, Spain): Impact, Viability, and Sustainability. Geosciences 2018, 8, 295.

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Artículo 2

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Artículo 3

Planagumà, L.; Martí, J.; Vila, J. Evaluation of the conservation of the geological heritage of volcanic fields: the case of la Garrotxa Volcanic Zone Natural Park 20 years after the approval of its geoconservation strategy. Geoheritage. 14, 39 (2022).

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RESUM

L'estudi de la geodiversitat d'una zona i la conservació del seu patrimoni geològic s'ha començat a sistematitzar, a diferència de la biodiversitat, des de fa pocs anys. En aquesta tesi s'analitza la conservació del patrimoni geològic en els camps volcànics, territoris geològicament interessants i que solen tenir dinàmiques socioeconòmiques força actives. L'estudi es basa en un camp volcànic situat al NE de la península Ibèrica on es van començar a fer polítiques de conservació des dels anys 80 en declarar-se bona part del mateix Parc Natural. Els camps volcànics quaternaris com aquest, que podria haver experimentat activitat volcànica a l'Holocè, es caracteritzen pel seu excel·lent estat de conservació, cosa que assegura que les seves morfologies volcàniques i els processos geològics encara siguin plenament visibles.

La zona volcànica de la Garrotxa és un cas d'estudi adequat per analitzar l'impacte en el patrimoni geològic i la sostenibilitat econòmica en un camp volcànic, ja que en només 40 anys s'ha permès transformar un territori poc conegut en un dels punts d'interès geològic més destacats i visitats de Catalunya. La protecció d'aquesta zona volcànica va representar la fi de les activitats d'explotació de grederes legals i il·legals que van fer malbé significativament la majoria dels volcans, però també va brindar una oportunitat per desenvolupar la zona per al turisme. Aquesta tesi avalua les conseqüències socials i econòmiques que ha tingut la promoció del geoturisme i si aquest és compatible amb la conservació dels béns naturals, especialment els geològics. Territoris com la Zona Volcànica de la Garrotxa representen laboratoris naturals on podem observar l'èxit o el fracàs respecte l'aplicació de polítiques respectuoses amb el medi ambient amb un impacte socioeconòmic positiu. Es proposa una metodologia adaptada als camps volcànics per seleccionar l'inventari de punts d'interès geològic, identificar quins cal conservar i quins divulgar. A partir d'indicadors s'avalua l'estratègia aprovada l'any 2000 per a la gestió del patrimoni geològic del Parc Natural de la Zona Volcànica de la Garrotxa (PNZVG).

La conservació de la geodiversitat i el patrimoni geològic proporciona una base per a la conservació d'altres tipus de patrimoni, per exemple, als camps de la silvicultura, l'agricultura, la indústria i el desenvolupament urbà. Vint anys després, una avaluació precisa d'aquest procés ajudarà altres zones volcàniques a dissenyar les seves estratègies per preservar millor el seu patrimoni geològic. En resum, tant els desafiaments que aquest tipus de patrimoni geològic té per les vulnerabilitats tant

intrínseques com antròpiques, així com els objectius de conservació que es plantegin són necessaris per assegurar una bona gestió d'una àrea protegida com aquesta.

RESUMEN

El estudio de la geodiversidad de una zona y la conservación de su patrimonio geológico se ha empezado a sistematizar, a diferencia de la biodiversidad, desde hace pocos años. En esta tesis se analiza la conservación del patrimonio geológico en los campos volcánicos, que son lugares de interés y que suelen tener dinámicas socioeconómicas bastante activas. El estudio se basa en un campo volcánico situado en el NE de la península Ibérica donde se empezaron a hacer políticas de conservación desde los años 80 al declararse buena parte del mismo parque Natural. Los campos volcánicos cuaternarios como éste, que pudo haber experimentado actividad volcánica en el Holoceno, se caracterizan por su excelente estado de conservación, lo que asegura que sus morfologías volcánicas y los procesos geológicos que los han creado sean plenamente visibles.

La Zona Volcánica de La Garrotxa es un caso de estudio adecuado para analizar el impacto en el patrimonio geológico y la sostenibilidad económica en un campo volcánico, ya que en apenas 40 años se ha permitido transformar un territorio poco conocido en uno de los puntos de interés geológico más destacados y visitados de Cataluña (España). La protección de esta zona volcánica representó el fin de las actividades de explotación de canteras legales e ilegales que dañaron significativamente la mayoría de sus volcanes, pero también brindó una oportunidad para desarrollar la zona para el turismo. Esta tesis evalúa las consecuencias sociales y económicas que ha tenido la promoción del geoturismo y si éste es compatible con la conservación de los bienes naturales, especialmente los geológicos ya que espacios como la Zona Volcánica de La Garrotxa representan laboratorios naturales donde podemos observar el éxito en la aplicación de políticas respetuosas con el medio ambiente con un impacto socioeconómico positivo en el geoturismo. Se propone una metodología adaptada a los campos volcánicos para seleccionar el inventario de puntos de interés geológico, identificar cuales se deben conservar y cuales divulgar. Se evalúa a partir de indicadores la estrategia aprobada en el año 2000 para la gestión del patrimonio geológico del Parque Natural de la Zona Volcánica de la Garrotxa (PNZVG).

La conservación de la geodiversidad y el patrimonio geológico proporciona una base para la conservación de otros tipos de patrimonio, por ejemplo, en los campos de la silvicultura, la agricultura, la industria y el desarrollo urbano. Veinte años después, una

evaluación precisa de este proceso ayudará a otras zonas volcánicas a diseñar sus propias estrategias para preservar su patrimonio geológico. En resumen, tanto los desafíos que este tipo de patrimonio geológico tiene por sus vulnerabilidades tanto intrínsecas como antrópicas, así como los objetivos de conservación que se planteen son necesarios para asegurar una buena gestión de un área protegida como esta.

ABSTRACT

The study of the geodiversity of an area and the conservation of its geological heritage, unlike biodiversity, has only recently begun to be systematized. This thesis analyses the conservation of geological heritage in volcanic fields, which are places of interest and usually have quite active socioeconomic dynamics. The study is based on a volcanic field located in the NE of the Iberian Peninsula where conservation policies began to be implemented in the 1980s, when a large part of this field was proclaimed a Natural Park. Quaternary volcanic fields such as this one, which may have experienced volcanic activity in the Holocene, are characterized by their excellent state of preservation, which ensures that their volcanic morphologies and the geological processes that have created them are fully visible.

The Garrotxa Volcanic Zone is an appropriate case study to analyse the impact on geological heritage and economic sustainability in a volcanic field, since in just 40 years it has allowed the transformation of a little-known territory into one of the most outstanding and visited points of geological interest in Catalonia (Spain). The protection of this volcanic zone represented the end of legal and illegal quarrying activities that significantly damaged most of its volcanoes, but also provided an opportunity to develop the area for tourism. This thesis evaluates the social and economic consequences of the promotion of geotourism and whether it is compatible with the conservation of natural assets, especially geological ones, since areas such as the Volcanic Zone of La Garrotxa represent natural laboratories where we can observe the success in the application of environmentally friendly policies with a positive socioeconomic impact on geotourism. A methodology adapted to volcanic fields is proposed in order to select the inventory geological interest points, and to identify which ones should be preserved and which ones should be publicized. The strategy approved in 2000 for the management of the geological heritage of the Garrotxa Volcanic Zone Natural Park (PNZVG) is evaluated on the basis of indicators.

The conservation of geodiversity and geological heritage provides a basis for the conservation of other types of heritage, for example, in the areas of forestry, agriculture, industry and urban development. Now, twenty years later, an accurate assessment of this process will help other volcanic areas to design their own strategies for preserving their geological heritage. In summary, both the challenges that this type of geological

heritage faces due to its intrinsic and anthropic vulnerabilities, as well as the proposed conservation objectives, are necessary to ensure good management of a protected area such as this one.

1. INTRODUCCIÓN

Las zonas volcánicas y en especial los campos volcánicos monogenéticos son sitios relevantes respecto al patrimonio geológico (Planagumà y Martí 2020), los cuales suelen casi siempre ir acompañados de unos valores naturales y culturales igual de importantes (Németh et al. 2017; Capdevila-Werning 2020). Estos campos volcánicos, repartidos por gran parte del globo terráqueo, consisten en pequeños conos de escorias con sus coladas de lava repartidos en áreas que van desde pocos a centenares de quilómetros cuadrados hasta algunos que pueden extenderse de forma más amplia y llegar a contener más de mil conos, como es el caso del campo volcánico de Michoacán. A diferencia de los grandes estratovolcanes que se pueden elevar miles de metros y crean una imagen que nos fascina, pero que también nos impone miedo por su majestuosidad sublime, los campos volcánicos monogenéticos ofrecen belleza y paisajes armónicos gracias a sus ricos suelos, producto de las cenizas volcánicas, y sus suaves formas de relieve entre llanos formados por las lavas y la sedimentación. Estos territorios de colinas de pocas decenas de metros han ofrecido un lugar idóneo para que sociedades humanas se instalen y prosperen. Desde la perspectiva de la geoconservación, estos campos volcánicos activos son de especial interés porque ofrecen la posibilidad de observar las complejas e interesantes relaciones estratigráficas que a menudo caracterizan sus productos acompañados de paisajes de inusual belleza (Casadevall et al. 2019). Estos sitios geológicos permiten a los visitantes apreciar toda la complejidad de la actividad volcánica, junto con la importancia de los valores del patrimonio geológico que deben preservarse.

Actualmente se tiene claro que la geoconservación es un beneficio para la sociedad al proporcionar información para comprender la historia de la Tierra (Gray et al. 2013), pero también como herramienta para conservar servicios ecosistémicos relacionados con la geología y que son importantes para las sociedades, como por ejemplo los de soporte (ej. suelos, riscos y cuevas), abastecimiento (ej. minerales, energía o agua), los de regulación (ej. clima, inundaciones, etc) o los culturales (ej. conocimiento científico, geoturismo, etc). La geoconservación integra el conocimiento de la geodiversidad y cómo conservar el patrimonio geológico en un territorio basándose en los principios de la gestión sostenible, por eso es una buena herramienta para el desarrollo económico sostenible de la zona. La protección de aquellos elementos de la geodiversidad que tienen un alto valor se llama patrimonio geológico, principalmente por razones científicas, pero también puede ser por su contenido educativo, cultural, estético, espiritual y ecológico. Por lo tanto, el éxito de la conservación de la geodiversidad de un área dependerá de qué tan bien protejamos su patrimonio geológico; por eso, la selección de geozonas y geositios y la gestión y monitoreo de su conservación son aspectos relevantes de las estrategias de geoconservación en todos los niveles (Brilha et al. 2018). La conservación y esfuerzo de gestión en estos lugares reclama más atención por la vulnerabilidad intrínseca de los materiales que la conforman, ya que son fácilmente erosionables.

Tradicionalmente, tanto los planes de gestión de las áreas protegidas como su personal y asesores encargados de la gestión directa están familiarizados con la importancia de la conservación de la biodiversidad. Este campo, inscrito dentro de la biología, es la base de muchos tratados internacionales que ya tienen largo recorrido, como el del Convenio sobre la Diversidad Biológica de 1992. En las áreas protegidas la conservación de su biodiversidad podríamos decir que es su razón de ser. Pero las rocas, sedimentos, suelos, sus procesos geológicos y su evolución son también vitales para el futuro del planeta y las sociedades humanas (Gray et al. 2013). Actualmente, hay una conciencia mucho mayor del significado de la geoconservación que va más allá del educativo o estético, integrando la geodiversidad y el patrimonio geológico como servicios ecosistémicos para las sociedades. Muchas áreas protegidas creadas para conservar la biodiversidad o el patrimonio natural del planeta también tienen valores geológicos relevantes (Crofts and Gordon 2014) como por ejemplo el primer parque nacional del mundo, Yellowstone (1872) en Estados Unidos, o uno de los primeros de España, como es el caso del Parque Nacional del Teide (1954), en la isla de Tenerife.

Actualmente existen numerosos ejemplos de preservación de la geodiversidad y de cómo se puede basar a partir de las características específicas de un área determinada, de los valores geológicos a proteger y de las regulaciones políticas y administrativas actuales. El resultado de todos estos esfuerzos para preservar estos valores geológicos se refleja en los geoparques de la UNESCO (Henriques and Brilha 2017), los parques nacionales y naturales que protegen las características geológicas, y muchos otros geosites o monumentos naturales protegidos que existen en todo el mundo. La protección y preservación de los valores geológicos no debe significar que sean inaccesibles para el público en general. Los sitios geológicos protegidos siempre cuya conservación esté garantizada deben ser visitables y disponer de información correcta sobre su relevancia y su valor local. Por lo tanto, la protección del patrimonio geológico también significa elaborar los mejores protocolos de gestión y conservación posibles para la identificación, acceso y difusión de todos los puntos de observación que definen un área protegida particular (Planagumà y Martí 2018).

Han pasado 21 años desde la instauración del programa de la UNESCO para la creación de los geoparques originado en el 1999 y la geoconservación ya se está planteando a diferentes escalas territoriales: internacional, regional (<10.000km2) y local (<100km2). Lo interesante es que cada escala territorial plantee sus objetivos, acciones, indicadores y evaluación diferenciados, dependiendo de su estrategia de geoconservación. 20 años es un tiempo ya suficiente para analizar y evaluar la conservación del patrimonio geológico en un territorio, es una escala temporal en la que ya se pueden ver afectaciones en el patrimonio geológico debido a procesos naturales como la erosión, o antrópicos como proyectos urbanísticos o infraestructuras, sobre frecuentación turística, minería, guerras, etc. Por eso es importante evaluar y analizar los indicadores y el estado del patrimonio geológico, así como de las primeras iniciativas de conservación en este campo, como es el caso del Parque Natural de la Zona Volcánica de la Garrotxa creado en el 1982 y su estrategia de geoconservación implementada en el 2000.

Las zonas volcánicas albergan relaciones estratigráficas complejas e interesantes y, a menudo, están dotadas de patrimonio geológico de una importancia extraordinariamente relevante. Una prueba de ello es la gran cantidad de áreas protegidas en volcanes a causa de la riqueza de sus suelos favorables a la biodiversidad, a la belleza paisajística, a sus valores intangibles y a los culturales (Németh et al. 2017). Una muestra de ello es que 80 lugares declarados patrimonio de la humanidad están en volcanes. Un tipo de región con volcanes son los campos volcánicos monogenéticos, territorios muchas veces declarados espacios de interés natural, ya que presentan suelos ricos, lugares de interés geológico accesibles y hermosos paisajes. Por ejemplo, en el Rift Europeo hay 9 campos volcánicos con diferentes formas de protección (Planagumà y Martí 2020). Frecuentemente estas zonas volcánicas se han vuelto cada vez más atractivas para los geoturistas, que buscan paisajes volcánicos vivos y extintos y buena gastronomía, así como aventuras y diversión. Por lo tanto, como ocurre con la conservación de la biodiversidad o alguna especie en peligro de extinción, la preservación del patrimonio geológico local genera dinámicas sociales y económicas positivas en el lugar.

La zona volcánica de la Garrotxa se encuentra localizada en el noreste de la Península Ibérica y forma parte de la provincia volcánica catalana de edad neógena-cuaternaria relacionada con el rift europeo, que se extiende desde el mar de Alborán hasta el centro de Europa. Este rift se empezó a formar debido a la distensión neógena iniciada hace unos 20 Ma, al detenerse la orogenia alpina que afectó al sur de Europa (Martí et al. 1992). El vulcanismo asociado a este rift es de tipo alcalino ha generado distintas zonas volcánicas; la de la Garrotxa, que cubre unos 600 km2 entre Olot y Girona, es una de las más recientes, y consta de unos cincuenta conos volcánicos, coladas de lava, anillos de tobas y maares de edad comprendida entre el Pleistoceno medio (0,12-0,78 Ma) y principios del Holoceno (0,01 Ma). Este vulcanismo se localiza sobre granitos y esquistos del Paleozoico, sobre todo en rocas sedimentarias eocénicas y en depósitos aluviales cuaternarios, y el magma que lo originó es de tipo basáltico y basanítico (una mezcla de basanitas con nefelina y basaltos con olivo). En muchos casos, el magma deriva directamente de fuente primaria, no diferenciado o contaminado por materiales de la corteza.

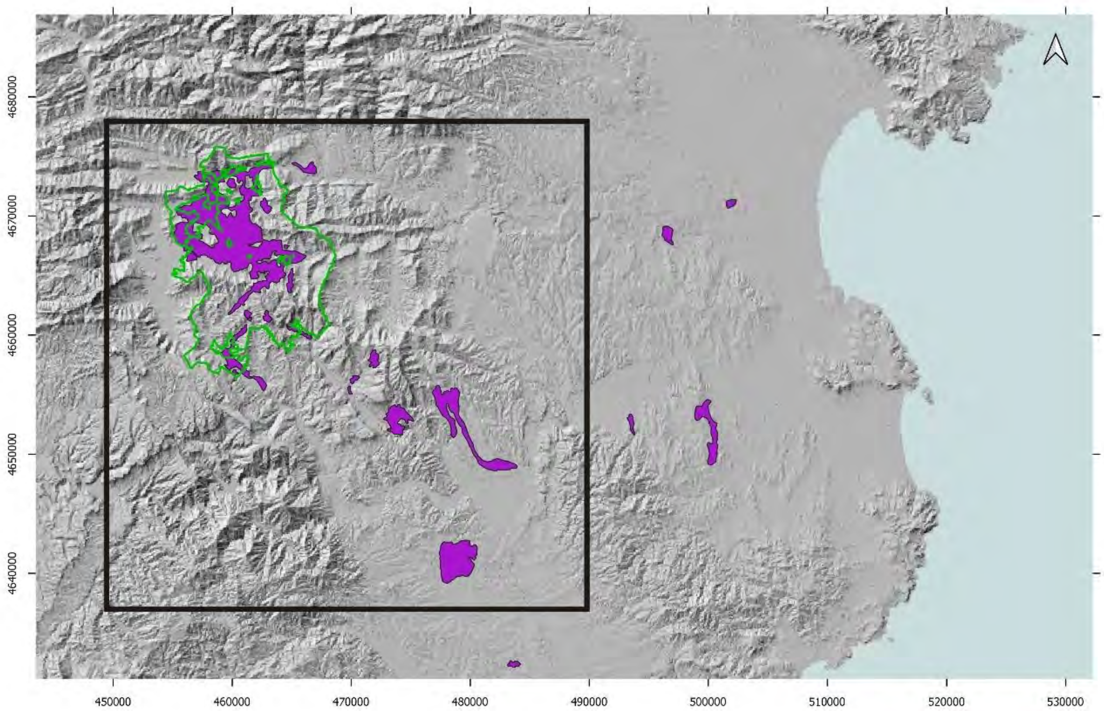

Figura 1a - Mapa esquemático de la zona de trabajo (recuadro negro), las zonas lilas corresponden a depósitos volcánicos. En verde los límites del Parque Natural de la Zona Volcánica de la Garrotxa.

La mayoría de los volcanes de la zona volcánica de la Garrotxa se encuentran en las inmediaciones de las localidades de Olot y Santa Pau, o a pocos kilómetros de estas localidades, como es el caso de la Cruz de Sant Dalmai, el volcán de Canet de Adri o el volcán del Puig de Granollers (Figura 1). Son pequeños conos monogenéticos que se formaron como consecuencia del ascenso de diferentes bolsadas de magma a lo largo del tiempo y a través de fallas de orientación noroeste y sudeste, activas desde finales del Mioceno (> 5 Ma). El magma aprovechó estas fallas para ascender hacia la superficie y generó un vulcanismo fisural que se concentra en fallas secundarias relacionadas con las principales, de forma que los volcanes de la Garrotxa se encuentran entre la falla de Llorà y la de Amer. Los diferentes pulsos de magma que ascendieron por estas fallas generaron volúmenes de magma extruido modestos, de entre 0,01 y 0,2 km3, emplazados en forma de conos de escorias, coladas de lava o maares. Debido a la diversidad del subsuelo, estos conos volcánicos se localizan sobre rocas sedimentarias eocénicas o cuaternarias y esquistos paleozoicos, de forma que la diversidad de secuencias y depósitos volcánicos resulta muy elevada. Por esta razón, no existe un patrón uniforme en la actividad volcánica de la zona (Martí et al. 2011). También cabe destacar la diversidad hidrogeológica, que provocó diferentes tipos de interacciones con el magma (freatomagmatismo) y que, por tanto, generó actividades y secuencias eruptivas diferenciadas una de otra como, por ejemplo, los casos del volcán de la Crosa de Sant Dalmai (donde el magma interaccionó con un acuífero aluvial cuaternario) o el volcán de Can Tià (con un acuífero sedimentario eocénico).

2. ÁREA DE ESTUDIO

El área de estudio se corresponde al campo volcánico de la Garrotxa, más comúnmente conocido como Zona Volcánica de la Garrotxa. Este campo volcánico comprende principalmente el Parque Natural de la Zona Volcánica de la Garrotxa, pero también incluye algunos volcanes situados fuera del mismo como el volcán de la Crosa de Sant Dalmai y los volcanes de la Vall de la Llèmena (figura 1). Si bien la mayoría de la información de la tesis se obtiene en el PNZVG al tener una gestión activa y de recogida de datos de muchos años, creo importante desde la visión geológica abordar todo el campo volcánico. La no correspondencia entre el campo volcánico y los límites del PNZVG se debe a criterios más administrativos que geológicos, ya que se definieron para no trascender inicialmente el área protegida a los límites de la comarca de la Garrotxa y uno de los objetivos de esta tesis es analizar estas disfunciones muy comunes en el patrimonio geológico.

La zona de estudio escogida tiene una larga trayectoria en políticas de conservación del patrimonio geológico (Planagumà 2017), ya que el PNZVG fue declarado en 1982 (tabla 1) para proteger los numerosos sitios geológicos de especial interés que se encuentran en este campo volcánico. A causa de estas estrategias de gestión, la comarca de la Garrotxa se ha caracterizado por una íntima relación entre los volcanes y la sociedad (Martí y Planagumà 2017), comparable o incluso superior a la de zonas de vulcanismo más activo e histórico. En La Garrotxa los volcanes están presentes en muchos aspectos de la sociedad local, como su patrimonio cultural, historia local, arquitectura, o incluso en su excelente gastronomía. La gente sabe que vive y convive entre volcanes y que representan el rasgo más característico de su región.

En el paisaje de la ZVG (Nogué y Sala 2017) destacan también aquellos relieves moldeados en colinas que se dan en las sierras, constituidas por una alternancia de materiales sedimentarios (margas, areniscas, conglomerados) que presentan una diferente resistencia a la erosión. La disposición de este territorio se encuentra en el corazón mismo de la dorsal húmeda, que se extiende del Vallespir al Montseny, y determina una pluviosidad superior a la de regiones vecinas y una sequía estival menos acentuada. Así, en los valles, situados entre los 400 y los 500 metros de altitud, se sobrepasan los 1.000 litros/m2 de media anual, valor que en Cataluña se da generalmente solo por encima de los 1.000 m de altitud. La existencia de la pantalla orográfica del Puigsacalm (1515 m), orientada de forma perpendicular a la llegada de los vientos húmedos del Mediterráneo, favorece un incremento de la precipitación en las partes más occidentales de los valles. Por otra parte, la barrera pirenaica en el norte entorpece la entrada de las masas de aire frío boreal. Las condiciones climáticas descritas y los suelos volcánicos ricos ayudan a explicar la diversidad del paisaje vegetal. En los fondos de los valles y en las zonas más llanas, la vegetación natural ha sido sustituida por los cultivos, pastos y áreas urbanizadas. El espacio agrícola está dedicado, fundamentalmente, al cultivo de forrajes y cereales forrajeros para la especialización bovina. Las dinámicas urbanísticas y de mejora de la red viaria se están traduciendo en un proceso de fragmentación de este suelo agrario y en la generación de unos espacios intersticiales que se abandonan y pasan a ser baldíos. El suelo agrario pierde superficie en la periferia del área urbana de Olot y en torno a las principales infraestructuras, aunque la elevada fertilidad de la mayor parte de los suelos y una orografía sin accidentes en el relieve son variables que juegan en favor de su mantenimiento futuro. El paisaje urbano recoge los rasgos de la organización territorial que tiene su origen en la creación de las parroquias rurales o las fortificaciones medievales, algunas de las cuales dan lugar a los núcleos urbanos históricos más importantes, como son los casos de Santa Pau, Besalú o San Feliu de Pallerols. Por el fondo de las llanuras discurren las principales vías de comunicación que conectan los valles de Olot con las ciudades de fuera de su ámbito. El valle de Bas es atravesado por la carretera C-153 hacia Vic, además de la salida de los túneles de la autovía que conecta Vic con Olot por Bracons; el valle de Hostoles es surcado por la C-63 hacia Santa Coloma de Farners; el valle de Bianya, mediante la C-26, da acceso al Ripollès; y el valle del Fluvià, aguas abajo de Olot, acoge la autovía A-26 (desdoblamiento de la N-260) hacia Besalú y, desde allí, permite llegar hacia Figueres o bien hacia Banyoles y Girona.

La ampliación de esta red viaria en los últimos tiempos ha supuesto un proceso de transformación del paisaje de los valles de Olot. La compleja orografía que rodea los valles ha determinado que, durante muchas décadas, la única vía de conexión con el exterior sin tener que atravesar collados y hacer un gran número de curvas fuera por el noreste a través del valle del Fluvia. A partir de la década de 1990, se inició un proceso de mejora que comenzó con la remodelación de la carretera del valle de Hostoles y el túnel de Bas y que ha seguido con la variante de la carretera N-260 por el norte de Olot y el nuevo trazado de la carretera C-153 con los túneles de Collabós. Sin embargo, los dos proyectos viarios de mayor incidencia desde la perspectiva territorial y paisajística, y que están relacionados entre ellos, son el de la conversión en autovía del eje pirenaico entre Besalú y Olot (A-26), con continuidad hasta Figueres y, sobre todo, el nuevo trazado de la vía rápida entre Vic y Olot mediante el túnel de Bracons (C-37). Estas vías han provocado una notable pérdida de conectividad ecológica y paisajística entre espacios de interés natural. De cara al futuro, falta todavía resolver el paso de esta carretera por el núcleo de Les Preses, la circunvalación de la capital garrotxina y el enlace con el Eje pirenaico.

Desde la perspectiva de las dinámicas en el paisaje debe mencionarse el papel que ha tenido, desde su creación, el Parque Natural de la Zona Volcánica de la Garrotxa (Nogué y Sala 2017). La vigencia y efectividad futuras de esta figura primordial para la gestión del medio natural será clave para el mantenimiento de un espacio con una elevada calidad paisajística y ambiental y para compatibilizar con el entorno las actividades económicas que se practican, sobre todo las relacionadas con la agricultura o el turismo. La situación de esta zona es estratégica al ser la única que puede ofrecer geoturismo en volcanes de toda la Eurorregión Pirineos-Mediterráneo, que engloba la región francesa de Occitania y las regiones autónomas de Cataluña y Aragón en España. Esta Eurorregión tiene una población de 14.529.912 habitantes que se encuentran a una distancia de menos de 300 km. Este es el potencial público que puede visitar frecuentemente dichos volcanes. Según las estadísticas proporcionadas por el parque natural, en 2010 la comarca de la Garrotxa recibió 355.735 visitantes, 53.000 más que en 2001 (Figura 3). De estos visitantes, el 48% eran familias y el 37% eran parejas, el 81% eran catalanes (es decir, turismo local), y el 76% de los visitantes venían a ver volcanes.

3. MARCO TEÓRICO

En esta tesis doctoral se pretende analizar a partir de diferentes datos e indicadores cómo la preservación del patrimonio geológico en un campo volcánico es una inversión que genera dinámicas sociales y económicas positivas en el territorio y para la gente que convive con los volcanes. Con dos décadas de información y análisis hechos respecto al patrimonio geológico y socioeconómicos de la zona ya se puede discutir si la geoconservación ha generado procesos de cambio respecto a la conservación de la geología, el turismo sostenible o el impacto de programas educativos. Los resultados y conclusiones tienen que servir para mejorar la geoconservación en las áreas protegidas y, sobre todo, ofrecer herramientas para conservar los valores geológicos en los campos volcánicos y que, a la vez, aporten beneficios ecosistémicos a la sociedad (Gray 2011).

Actualmente se tiene claro que la geoconservación es un beneficio para la sociedad al proporcionar información para comprender la historia de la Tierra (Henriques et al. 2011) pero también como herramienta para conservar servicios ecosistémicos relacionados con la geología y que son importantes para las sociedades. Algunos ejemplos son los de soporte (por ejemplo relieves, riscos y cuevas), abastecimiento (por ejemplo minerales, energía o agua), los de regulación (por ejemplo clima, inundaciones, etc.) o los culturales (por ejemplo conocimiento científico, geoturismo, etc) (Gray et al. 2013). La geoconservación incluye el conocimiento de la geodiversidad y cómo conservar el patrimonio geológico en un territorio basándose en los principios de la gestión sostenible y la protección de aquellos elementos de la geodiversidad que tienen un alto valor se llama patrimonio geológico, principalmente por razones científicas, pero también por su contenido educativo, cultural, estético, espiritual, histórico y ecológico. Por tanto, el éxito de la conservación de la geodiversidad de un área dependerá de qué tan bien protejamos su patrimonio geológico natural. Por ello, la selección de geozonas y puntos de interés geológico, así como la gestión y monitorización de su conservación son aspectos relevantes de las estrategias de geoconservación en los espacios naturales protegidos (Crofts et al. 2020).

La estrategia del Patrimonio Natural y la Biodiversidad de Cataluña (Comas et al. 2018) incluye el patrimonio geológico y la geodiversidad como componente del Patrimonio Natural, y señala como reto mejorar la conservación tanto de las especies autóctonas, los ecosistemas, como también de la geodiversidad. La geodiversidad y el patrimonio geológico en 2030 debe haberse equiparado al resto de los componentes del patrimonio natural en materia de planificación, gestión y toma de decisiones (Planaguma y Marti 2020). Asimismo, como línea de actuación también prioriza que los espacios naturales de protección especial consideren el patrimonio geológico de forma equivalente a como se hace con el resto de los elementos del patrimonio natural. Por eso es necesario sistematizar la conservación del patrimonio geológico en la zona volcánica de la Garrotxa. Por eso analizar qué recursos se han destinado, cuál ha sido el resultado y si se han conseguido los objetivos planteados es tan importante (Crofts et al. 2020).

La gestión del patrimonio geológico en estos territorios volcánicos se enmarcaría en el enfoque de resiliencia socioecológica donde los seres humanos y la naturaleza se estudian como un todo, no como partes separadas (Folke et al. 2016). La humanidad está incrustada en la biosfera y en esta tesis se contempla también en la gea. En este sentido la gente, independientemente de los contextos sociales y culturales, coevoluciona imprescindiblemente con el planeta y nuestras creencias, percepciones y elecciones tienen que dar forma a nuestras acciones y tecnologías para un futuro en la biosfera sostenible (Folke et al. 2016). Cuestiones fundamentales para la humanidad como la democracia, la salud, la pobreza, la desigualdad, el poder, la justicia, los derechos humanos, la seguridad y la paz descansan en la vida, la capacidad de apoyo de la gea y resiliencia de la biosfera (Funtowicz y Ravetz 1991).

4. OBJETIVOS

Como objetivos se pretende analizar los procesos de desarrollo sostenible de la conservación del patrimonio geológico en volcanes. Qué importancia ha tenido la conservación del patrimonio geológico en la economía local y el emprendimiento social de la Garrotxa. Se busca proponer modelos de conservación futura e indicadores para su evaluación y comprender qué impactos sociales y económicos se generan cuando se da valor al patrimonio geológico.

A parte de estos objetivos relacionados con el área de trabajo, también se plantea determinar el papel de la geología respeto a los objetivos de desarrollo sostenible que se emmarcan en los retos para el 2030 y que no está contemplada por ningún organismo.

5. METODOLOGÍA

La metodología aplicada en la tesis y que constituye de manera transversal los tres artículos publicados se ha basado en dos líneas de trabajo principales que han permitido desarrollar y llegar a las conclusiones que se exponen. Los siguientes puntos son un resumen de la metodología aplicada en los artículos publicados, que exponen la experiencia de 20 años de trabajo con la participación de expertos en gestión y vulcanismo, visitas al campo y ensayo y error respecto a experiencias de conservación del patrimonio geológico. Cada artículo publicado aborda la síntesis de un conocimiento de cómo aplicar a la practica planes de gestión en la conservación de la geología y, al final, evaluarlos para así obtener indicadores que otras zonas puedan aplicar. En definitiva, en esta tesis doctoral una gran parte de la metodología consiste en ordenar y recopilar en tablas, sean excel o Word datos generados en los últimos 20 años para así abordar datos inciertos si se recogen a corto plazo (Funtowicz y Ravetz 1991). Difícilmente, por poner un ejemplo, se podría generar la tabla 3 sin tener un elevado conocimiento de vulcanismo y de la zona producto de cartografías y la participación en trabajos cientifícos como por ejemplo los generados por Martí et al. 2011, 2017; Bolós et al. 2014.

Revisión bibliográfica y recopilación de datos. En el PNZVG se lleva más de 20 años recogiendo datos relacionados con el patrimonio geológico: más de 100 afloramientos efímeros, estadística de visitantes en los lugares de interés geológico como es el volcán del Croscat, diferentes estudios científicos, así como datos de publicaciones elaboradas a partir de un análisis sistemático de esta información y bibliografía expresada en gráficos, tablas y mapas para su discusión e interpretación. La elaboración de mapas como el de geodiversidad (figura 12) se ha basado en el programa QGIS y con las bases que el ICGC elaboró en el 2010 para publicar el mapa vulcanológico.

El primer plan especial de protección diseñado para regular la conservación de esta área protegida catalogó 50 afloramientos de interés geológico. Dado que la conservación de tantos sitios es compleja en términos tanto de recursos humanos como económicos, se ha desarrollado una metodología adaptada a nivel local de otras que se utilizan para seleccionar lugares de interés geológico más a nivel regional (Brilha, 2016). El objetivo es seleccionar los afloramientos más interesantes e ilustrar la gran variedad de tipos de depósitos volcánicos existentes en la zona. Como base para aplicar la metodología se han escogido 50 afloramientos (tabla 4) ya protegidos y 10 afloramientos más descubiertos en los últimos años (Bolós et al. 2014).

Trabajo de campo. Previo al trabajo de campo se ha recopilado información del mapa geológico 1:25000, carta vulcanológica del PNZVG y ortofotos a 1:5.000 para poder evaluar los puntos de interés geológico y estado de los volcanes. A posteriori se ha desarrollado trabajo de campo para visitar los AIG para recoger datos necesarios, como por ejemplo el grado de conocimiento que se tiene respecto a la ciencia vulcanológica: para realizar este trabajo se ha ido a cada afloramiento con expertos y/o artículos y trabajos publicados. A parte, para cada AIG, en el campo, se ha valorado su estado de conservación actual (tabla 4), las posibles amenazas y los impactos a los que está sometido y las condiciones actuales para su aprovechamiento/uso. Se han elaborado diferentes fichas descriptivas (tabla 4) que han seguido una sistemática específica desarrollada para conseguir unificar criterios de valoración.

6. GEOTOURISM AT THE NATURAL PARK OF LA GARROTXA VOLCANIC ZONE (CATALONIA, SPAIN): IMPACT, VIABILITY, AND SUSTAINABILITY

Geotourism at the Natural Park of La Garrotxa Volcanic Zone (Catalonia, Spain): Impact, viability, and sustainability

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Abstract: La Garrotxa Volcanic Zone is a suitable case study to analyse the impact and sustainability of geotourism on a protected volcanic field, as it has allowed to transform a poorly known territory into one of the best known and most visited geosites of Catalonia (Spain). The protection of this volcanic area represented the end of legal and illegal quarrying activities that significantly damaged most of its volcanes, but also provided an opportunity to develop the zone for tourism. We compiled the available information from its establishment in 1982 as a Natural Park by the Catalan Government to present, in order to analyse the socio-economic impact of geotourism on this protected area and its surroundings. We payed attention to its evolution in terms of the number of visitors, the social and economic consequences that this type of tourism has had, and on whether it is compatible with the conservation of natural assets, especially the geological ones. We also studied the role that the co-management of the protected space by local administrations and private entities has had on its sustainability. The results obtained are relevant to visualise the viability of geotourism in a protected area by combining the economic drive and the conservation of the natural assets. Spaces such as La Garrotxa Volcanic Zone represent natural laboratories where we can observe the success in the application of environmentally friendly policies with a positive socioeconomic impact on geotourism.

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Keywords: Catalan Volcanic Zone, geological heritage, geotourism, monogenetic volcanism, Spain. ,

1. Introduction

Geotourism is an increasing business in the modern society. Geotourism is a knowledge-based tourism that looks for an interdisciplinary integration of the tourism industry with conservation and interpretation of geological heritage at the same time as it promotes the economic and social development of local communities (Hose 1995; Newsome and Dowling 2010; Hose 2012). In this sense, it is considered as a sustainable tourism that places at the point of intersection between tourism as a global phenomenon and sustainable development as a global task (Hunter and Key 1995; Hunter 1995; Høyer 2000; Dowling 2013).

One particular type of geotourism is "Volcano Tourism”(Sigurdsson and Lopes-Gautier 2000; Erfurt-Cooper 2011, 2014; Dóniz 2014), as volcanoes and volcanic terrains have a worldwide fascination and many are visited by huge numbers of people each year (e.g.: Iceland, Canary Islands, Hawaii, Yellowstone, Etna, Vesuvius). These visits to both live and extinct volcanic landscapes provide for much public recreation, adventure and enjoyment. They also afford opportunities to observe, learn and appreciate the power and role of volcanism in building the planet's surface.

The benefits of geotourism can be measured through environmental, social and economic indicators, such as increased natural heritage conservation, improved social benefits like self esteem, jobs and incomes (Hose 1995; Newsome and Dowling 2010; Hose 2012). Since geotourism “adds values” to local or regional communities, it economically supports geological heritage conservation (Newsome and Dowling 2010). Consequently, there is a need to gain a greater understanding of the nature and characteristics of geotourism, especially in relation to the importance of placing geology at the centre of a destination, but also in regard to its characteristics, impacts and management.

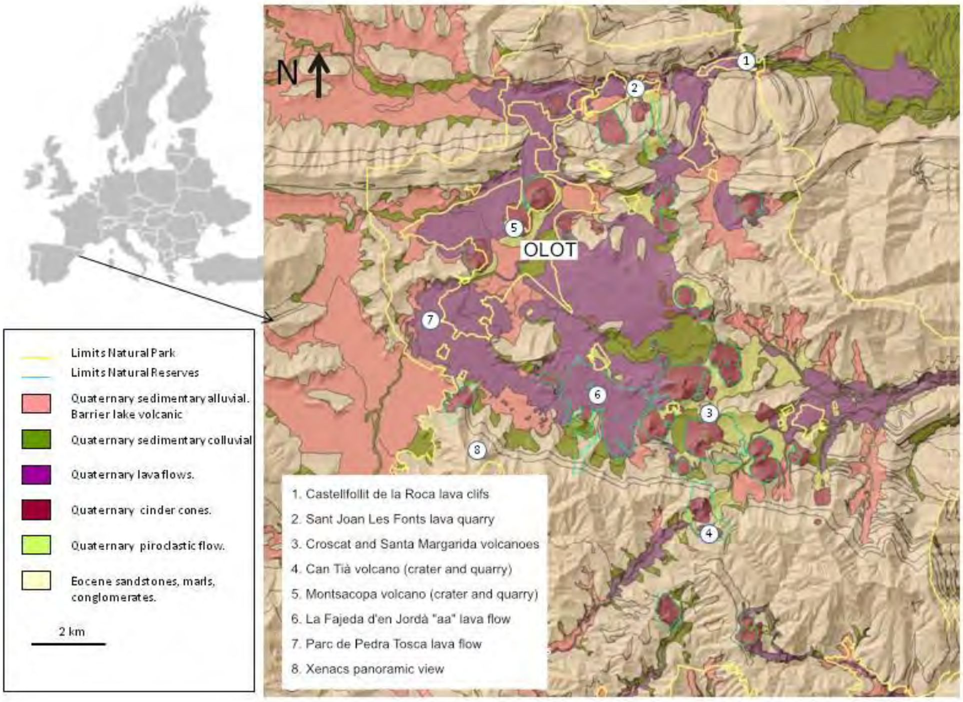


Figure 1 Simplified geological map of La Garrotxa Volcanic Zone with indication of the limits of the La Garrotxa Volcanic Zone Natural Park and the nature reserves and places of geological, natural and cultural interest.

Most protected volcanic areas have generated exciting tourism products and opportunities for public use, which provide substantial community benefits. Several studies have proposed guidelines for planning and managing sustainable tourism in protected areas (Eagles et al. 2001) and a few of them include analysis of revenue sharing in such areas (Nogué and Sala 2017). However, we still need to estimate the benefits of tourism in many protected volcanic areas and how to maintain and increase this business in a manageable and sustainable way. Unfortunately, due to the relatively early stages of volcano tourism, there are still very few data compilations concerning exploitation and benefits from volcano tourism (Munanura et al. 2016; Nogué and Sala 2017). Therefore many more case studies need to the analysed in order to quantify and evaluate this tourism sector in-depth and propose innovative... products that could guaranty the sustainability of volcano tourism.

The Natural Park of La Garrotxa Volcanic Zone is an area of great geological, botanical, faunistic and landscape value and, although it is an area with considerable human activity, its landscape and unique natural environment have been well preserved (Nogué and Sala 2017) (Fig. 1). This protected area includes the northern side of the La Garrotxa monogenetic volcanic field, which contains about 50 well preserved volcanic cones that show a large diversity of Strombolian and phreatomagmatic volcanic products (Martí et al. 2011; Bolós et al. 2014) (Fig. 1). Volcanic activity and humid climate particular of this area gave rise to the fertile soils (Palou and Boixadera 2001) that provide the area with excellent biodiversity.

Since its declaration as a Natural Park in 1982, but particularly since 1986 when an administration team took the responsibility of its management, this area became an important lure for local, national and foreign tourism, transforming this poorly known territory into one of the best known and most visited geosites of Catalonia. As an example of volcano tourism that has been exploited in a sustainable way, we describe in this study how La Garrotxa Volcanic Zone was protected in a Natural Park and how the different actions taken under this protection e contributed to a sustainable geotourism that has led to important socio-economic benefits for the region. This is a particular case study that, together with the others that already exist, will contribute to a better understanding of the possible benefits and threats of volcano tourism.

Figure 2 Tephra quarry at the Croscat volcano that was restored in 1995. Outcrop of interest in the Natural Park.

2. Geographic and geological setting

Geologically, La Garrotxa Volcanic Zone is the best preserved volcanic region in the Iberian Peninsula and one of the best examples of Neogene-Quaternary basaltic volcanism in continental Europe (Fig. 1), with intense human activity, which at times impedes the conservation of the land. Volcanic activity began some 700,000 years ago in La Garrotxa (Araña et al. 1983; Guerin et al. 1982), and continued until the early Holocene with the eruption of the Croscat volcano about 10,000 years ago . In total, at least 50 eruptions have been identified (Bolós et al. 2014) leading to volcanic cinder and spatter cones, maars and tuff rings, as well as several lava flows that filled the valleys in the area. The stratigraphic, structural and hydrogeological characteristics of the substrate above which these volcanoes were emplaced favoured phreatomagmatic activity, which combined with the magmatic Strombolian activity, causing a large variety of eruption sequences (Martí et al. 2011).

The richness of volcanic soils and the climate is one of the other determining factors in the zone, where the Mediterranean climate, characterised by mild winters and hot summers with low rainfall, mixes with the Atlantic climate, where rain and temperature inversion is abundant in summer, whereas in winter this inversion causes lower temperatures and frequent frost. The diverse relief, the confluence of the Mediterranean and Atlantic climates, and the diversity of substrates lead to a great variety of plant species and also to a wide variety of natural environments, which has allowed a very diverse and interesting faunistic population to exist, characterised by the cohabitation of typical Mediterranean fauna with typically Central European species (Oliver 2016).

The landscape, shaped by volcanic activity, geomorphological agents, and by humans, is one of the most distinctive features of this area. For many centuries, human presence was associated with the exploitation of agricultural, livestock and forest resources, and the landscape became a harmonious mosaic of fields, pasture and woodland that supported the family economy. The craft and industrial activity contributed towards great social and landscape change.

3. History of the protection of the zone

The urban and industrial growth of the 1960s led to a number of serious environmental problems: extraction of volcanic tephra, urban growth that did not respect the environment, river pollution and the proliferation of uncontrolled dumping. The combination of all these problems posed a serious threat to the natural assets. The need to protect this natural space triggered a series of sociocultural movements that culminated when the parliament of Catalonia, in 1982, passed the law to protect La Garrotxa Volcanic Zone, converting it into a natural park. The goal was to protect its geological, botanical and landscape assets, and to combine the conservation of the zone with its economic development. Currently, this protected space covers 15,308 ha, where more than 40,000 inhabitants are distributed across 11 towns, and includes 28 nature reserves.

The mining exploitation of the Croscat volcano (Fig. 2) served as a springboard for demands for the conservation of the natural heritage and the volcanoes in the area. Its history ties in very much with the geotourism that began to be promoted in the area after the declaration of the Natural Park of La Garrotxa Volcanic Zone. Table 1 summarises the activities and actions taken before and after the declaration of the Natural Park.

Table 1 Chronology for the preservation of the La Garrotxa volcanoes, which illustrates how they passed from an extractive activity to a natural reserve and a touristic attraction.

1966	The executive management of mines authorises the mining concession "Santa Margarida" (no. 3140), with a surface area of 861 hectares, as a result of a report from the laboratories of the Higher Mining Council, which considered that "pumice stone" would be obtained from the extractions. The concession covered the zone of the Croscat, Santa Margarida, Puig de Marinyà and Puig Astrol volcanoes.
1976	Awareness-raising campaigns were held for scientists to study the volcanic region and they were asked to support the application for the zone to be declared a Natural Park. A vast response was received. Safeguarding campaign promoted by scientists from the zone with the backing of sociocultural institutions and political groups from the region in the 1970s.
1977	Via a resolution, the Directorate General of mines and construction industries of the Ministry of Industry consolidated the mining rights of the "Santa Margarida" concession in favour of Minas de Olot, SA, for a period of 90 years.
1982	Law 2/1982, of March 3rd, for the protection of La Garrotxa Volcanic Zone with the creation of the Natural Interest Area of La Garrotxa Volcanic Zone.
1985	Passing of Law 2/85 of Natural Spaces in which it becomes a Natural Park.
1990	Halting of the clay extractions as a result of the autonomous government of Catalonia purchasing the majority of the shares in the company.
1992	It took 9 years after the law was passed to finally execute that stipulated in the law. From then on, intervention in the Natural Park consisted of restoring the zone occupied by the uncontrolled dumping of town waste. It was the first case in Catalonia that a farm with conservationist goals was expropriated. In total, 77.2 expropriated hectares were turned into the only fully public nature reserve to exist in La Garrotxa Volcanic Zone Natural Park.
1994	Restoration works begin on the quarry of the Croscat volcano and the former dump, with a view to recovering the morphology of the base of the volcano, thereby preventing its erosion; as well as the pastures and flat zones; and reintroducing autochthonous species from the zone into the steepest areas, to integrate them into the landscape and facilitate public access for educational purposes since the extraction of more than 2,200,000 m^3 of clay left two large vertical cuts that were difficult to restore.
1995	The restoration works on the clay pit and the sealing up of the dump begin. The main criterion of this activity was to organise the space, creating a network of paths, to render it apt for essentially pedagogic use. Today, the Croscat quarry are one of the most visited parts of the Natural Park.

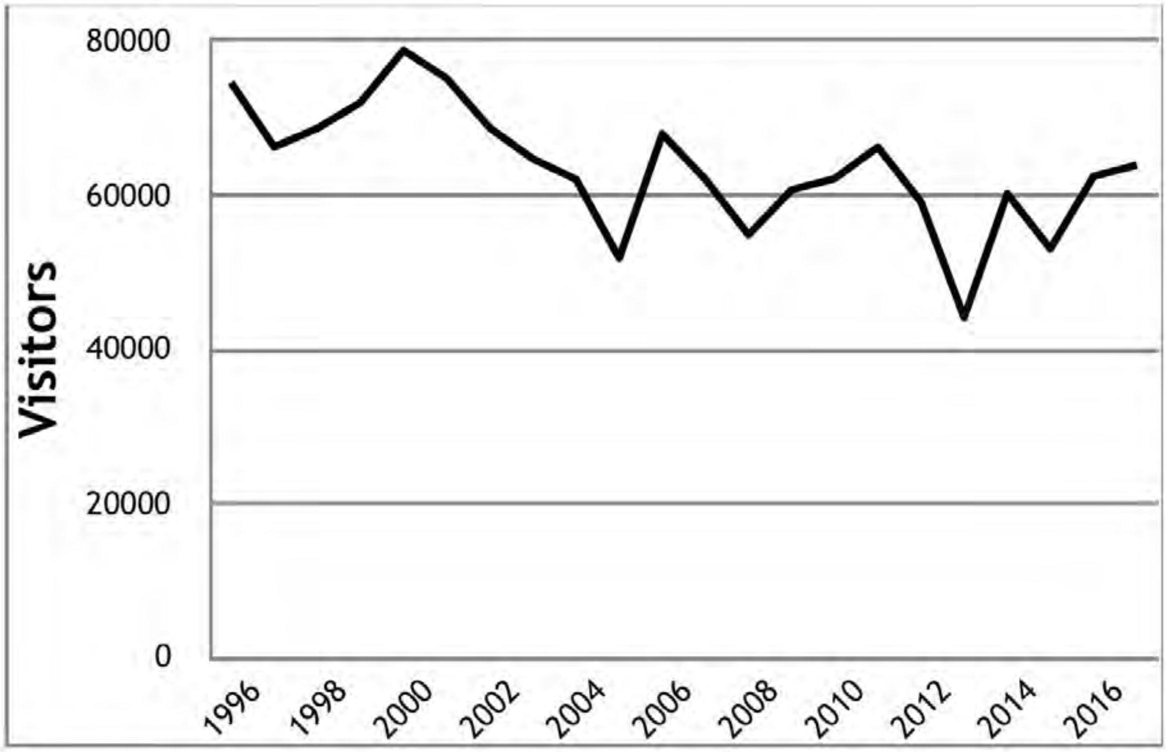


Figure 3 Graph of visitors who attended the information centres of La Garrotxa Volcanic Zone Natural Park. The decline in the number of visitors in 2005 is due to the closure of the Casal dels Volcans for restoration works, and in 2013 to the closure of the centres, due to economic restrictions. Source: La Garrotxa Volcanic Zone Natural Park.

4. Tourism resources in the area

La Garrotxa Volcanic Zone is the only zone for volcanic geotourism with well-preserved volcanoes located in the centre of the Pyrenees-Mediterranean Euroregion, which encompasses the French region of Occitanie, and the autonomous regions of Catalonia and Aragon in Spain. This Euroregion has a population of 14,529,912 over a distance of less than 300 kilometres. This is the potential audience to visit these volcanoes, since it is a unique destination. The area has different places of geographical interest, with natural and cultural resources, which complement each other perfectly and determine the attractiveness of the zone.

According to the statistics provided by the Natural Park, in 2010 La Garrotxa region received 355,735 visitors, 53,000 more than in 2001 (Fig. 3). Of these visitors, 48% were families and 37% were couples. 81% were Catalans (i.e., local tourism). 76% of the visitors came to see the volcanoes (Institut Cerdà 2015).

Figure 4 . Photographs of the main geosites. 1: Castellfollit de la Roca lava cliff, 2: Detail of Sant Joan Les Fonts (Moli Fondo quarry) lava flows, 3: Aerial view of a rootless scoria cone at the Pedra Tosca Park, 4: Montsacopa volcano quarry, 5: Aerial view of the Croscat and Santa Margarida Volcanoes, 6: Aerial view of the Montsacopa volcanoes, 7: Pyroclastic deposits at the Can Tià volcano quarry, 8: La Fageda d'en Jordà lava flow, 7: Landscape view of Crosca (left) and Santa Margarida (centre) volcanoes from Xenacs.

4.1. Outcrops and places of geological interest

La Garrotxa volcanic zone holds several places of geological interest, from which eight are remarkable (Martí and Planagumà 2017) (Figs. 1 and 4): (1) To the north of the zone stands the lava flow cliff of Castellfollit de la Roca, where the town is perched on top of a 50-meters crag of basalt columns. (2) Nearby are the former quarries of Sant Joan les Fonts, where different lava flows with different internal morphologies (e.g.: columnar joints, tumuli, etc) can be observed. (3) The most recent volcanic activity is located in the centre of the volcanic zone, with easy access to the cinder cone of the Croscat volcano, to the Santa Margarida maar-type crater and its deposits, to the tephra quarry of the Croscat volcano, and to the Rocanegra volcano. (4) Another place of geological interest is the Can Tià volcano, its maar-type crater and the outcrop that corresponds to an old quarry, which shows the full stratigraphic succession of this volcano. (5) The Montsacopa volcano in Olot, a route that reveals a cinder cone with a circular crater at the top and an interesting route through its tephra pits that serve to interpret the formation of the volcano. (6) The Jordà beech forest, a geological, natural and cultural asset that leads visitors through the well-preserved "aa" type lava flow from the Croscat eruption; this type of beech forest is unusual at this latitude, as it is more common in Atlantic climates than Mediterranean ones (Palou and Boixadera 2001), and served as a source of inspiration to poets and painters alike. (7) The Pedra Tosca Park in the Tosca Forest is another place located at the top of a lava flow; in this case from the Puig Jordà volcano. This is a place of geological interest due to the large number of the rootless spatter cones that can be observed on this lava, but also of cultural interest for the dry stone constructions, shelters and land clearing present. (8) The last main place of geological interest is the Xenacs viewpoint where the zone's Landscape and relief can be contemplated and understood as well as the location of the volcanoes.

Figure 5 Photographs of the main natural and cultural sites. 1: Olot city, 2: Volcano Museum (Casal dels Volcans), 3: The Medieval centre of Santa Pau, 4: Besalú medieval town, 5: Santa Pau haricot beans. Source: Documentation Centre, Garrotxa Volcanic Zone Natural Park. 6: The Gaietà Vila Art Nouveau house in Olot.

4.2. Other places of natural and cultural interest

In addition, this volcanic area has several places of cultural, natural and intangible interest (Tresserras and Duran 2017) (Fig. 5), from which the following seven are the most remarkable: (1) In Olot we find the Parc Nou – Moixina a place that holds the last pockets of English oak in the Olot valleys, a humid area, as well as the Volcano Museum. (2) Olot's old quarter and its modernist architecture built during the industrial growth of the 18th century are also notable. (3) The Colltort Castle between Santa Pau and Olot is a place to observe volcanic cones, craters and landscape, and is a prime example of the 15th-century Rebellion of the Remences, the first peasant revolution to occur in Europe. (4) Santa Pau is a town built around a castle during the 13th and 14th centuries, with an arcaded square where a market was held. (5) Besalú, the former capital of the region is a town with excellently preserved ancient medieval buildings, an impressive bridge, squares, miqwe jueu (baths), and churches and monasteries. (6) The town of Sant Feliu de Pallerols is one of the finest examples of a medieval town with a holy space. (7) Finally, the intangible value of the gastronomy based on natural products, such as local beans, meat and cured cold cuts are all falling under what is locally known as Volcanic Cuisine.

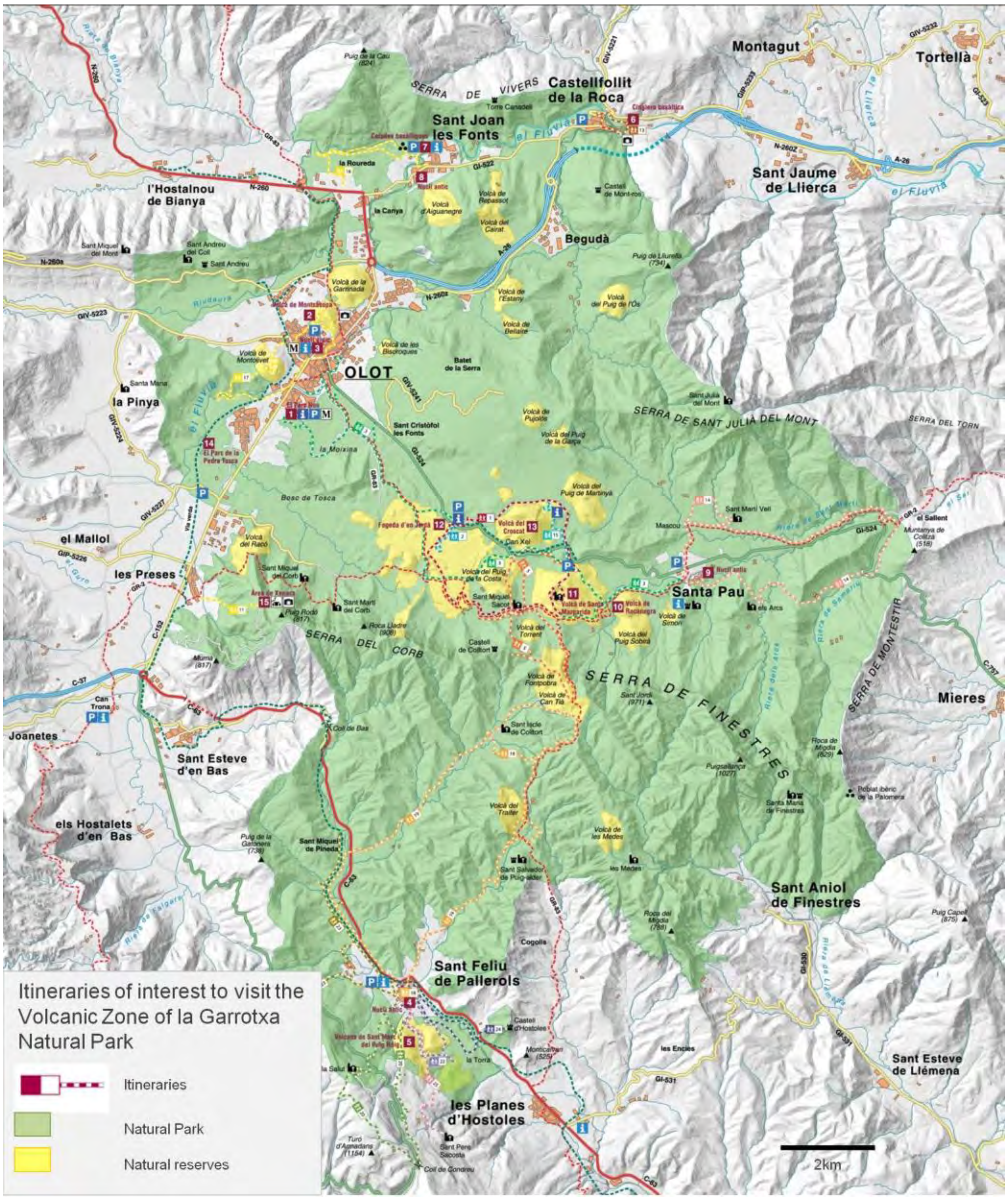


Figure 6 Itineraries scheme of La Garrotza Volcanic Zone Natural Park (with permission from the PNZVG - Governement of Catalonia)

4.3. Tourism interpretation centres.

During the creation of the Natural Park, a series of centres were established to disseminate among the visitors the information of the main values of the park. The management and number of these tourism centres has fluctuated over the past 30 years according to the conservation policies of the natural environment (Table 1). The Natural Park has created four centres to attend to visitors: The Casal dels Volcans, at the Parc

Nou – Moixina in Olot; Can Serra, at the entrance of the Nature Reserve of the Jordà beech forest, on the road to Santa Pau; Can Passavent, at the entrance of the Nature Reserve of the Croscat volcano; and the Sant Feliu de Pallerols station, which only operated as a centre for the park for three years. The goal of these centres is to inform and educate visitors both about the zone and about respecting the Natural Heritage. In recent years the centres have been attended by more than 1,500,000 visitors, with an average of 65,000 visitors per year from the more than 300,000 who visit the park, which means that 1/5 of the total visitors of the park per year are informed, according to the statistics provided by the Natural Park.

4.4. Itineraries to visit the volcanoes

The Volcanic Zone has 25 itineraries of varying durations, from as short as 30 minutes (the Joan Maragall itinerary to the Jordà beech forest) to longer ones such as itinerary 19 to visit the Can Tià and Fontpobre volcanoes, which takes five hours (Fig. 6). Some of these itineraries, such as the Joan Maragall route, have overcrowding issues in the Autumn and Easter, with an average of 2,025 visitors per day, according to the statistics provided by the Natural Park in 2015. Another itinerary, the one that takes visitors to the Croscat volcano tephra quarry (itinerary 15), the number of visitors attended in the same year in the Can Passavent information centre was 37,614, of whom almost half, 15,971 were school groups, as indicated by the Natural Park.

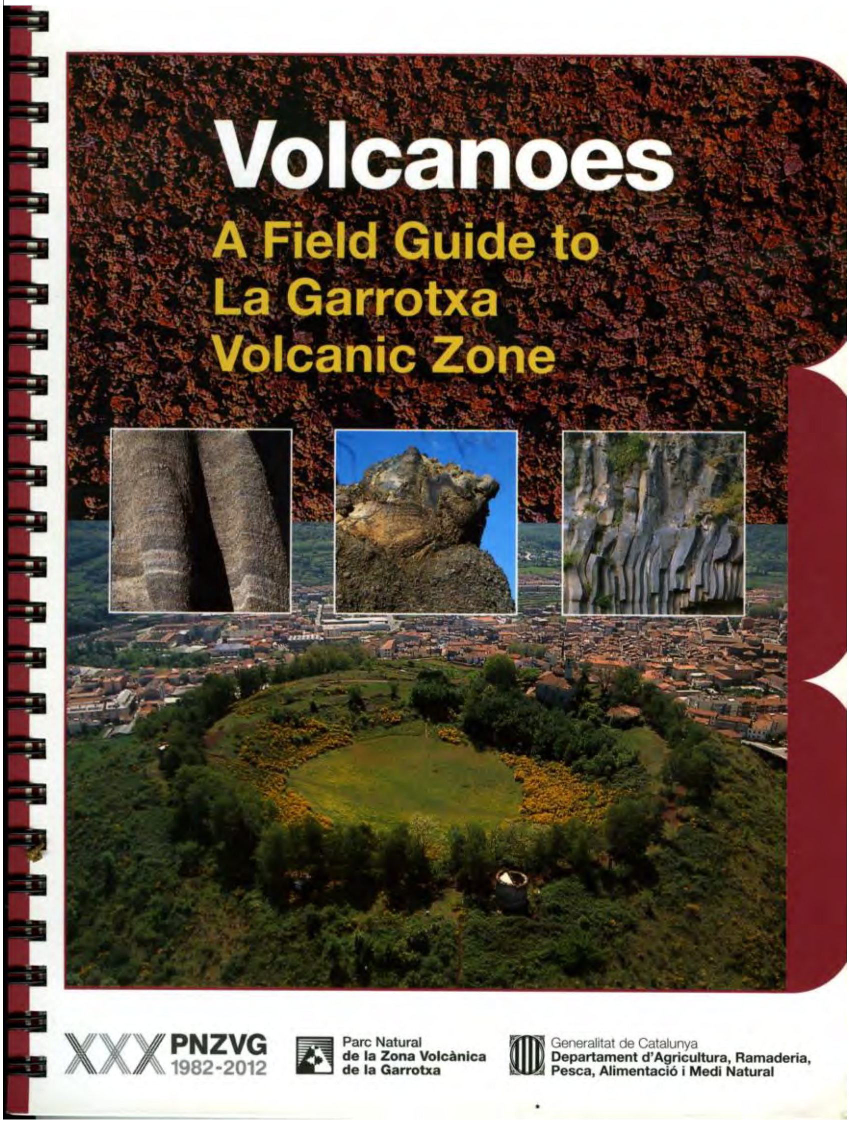
4.5. Outreach

In order to help visitors to understand the existing volcanic activity, several outreach products have been published with the goal to highlight the interest of the zone for visitors, and to encourage visits that last more than one day. Among these outreach products, the Field Guide of the La Garrotxa Volcanic Zone (Martí et al. 2000) (Fig. 7) relates how to observe and interpret the volcanic activity of this zone from twelve places of geological interest. Moreover, the Volcanological Map of La Garrotxa Volcanic Zone Natural Park (Mallarach 1982) complements this guide and helps visitors to discover the volcanoes on every itinerary or in every place. In the information centres visitors are provided with maps to visit the different places that are considered the most representative of the natural park.

4.6. *Education and training*

Education is one of the essential strategic lines to preserve protected natural spaces (Martí and Planagumà 2017). Educational programmes developed in the Natural Park of La Garrotxa Volcanic Zone are aimed at raising awareness among the population and visitors about the environment and volcanic activity through the assimilation of contents necessary to obtain skills, abilities and the desire to participate in the prevention and solution of environmental problems. For this reason, the level of knowledge on the volcanological values of those people who live near the volcanoes and of those who visit them is important. Therefore, programmes are required both for the local population and for visitors. Local residents need to understand volcanic activity and how to transmit their values to visitors, and as such it is important to train all related workers in activities directly or indirectly related to tourism. A particular effort is made in training guides who take visitors to La Garrotxa Volcanic Zone, both through school groups and adult visitors. Approximately, 60,000 schoolchildren visit the zone each year, and in effect they constitute one of the main channels for the dissemination of the natural geological values and to increase awareness about their conservation. Therefore, we can say that since 1994, more than 1,500,000 students have visited the volcanoes of La Garrotxa, thus becoming a very significant figure that represents the majority of the school-age Catalan population (Bonet 2017).

Figure 7 Front cover of the area's volcanic guide that was designed for users to interpret all zones with different volcanic activity from a single publication. Hence, it has three parts: General description of volcanism, volcanic activity in NE Catalonia, and description of the outcrops of interest to interpret volcanic activity in the area. (with permission from the Natural Park of La Garrotxa Volcanic Zone)]



5. European Charter for Sustainable Tourism

La Garrotxa Volcanic Zone undertakes to achieve sustainable tourism through the European Charter for Sustainable Tourism (ECST) (Prats and Bassols 2014). Through its principles and phases, this charter structures a strategy of sustainable local development. La Garrotxa Volcanic Zone was one of the first Natural Parks to carry out a pilot test in 2000 aimed at:

• Fostering the knowledge and support of protected natural spaces, which represent a fundamental part of our natural and cultural heritage, and which therefore must be conserved for the enjoyment of current and future generations.

• Orienting the management and tourism development of the protected spaces around sustainability, that is to say, make the conservation of the land's assets compatible with the satisfaction of private sector aspirations, the expectations of visitors, and the needs of the local population.

Initially, the Natural Park and the local governments undertook to work according to the 10 principles established by the ECST:

1. To involve all parties related with tourism in the protected space and the surrounding areas in the development and management of the protected area.
2. To prepare and implement a sustainable tourism strategy and action plan for the protected area.
3. To protect and enhance the area's natural and cultural heritage, for and through tourism, and to protect it from excessive tourism development.
4. To provide all visitors with a high quality experience in all aspects of their visit.
5. To provide visitors with adequate information about the special qualities of the zone.
6. To promote specific tourism products which help visitors to discover and understand the area.
7. To increase knowledge of the protected area and of sustainability issues amongst all those involved in tourism.
8. To ensure that tourism improves, and does not reduce, the quality of life of the local population.
9. To increase the profits derived from tourism for the local economy.
10. To control and monitor the flow of visitors to reduce their potential negative impact.

Later, in a second phase, a total of 18 companies from the private sector joined the charter and participated in the co-management of the Natural Park. As main positive impacts these companies highlighted: i) the improvement of the relations and communication with the team managing the protected space, ii) the collaboration with other companies associated with the ECST, iii) the improvement in clients' behaviour in the use of resource saving and efficiency based on information provided by the companies during the adhesion process, and iv) encouragement of the support and promotion of local products and services associated with tourism – agri-food sector, crafts, etc.

One of the star products of the ECST is the network of itineraries called Itinerannia, which provides different itineraries to visit and enjoy the landscape and natural values, such as the deposits and morphologies of the volcanic activity in the zone. In 2014, according to Turisme Garrotxa (Turisme Garrotxa 2018). The Land of Volcanoes. Retrieved 8 July 2018, http://en.turismegarrotxa.com/home/) , the network received 67,850 walkers and an economic impact of 3,263,000.00 €.

6. Threats to the conservation of the natural and social assets due to tourism.

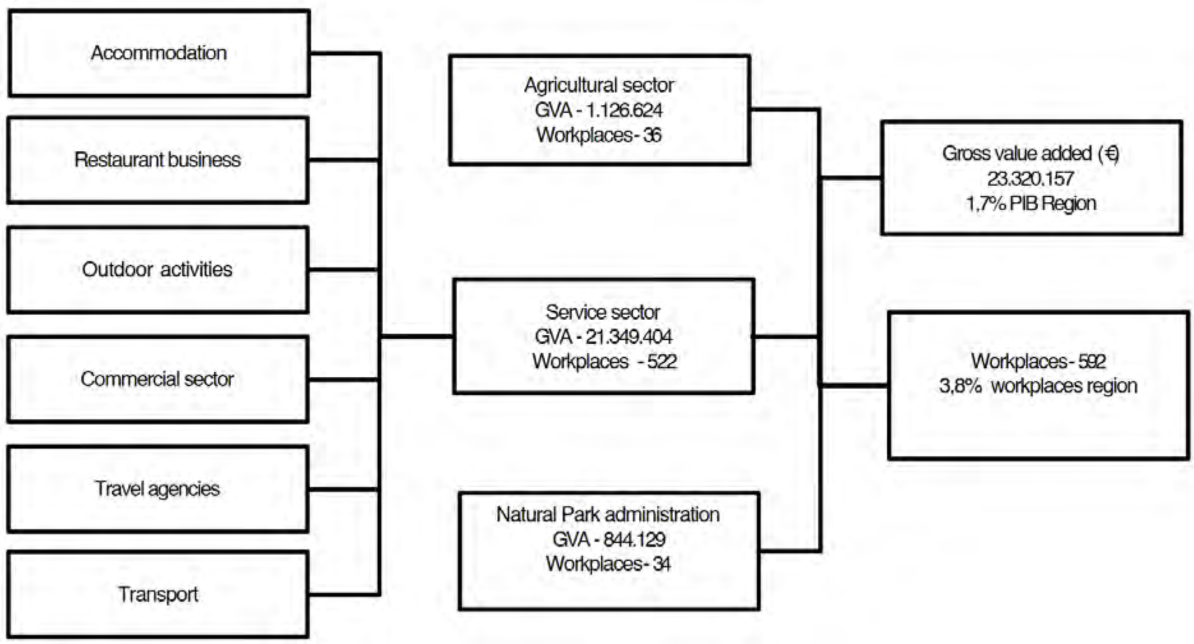
The main problems that the increase of geotourism in areas such La Garrotxa Volcanic Zone encompasses are mainly related to the possibility of getting a tourism based on short, low quality visits, concentrated in time and space, and with serious overcrowding problems, causing a collapse of services and significantly lowering the quality of the visits.

In view of this situation, protected areas call for the need to manage, channel, and shape the affluence of visitors at the same time that their traditional missions (i.e., the conservation and development of the territory) are respected. In the particular case of La Garrotxa, there are essentially three impacts and threats that are incompatible with the promotion of tourism: overcrowding, sustainable mobility and disparity in management policies and cuts in the protected natural spaces applied in 2010.

The overcrowding in the zone occurs in the autumn, coinciding with visits to the beech forest to admire the red tones of trees and the volcanoes, especially the Jordà beech forest. For example, some 700 metres in length of Itinerary 2, can be walked by 2,025 visitors in one single day (Pijoan 2014). These are concentrated between 11a.m. and 1p.m., causing mobility problems and concerns with neighbours, in addition to effects on the environment. The goal is to be able to regulate this intensity of visitors through car parks, payment of entrance fees, and future actions to promote sustainable mobility in the area, avoiding access with personal vehicles.

Since the La Garrotxa Volcanic Zone became a Natural Park, the commitment from the administration responsible for the conservation of the natural heritage has been inconsistent, and the policy and management of nature has gone through different stages and periods (Casademunt 2017), which reveal diverse sensitivities in relation to the way it is considered (social relevance) and managed (resources, strategies and instruments). Each phase has been characterised by common elements in governance (dividing responsibilities, tensions between administrations and governments, public-private relations, etc.). In turn, these phases have been subdivided into periods that define and characterise the action of the successive governments. The Natural Park has not been left unaffected by these occurrences (Table 1) and has seen its management and good reputation at conserving the geological heritage endangered. The reduction in the budget by half suffered in last years due to the global economic crisis, represents a serious problem for the area. This has clear implications, although these have been mitigated through a key factor which is the administrations' and local entities' participation in the co-management of the Natural Park (Table 2 and Fig. 9)).

Figure 8. Calculation of the gross value added (GVA) and workpleces per type of economic activity (social and economic impact of protected natural areas) (year 2012) (based on [(Institut Cerdà 2015)*])*



7. Socio-economic impact

The number of people who, for different reasons are interested in discovering these spaces that have been given special protection is increasing every day. In Catalonia for example, approximately 5.1 million people visited the different protected areas located in its territory in 2012, and 5.5 million in 2013 (Institut Cerdà 2015). This means that a new economic activity has been developing alongside this type of tourism activity. At the same time, the protected natural areas act as ecosystem services, which are those services that people receive from ecosystems and that maintain, directly or indirectly, their quality of life (2005).

As regards the economic value, its profit is clear according to Institut Cerdà 2015 (Table 2). Despite the recession that affected Catalonia during the recent economic World crisis, for every 1 Euro that the administration has invested in the Natural Park of La Garrotxa, the return for the zone has been of 8.8 Euros. The economic impact of this protected space exceeds that produced by some of the country's top tourism attractions. For example, it represents more than double of the economic impact generated by the Dalí Museum and the Gala-Salvador Dalí Foundation (Institut Cerdà 2015). In the case of the volcanoes in La Garrotxa, this economic impact represents a total of €23,320,157 of annual gross added value (Table 2), which is the equivalent to 1.7% of the GDP of the entire Garrotxa region. But the balance is also positive in employment since, directly or indirectly, the preservation and good management of the volcanoes in the zone has led to the creation of 592 jobs, 3.8% of La Garrotxa employment (Fig. 9). The difference in the benefits obtained from the same volcanic zone comparing between a mining extraction that had four- or five workers and conservation is clear, since benefits related to the second option have multiplied by ten. Moreover, another clear indicator of this economic benefit and the creation of jobs is that since the creation of the Natural Park, the offer in hotel beds has doubled in the area (Fig. 10), thus supporting the fact that an efficient management of geological heritage is a suitable tool for sustainable tourism (Sigurdsson and Lopes-Gautier 2000; Erfurt-Cooper 2014)

Table 2. How policies related to the natural heritage of the government of Catalonia have affected La Garrotxa Volcanic Zone Natural Park. Adapted from Casademunt 2018.

Stages in the policy and management of nature in Catalonia, applied to public use and environmental education in La Garrotxa Volcanic Zone Natural Park.	**FIRST STAGE (1980 – 1991): Distribution of skills and separation of planning - management**	**SECOND STAGE (1992 – 2010): Lost opportunities**	**THIRD STAGE (2011 – 2015): Regression, marginality and subordination**
Information / interpretation centres.	Casal dels volcans. (Volcano House)	Expansion of the information centres to include three more: Can Serra for the Jordà beech forest, Can Passavent for the Croscat volcano and the Sant Feliu de Pallerols station.	Reduction of information centres: Sant Feliu de Pallerols station. Reduction of days and times at the Casal dels Volcans and Can Serra. Paid parking in Can Serra and Santa Margarida.
Materials and resources.	Volcanological map. First map of the Natural Park. Informative posters.	Leaflets: Map of the Natural Park, more detailed routes. Publications: volcanic activity guide, reviewed volcanological map.	Payment for the map and route leaflets. Translations of the volcanic activity guide.
Routes and itineraries.	Creation of the first network of itineraries (14 itineraries).	Creation of the other itineraries (11 itineraries).	Creation of museum spaces.
Environmental education.	School groups and arbour day.	Divisions of programmes aimed at two different users: Local population and visiting population. New pedagogical offering. Presence at the Sant Lluc fair and in the media. Resources and materials for local schools.	Removal of programmes: school and surrounding area, Sant Lluc fair, radio programmes, ...
Annual budget for the Natural Park (average of all the years).	€800,000.00	€1,750,000.00	€800,000.00

8. Discussion and conclusions

The innovation of our research is to provide a clear description and quantification of the main benefits and threats that volcano tourism can represent for a particular protected area, thereby contributing to the improvement of scientific research and sustainable tourism. The Natural Park of La Garrotxa Volcanic Zone is a good example how sustainable tourism represents a considerable benefit when efficient management is applied to geological heritage. From its creation in 1982 to the present day, the natural values have been preserved and this has implied a positive social and economic impact.

La Garrotxa Volcanic Zone clearly demonstrates that using geo-conservation as a tool for sustainable tourism is a good strategy to follow. If well-managed, it brings economic and social improvements to the area, not only in tourism, but also in the global image of the territory. This good image that the territory exports can be seen in the logos used by local companies and entities, as most of them show a clear reference to the volcanoes.

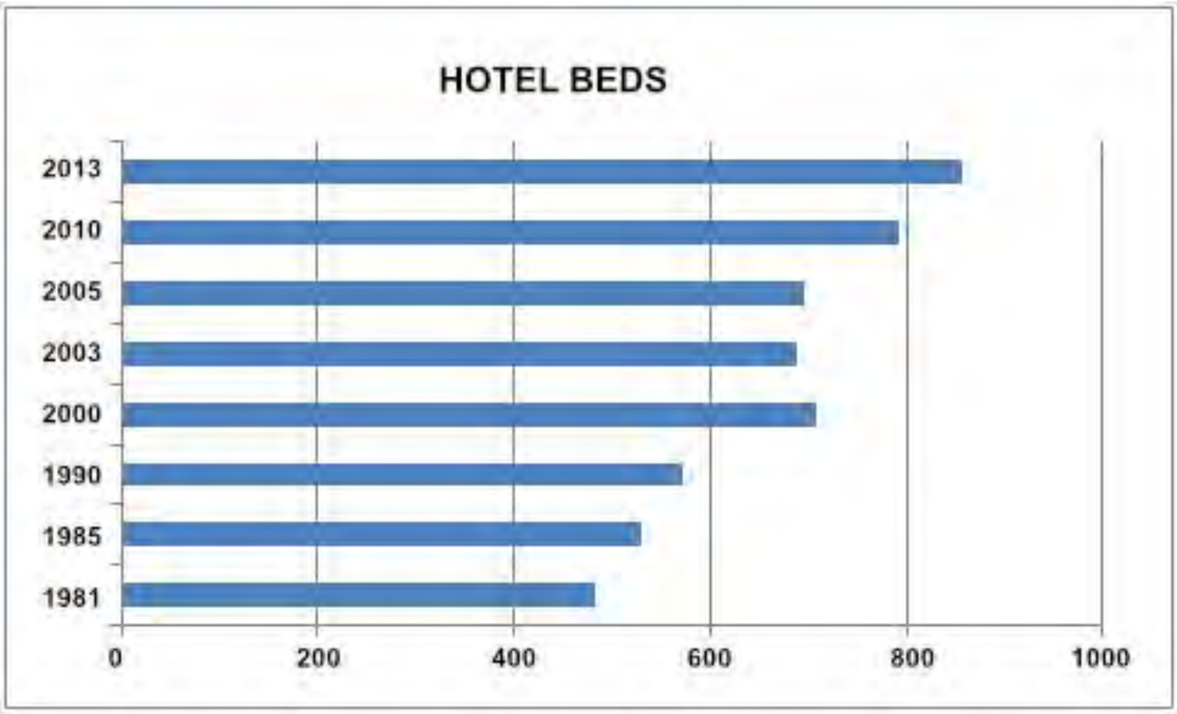


Figure 9. Evolution of the number of hotel beds available at La Garrotxa from the creation of the Natural Park in 1982 to date (source: [(Institut Cerdà 2015)*]).*

The positive social and economic impact that geotourism has had in La Garrotxa is based on different essential factors One of these has been the scientific knowledge of the area. High quality scientific research about La Garrotxa volcanoes has been important to assess the best places to be promoted and be able to provide correct and rigorous information to visitors. For this reason, cartography, guides and data bases built in a suitable geographic information system have been essential. Another important aspect has been the involvement and co-management of local actors such as town councils and public and private entities. In this way, changes in environmental policies and budget cuts by the Catalan government (Table 2) can be overcome. The involvement of these actors means that there has been effective pressure to revert possible cuts and to become involved in management deficits. A better co-management of the area is still required in order to progress in the conservation of the volcanoes, alongside the social and economic improvement that geotourism entails. This has been the key to be able to transmit the importance of the zone to visitors, to be able to generate a critical spirit in order to continue generating sustainability policies and prevent tourism from having serious ecological and social impacts. In this sense, the training and education programs that have been carried out for decades in La Garrotxa have been significant, which should be maintained in the future as a guarantee for its preservation and sustainable management.

The experience acquired at La Garrotxa can be exported to other protected areas with similar characteristics and potential problems. Looking at current trends in tourism it is obvious that geotourism and volcano tourism will continue to grow. Therefore, it is important to prevent the potential problems this may cause. Despite each particular area may have different characteristics and, consequently, may undergo different problems related to geotourism, these may not differ so much from those identified in La Garrotxa. Hence, the same solutions applied here are recommended for other areas, in particular the application of revenue sharing and public and private investment to guarantee undertaking scientific research that can ensure a good knowledge of the natural values of the area, and the establishment of good training and education programs aimed at local populations and visitors in order to raise awareness about them.

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7. IDENTIFICATION, CATALOGUING AND PRESERVATION OF OUTCROPS OF GEOLOGICAL INTEREST IN MONOGENETIC VOLCANIC FIELDS: THE CASE OF LA GARROTXA VOLCANIC ZONE NATURAL PARK

Identification, cataloguing and preservation of outcrops of geological interest in monogenetic volcanic fields: the case of La Garrotxa Volcanic Zone Natural Park

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Abstract

Volcanic zones are important geoheritage sites. Active volcanic fields are of special interest because they allow to observe the complex and interesting stratigraphic relationships that often characterise their products and processes, as well as landscapes of unusual beauty. These geological sites enable visitors to appreciate the full complexity of volcanic activity and the importance of the geoheritage values that should be preserved. To ensure a correct preservation of these zones whilst opening them up to visitors, management plans should establish and consolidate a network of outcrops that allow visitors to get to know the area in question, and preserve its geological heritage and the social and economic dynamism. In La Garrotxa Volcanic Field, most of which is protected by a natural park, a new methodology has been created to identify the sites of greatest geological interest and, above all, those that exemplify the diversity of eruptive styles and volcanic products and landforms in the area. Taking into account the most relevant management requirements (conservation and dissemination), in 1994 a total of 60 outcrops were classified as points of geological interest of the area. In this study we further present a specific methodology to select the most suitable sites for the preservation the main volcanological features of La Garrotxa Volcanic Field. A group of 12 sites were selected from the initially identified outcrops and included in an itinerary as the most representative geological and pedagogical sites, whilst also bearing in mind their ease of access and preservation and the possible impact of visitors (e.g. erosion). The following five criteria were considered when restoring these outcrops: integration into the landscape, consolidation of their geology, regulation of visits, the mitigation of risk, and the participation of the people that live in the area.

Keywords: Catalan volcanic zone; geological heritage; monogenetic volcanism; Spain; outcrops, geosites.

Introduction

Geoheritage and geoconservation are important global endeavours designed to preserve Earth Science features recognized by various international and international conservation bodies, and enshrined in numerous agreements, conventions and inter-governmental initiatives (Brocx and Semeniuk 2007). Geodiversity embraces all of the geological aspects identified on Earth and as such is a measure of the geological diversity of a particular area; Geoheritage, on the other hand, is defined as those parts of geodiversity that are important for reconstructing the history of our planet (Sharpes; Gray 2019) and thus is a measure of the value of the geological elements that are present therein (Gray et al. 2013; Brilha et al. 2018). Geodiversity and geoheritage benefit society, as they provide evidence of our understanding of the history of the Earth and are a convincing reason for the conservation of geological values (Gray 2019).

Geoconservation includes the protection of geoheritage features and geosites and, more generally, the application of geoconservation principles in the sustainable management of protected areas and the wider landscape (Gordon 2018). In this sense, geoconservation involves the protection of those elements of geodiversity that are of high geoheritage value, mainly for scientific reasons but also for their educational, cultural, aesthetic, spiritual and ecological content (Gray et al. 2013; Crofts and Gordon 2014). Therefore, the success of the conservation of the geodiversity of an area will depend on how well we protect its natural geological heritage (Németh et al. 2017); thus, geosite selection and conservation management and monitoring are critical aspects of geoconservation strategies at all levels (Carcavilla et al. 2009; Gordon 2019).

The study and appreciation of the geodiversity of an area are essential elements in the identification and protection of the geological values that best represent its geological heritage. First, it is crucial to undertake a geodiversity assessment based on a selection of criteria dependent on factors such as the purpose of the assessment, the type of landscape in the study area and its spatial dimension, the significance of the different geological values to be preserved, and the availability of spatial data at an appropriate scale (Brocx and Semeniuk 2007; Zwoliński et al. 2018). Once this assessment has been conducted, the next step is to identify the elements that reflect the geological value of the area and contribute most to explaining its geological history. Finally, it is necessary to decide which management and preservation policies from various perspectives – i.e. based on geotouristic, geoconservation and geoeducation values – are of greatest importance (Németh et al. 2017).

Numerous examples exist of geodiversity preservation and of how it can be based on the specific characteristics of an area, the geological values to be protected, and current political and administrative regulations e.g. (Burek and Prosser 2008) and references therein; (Brilha 2016; Brilha et al. 2018b). The result of all these efforts to preserve these geological values is reflected in the UNESCO geoparks, the national and natural parks that protect geological features, and many other protected geosites that exist worldwide. The protection and preservation of geological values should not mean that they are inaccessible to the general public. On the contrary, protected geological sites, whenever possible, should be visitable, provided that their conservation is guaranteed and visitors are furnished with correct information about their relevance and their local value. Therefore, geoheritage protection also means drawing up the best possible management and conservation protocols for the identification, access and dissemination of all points of observation that define a particular protected area (Planagumà and Martí 2018).

Volcanic zones are home to complex and interesting stratigraphic relationships (Cas and Wright 1988) and are often endowed with immensely important geoheritages. Active volcanic fields are of special interest since they tend to boast rich soils, accessible sites of exceptional geological interest and beautiful landscapes, along with active volcanic features (Németh et al. 2017; Casadevall et al. 2019). In fact, active volcanic zones have become increasingly attractive to geotourists, who seek both live and extinct volcanic landscapes, as well as adventure and enjoyment. Therefore, as occurs in other protected geozones, the creation of a network of outcrops is a key step in the preservation of local geological heritage and the protection of related social and economic dynamics in these protected volcanic zones.

In this study we discuss how the protection of a volcanic heritage zone has been carried out in La Garrotxa Volcanic Field (Martí et al. 2011), a large part of which lies within the boundaries of a natural park (La Garrotxa Volcanic Zone Natural Park, PNZVG) that annually receives around 350,000 visitors. In order to identify and define a network of visitable outcrops that could best represent the main geological and volcanological values of the area (Table 6, Fig. 10), a specific methodology was developed with objective to incorporate the whole diversity of eruptive styles, products and landforms present in the area. Thus, in order to identify the most representative features, within this area of 200 km^2, in terms of their relevance and potential dissemination, a hierarchical selection of outcrops of geological interest was carried out; it also took into account access, future management and preservation criteria, and the need to minimize risks for visitors. Here we describe how this methodology was developed and applied, and analyse the results of its implementation in this area over the past 30 years.

Table 3. Different types of volcanic deposits in La Garrotxa Volcanic Zone Natural Park.

			Volcanic deposit	Examples of outcrops
Effusive		1	Lava flow with basalt columns	Castellfollit de la Roca, El Boscarró (Sant Joan les Fonts)
		2	Lava flow with rootless volcanic cones	Bosc de Tosca, Pla de Dalt
		3	Lava flow with lenticular formations and blisters	Molí Fondo (Sant Joan les Fonts)
Explosive	Strombolian	4	Welded pyroclasts in rootless volcanic cones	Parc de Pedra Tosca, Pla de Dalt.
		5	Pyroclasts in spatter cones	La Pomareda
		6	Pyroclasts (blocks, lapilli and bombs) in Strombolian fall deposits	Former quarries on volcanoes of Rocanegra and Puig Jordà
	Violent Strombolian	7	Pyroclasts (blocks, lapilli and bombs) in violent Strombolian fall deposits	Former quarries on El Croscat.
		8	Pyroclast layers in violent Strombolian fall deposits	Outcrop along Torrent de Can Bosquet
	Phreatomagmatic	9	Pyroclastic flows with Eocene lithics	Former quarry on Can Tià, along track to Mas El Cros in Santa Margarida.
		10	Explosive breccia	Former quarry of Can Barranc del Cairat
		11	Pyroclastic flows with volcanic lithics	Former quarry on south flank of El Montsacopa; former quarry on El Croscat.
		12	Basaltic ignimbrites	El Carrer, Can Bufador de la Garrinada

Figure 10. Aerial photograph of the northern side of La Garrotxa Volcanic Field.

Geological setting

La Garrotxa Volcanic Field (LGVF) (Fig. 10) lies in the north-east Iberian Peninsula (Fig. 11) and forms part of the Neogene-Quaternary Catalan Volcanic Field, which is associated with the European Rift that extends from the Alboran Sea to the centre of the continent (Martí et al. 1992; Lewis et al. 2000). This rift began to form as a result of the distension initiated 20 Ma during the Neogene when the Alpine orogeny affecting southern Europe came to a halt. The volcanism associated with this rift is alkaline in type and has given rise to a number of volcanic zones, of which LGVF (200 km^2), lying between the cities of Girona and Olot, is the most recent. This volcanic field (Fig. 12) contains around 50 cinder cones (Bolós et al. 2014), as well as numerous lava flows, tuff rings and maars dating from the Middle Pleistocene (0.12–0.78 Ma) to the beginning of the Holocene (0.01 Ma) (Bolós et al. 2014). These volcanic features lie atop Eocene sedimentary rocks and Quaternary alluvial deposits, as well as a series of Paleozoic granites and schists (Losantos et al. 2000). The magma generated in this volcanic field is basaltic, basanite, nepheline basanite and olivine basalt; in many cases the magma is the primary source and is not differentiated or contaminated by materials from the Earth's crust (Cebría et al. 2000).

Most of the volcanoes in LGVF lie around the city of Olot and the village of Santa Pau, or, as in the case of the volcanoes of La Crosa de Sant Dalmai, Canet d'Adri and Puig de Granollers, a few kilometres south of the latter locality (Bolós et al. 2014). These small monogenetic cones arose as a result of a succession of different pulsations of magma that rose to the surface through a series of secondary NW-SE-running faults associated with the major Llorà and Amer faults, active since the Miocene (20 Ma) (Martí et al. 1992), that generated fissural activity. The volume of these magmatic pulsations was moderate (0.01–0.2 km^3) (Bolós et al. 2014) and the resulting lava was emplaced in spatter and scoria cones, lava flows, maars and tuff rings. Due to the varied lithology of the substrata and the variety of hydrogeological features it has generated, the volcanic cones display a great variety of sequences and types of volcanic deposits (Martí et al. 2011). For instance, in the volcano of Crosa de Sant Dalmai the magma interacted with the Quaternary alluival aquifer, while in the volcano of Can Tià interaction occurred with the Eocene sedimentary aquifer.

The main type of volcanic activity in this area was Strombolian and gave rise to scoria cones composed of a series of fall deposits (lapilli and blocks). Many of these monogenetic cones (e.g. the volcanoes of Rocanegra, Montolivet, Sant Marc and L'Estany) are characterised by the presence of horseshoe-shaped cones. In some cases, however, where magma and groundwater from shallow aquifers interacted the eruptions were more complex and were characterised by phreatomagmatic phases involving phreatic explosions with ejection of lithic fragments from the substrate, as well as different types of pyroclastic density currents and phreatomagmatic fallout (Martí et al. 2011). Examples of this type of volcanic activity include the volcanoes of Santa Margarida, Croscat, Garrinada, Crosa de Sant Dalmai, Canet d'Adri and Can Tià (Martí et al. 2011). As a whole, Strombolian and phreatomagmatic activity have created a complex variety of eruptive sequences and volcanic morphologies that include cinder cones, maars, lava flows, rootless cones and lava tubes.

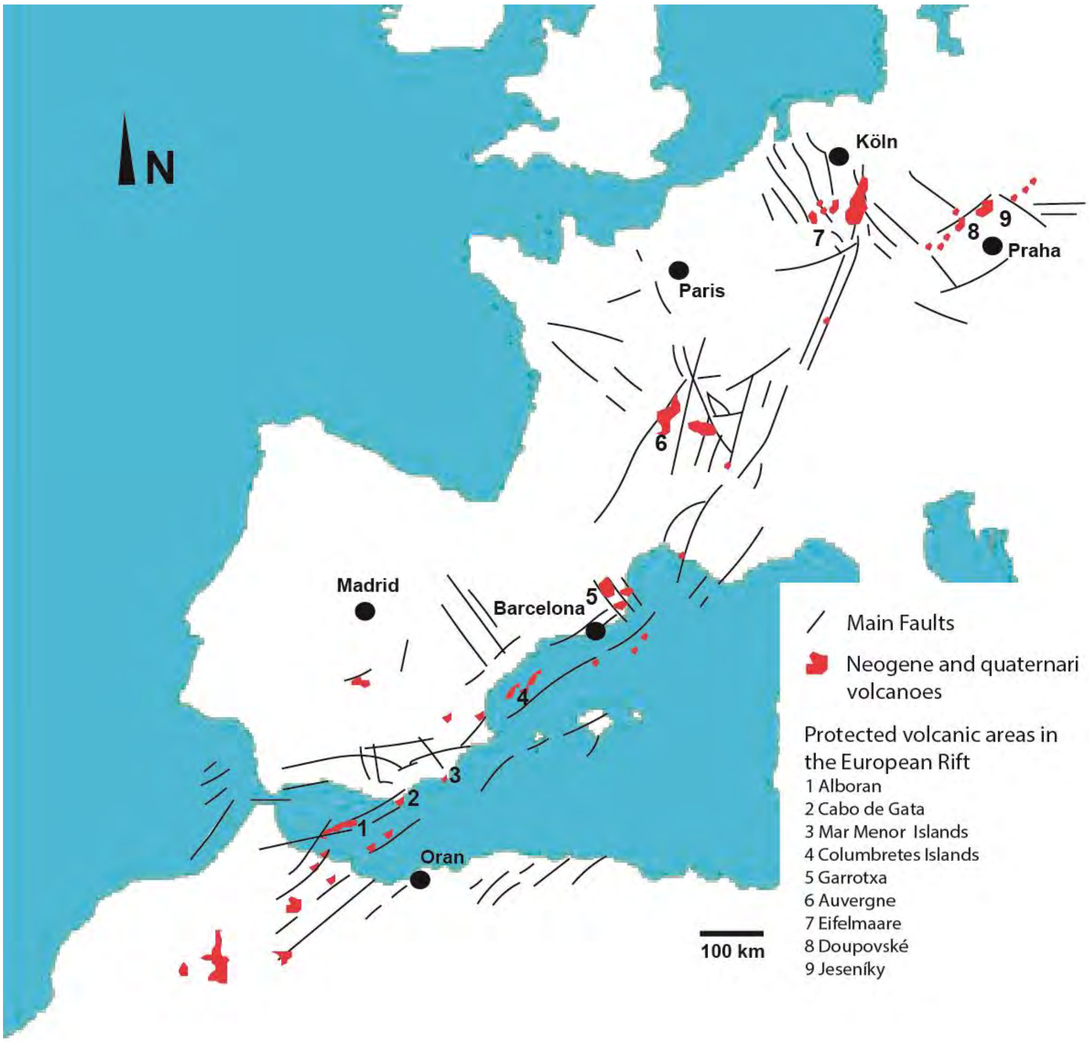

Figure 11. Map the European rift, the main volcanic zones and protected volcanic areas.

The inspection of the lithic fragments found in the phreatomagmatic deposits, has permitted to identify the existence of three main aquifers that interacted with basaltic magma during the construction of LGVF (Martí et al. 2011). One aquifer lies at around 300–100 m and another much nearer the surface, just a few dozen metres below ground level. The deeper of the two lies in Eocene detritic sedimentary rocks (Bellmunt Formation), which consist of continental sediments composed of conglomerates, mudstones rich in feldspars and red lutites; the more superficial aquifer lies within alternating beds of volcanic and Quaternary alluvial deposits composed largely of unconsolidated sands, clays and volcanic rocks (lavas and pyroclasts) dating from previous eruptions. Finally, there is a third aquifer that also played an important part in some of the most explosive eruptions in LGVF (Puig de Banya del Boc and Crosa de Sant Dalmai), which lies within highly fractured Paleozoic rocks at depths varying from a few hundred metres to just a few metres, depending on the tectonics of each particular area (Bolós et al. 2014; Pedrazzi et al. 2014).

Therefore, the volcanoes of the La Garrotxa reveal how complex a small volcanic field can be when magma interacts with groundwater, thus producing a great diversity of eruptive sequences which contrast with the relative monotony of the co-existing Strombolian volcanism. This complexity is heightened if the aquifers possess differing hydrogeological characteristics and the structure of the terrain is heterogeneous due to tectonic movements and/or differences in local stratigraphy (Martí et al. 2011).

La Garrotxa Volcanic Zone Natural Park

La Garrotxa Volcanic Zone Natural Park (PNZVG, in its Catalan spelling) covers an area of 15,000 ha and includes most of the northern part of La Garrotxa Volcanic Field (Fig. 3). The Park contains both public and private land, including built-up areas with 33,000 inhabitants, and forty well-preserved volcanic cones, twenty-six of which are natural reserves(Martí and Planagumà 2017). The PNZVG was declared by the Parliament of Catalonia in 1982 (Law 2/1982, March 3) to guarantee the protection of the volcanic area of La Garrotxa. It was declared as a Natural Site of National Interest to ensure that its flora, volcanic geomorphology and exceptional scenic beauty would be preserved.

Two main elements can be distinguished in the geological heritage of the PNZVG: volcanic morphologies and outcrops (Fig. 13). Their importance lies in the uniqueness of their constituent materials and the representativeness of the geological processes that allow them to be interpreted as the result of hundreds of thousands of years of geological and volcanological activity. The best-preserved volcanic cones are protected as natural reserves, while other geological outcrops are catalogued as outcrops of geological interest. The regulations governing the protection of this geological heritage are enshrined in the PNZVG's management plan (Planagumà 2017).

All the natural reserves (i.e. all the best-preserved volcanic cones) (Fig. 4) are natural areas that receive special protection, conservation and management to prevent any deterioration, transformation or disfiguring of their geomorphology or flora. The protection of the geological heritage of the PNZVG ensures that no activities that might provoke or accelerate erosive processes or increase the instability of the substrata may be performed, and that the singular volcanic soils present in most of the area are strictly preserved. In addition, the outcrops considered of geological interest are identified and catalogued and strict regulations govern their protection. For instance, no activity that might degrade or deteriorate the protected area or hamper its observation or study is permitted. Moreover, excavations and other types of earth movements are forbidden unless they are designed to improve or restore the volcanic outcrops for scientific or educational purposes, and have been approved by the protected area's management team. The areas adjacent to these outcrops should also be kept free of any disturbance that might obstruct their observation. The PNZVG gives priority to the active management of outcrops of exceptional interest and seeks agreements and collaboration with landowners as a way of guaranteeing the maximum protection for these sites, if necessary in combination with external support.

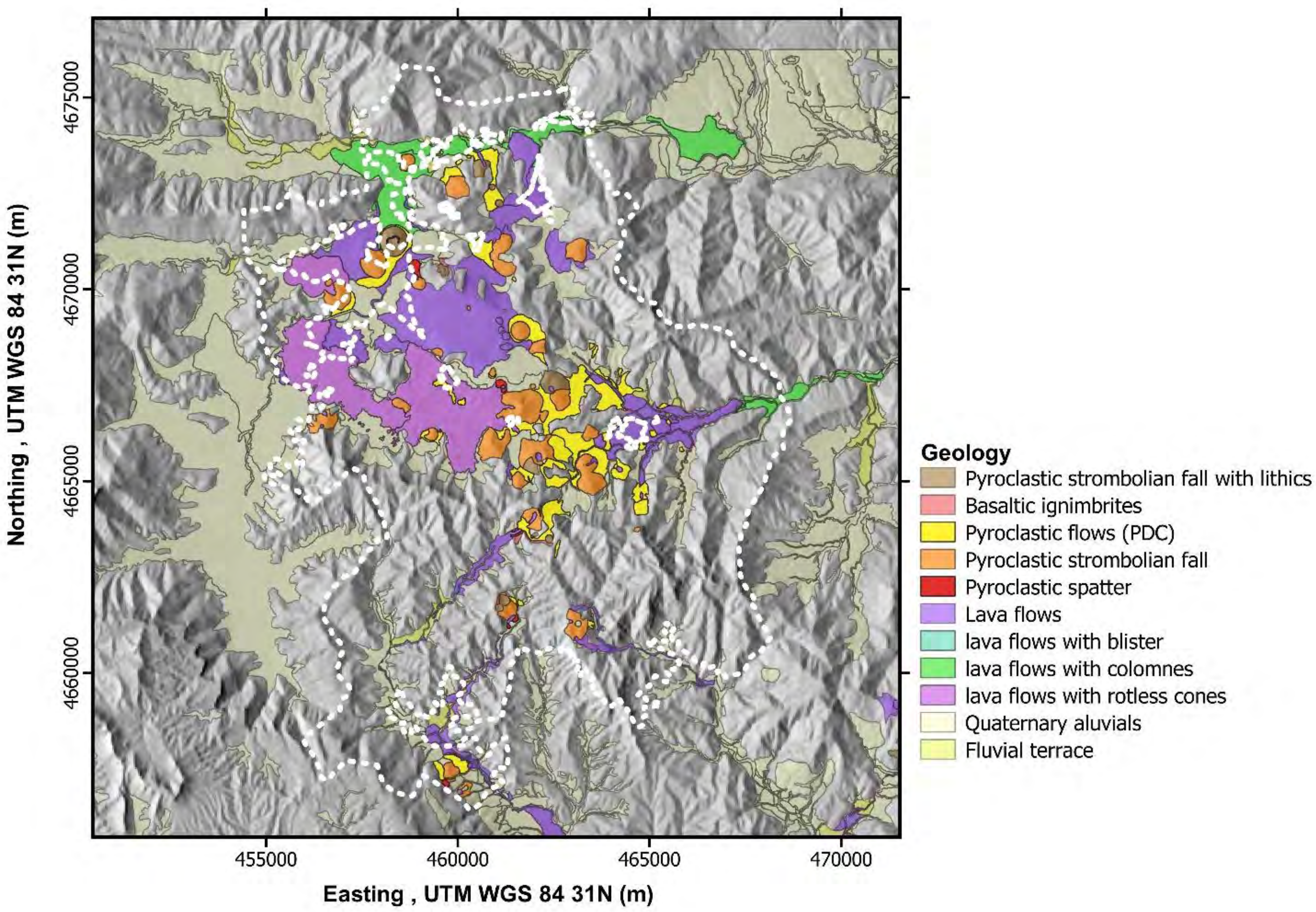

Figure 12. Map of the geodiversity of the volcanic deposits in La Garrotxa Volcanic Zone.

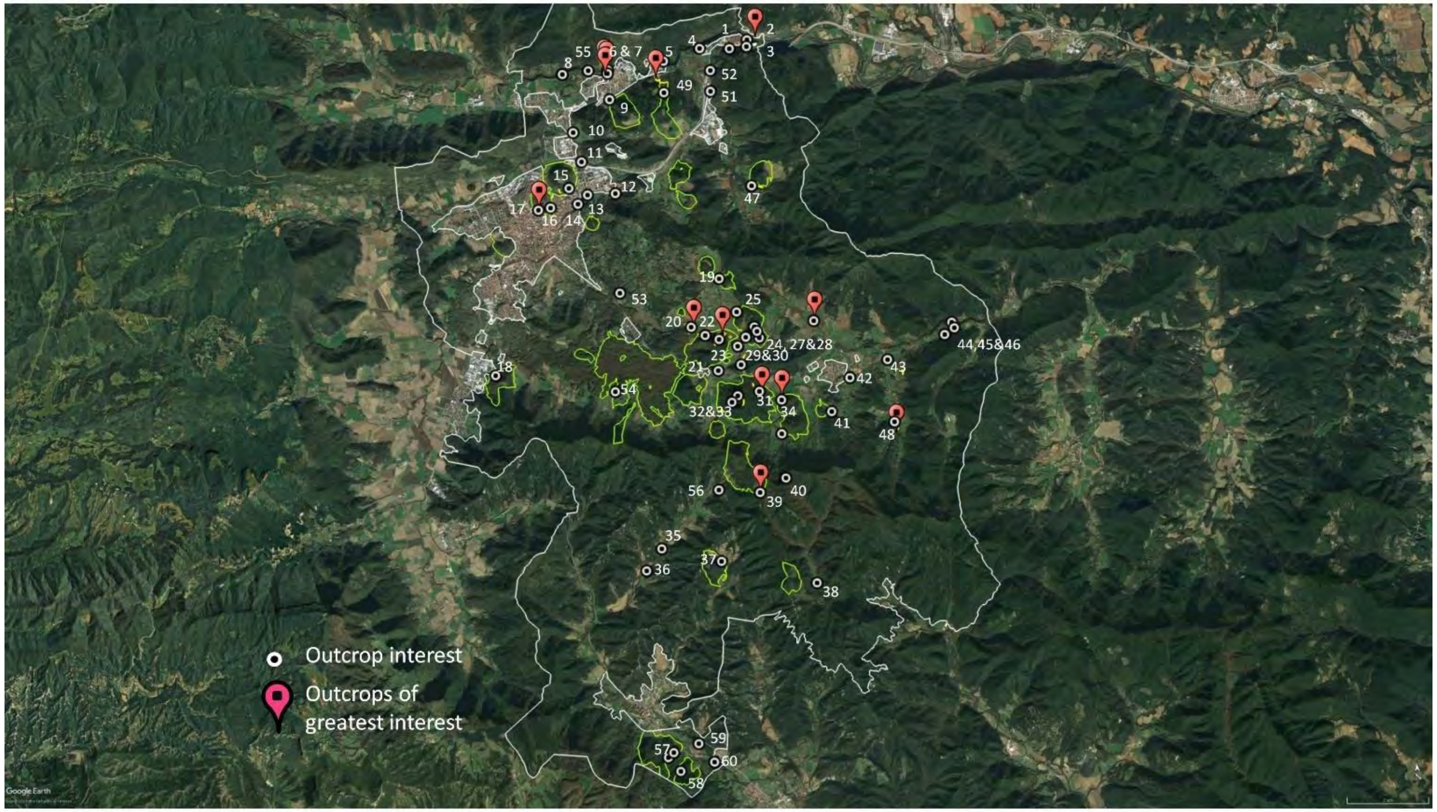

Figure 13. Map of the selected outcrops.

Criteria used to select the outcrops that best represent the volcanic geological heritage of the zone

In addition to the rich soils and benign climate that favour the development of dense vegetation cover (Oliver 2016), and despite the burgeoning economic development of this relatively well-populated zone, the PNZVG harbours a large number of visible volcanic outcrops. The first special protection plan designed to regulate the conservation of this protected area catalogued 50 sites of geological interest (Planagumà 2017). Given that the conservation of so many sites is costly in terms of both human and economic resources, a methodology was established to select the most interesting outcrops and illustrate the great variety of types of volcanic deposits existing in the area.

Therefore, as part of the protection of this volcanological geoheritage and to facilitate public access in a sustainable manner, a selection of the most representative outcrops of the greatest geological and volcanological interest was established based on their relevance in terms of three main aspects: research, conservation and dissemination. After testing 50 selected outcrops and 10 further outcrops discovered in recent years during a study of ephemeral sites (Bolós et al. 2014) (Table 6 and Fig. 13), 12 outcrops of great geological interest were identified (Table 6 and Figs. 13, 14, and 15). The remaining outcrops were discarded as being poorly representative, poorly accessible, or irreversibly damaged, or due to a combination of two or more of these reasons (Figs. 14 and 7).

These selected outcrops (Fig. 15) represent the main aspects of the volcanic activity that has characterised the evolution of La Garrotxa Volcanic Field. However, outher outcrops that were potentially the most informative for visitors and other aspects such as state of preservation, facility of access, future management, and their landownership were also taken into account.

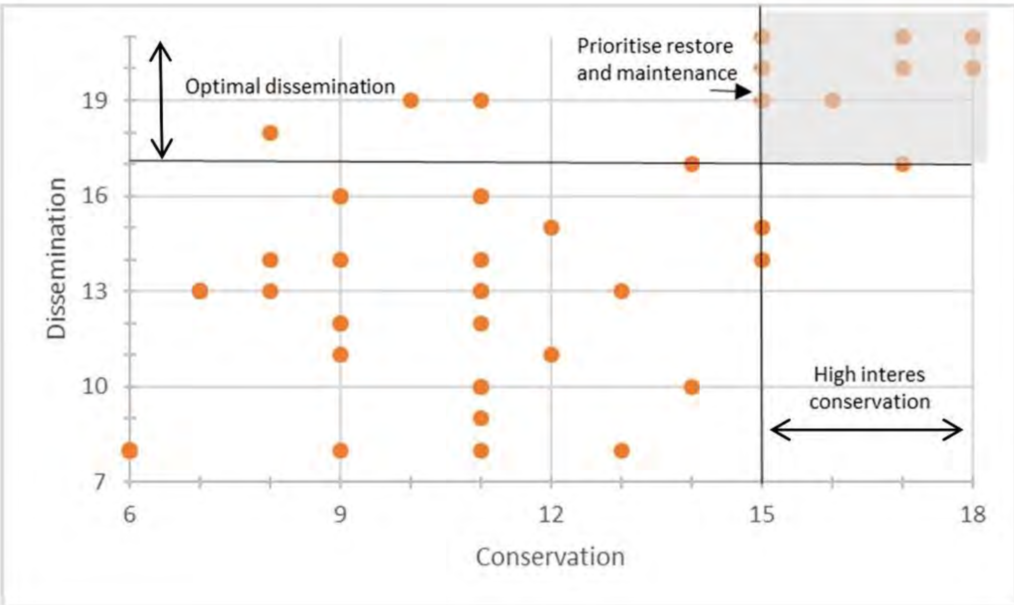

Figure 14. Graph showing the relationship between dissemination and conservation prioritizing outcrops. Red dots correspond to the outcrops; recommendations for active management are in the grey square (top and left).

These 12 outcrops were then subdivided into two groups according to their interest in terms of i) conservation and ii) dissemination and public use. In the former group aspects such as the state of conservation, potential for restoration, the rarity and exceptionality of its scientific features, whether or not it was a typical locality for geological description, its potential from a pedagogical point of view, and its spectacularity and beauty, were evaluated. In the latter group, the aspects to be considered were the potential for dissemination and use for tourism, their pedagogical value, and potential for developing scientific activities, as well as how ease was access and observation, the type of landownership 4f the outcrop, and the fragility of both the natural and social environment (Table 4).

What follows are short descriptions summarising the main aspects of each of the 12 selected outcrops that constitute the most important volcanic sites in the PNZVG.

Table 4. Criteria for selecting the main outcrops.

Conservation	Public use and awareness-raising
A) Conservation state 3 Well conserved or easily restorable 2 Poorly conserved and difficult to restore 1 Poorly conserved and impossible to restore	A) Possibility of use for activities (scientific, educational, tourism, recreation) 3 Possible use for three type of activities 2 Two types 1 One type
B) Abundance/uniqueness 3 The only outcrop of this type in the natural park 2 Two other outcrops of this type exist in the natural park 1 More than five other outcrops of this type exist	B) Observation conditions 3 Good 2 Average 1 Poor
C) Useful for illustrating volcanic processes 3 Very useful 2 Moderately useful 1 Of little use	C) Accessibility 3 Quick access from main roads for all types of vehicles 2 Access along unsurfaced roads not suitable for all vehicles 1 Far from roads (over 30 min on foot)
D) Type locality 3 Used to describe a volcanic-related process 2 Used to illustrate a description of a volcanic-related process 3 Not used to illustrate a description of a volcanic-related process	D) Private property 3 Outcrop on public property or where landowner is amenable 2 Permission required from landowner 3 Problems with landowner
E) Associated with other features of interest 3 Associated with other natural or cultural features of interest 2 Few associations 1 Not associated	E) Surroundings 3 Visits do not affect the natural, social o architectural surroundings 2 Visits may slightly affect surroundings 1 Visits will seriously affect surroundings
F) Diversity of elements (mineralogical, geomorphological, dynamism, etc.) 3 More than three other visible elements 2 Two or three other visible elements 1 One visible element	F) Space 3 More than 30 people can access the site at once 2 15–29 people can access the site at once 1 Fewer than 15 people can access the site at once

	G) Fragility 3 Visits do not cause any degradation of the site 2 Visits could cause deterioration of the site 1 Visits could seriously damage the site
6–10 Category 3 Low conservation interest **10–14 Category 2 Moderate conservation interest** **15–18 Category 1 High conservation interest**	**7–12 Not apt for visits or raising awareness** **12–17 Potentially apt for visits or raising awareness** **18–21 Excellent possibilities for visits or raising awareness**

Castellfollit de la Roca basaltic cliffs

Located about seven kilometres east of the city of Olot, these basaltic cliffs lie in the extreme north-east of PNZVG, between the rivers Turonell to the south and Fluvià to the north (Fig. 13). These cliffs are an excellent example of effusive activity and consist of two superimposed lava flows, 210,000- and 192,000-years old (Lewis et al. 2000), which have been partially eroded away by the two abovementioned rivers. The cliffs, which rise 50 m above these rivers and run for 1 kilometre, provide excellent views of the internal structure of a lava flow (Fig. 15a). The main feature of this outcrop is the well-developed columnar jointing that affects the succession of lava flows. Due to the existence of this pervasive network of joints, frost weathering (freezing-thawing) is concentrated along these cracks and eventually leads to the crumbling and fall of the blocks. They are then carried off periodically by the river when in floods, thereby preventing the fallen blocks from building up and stabilising at the bottom of the cliff.

The lava flows rest on Eocene sandstones and marls, and Quaternary gravels, and consist of a 40-m-thick layer of black and grey basalt. About nine metres from the top of the volcanic materials, a layer (0.2–1.5-m thick) of clay and pyroclasts, easily recognisable by the abundant herbaceous vegetation that grows there, divides the escarpment into two discrete parts, each one corresponding to a different lava flow. The lower zone of the lower lava flow has i) a 5.5-m-thick, well-developed columnar jointing with prisms around 50 cm in diameter, ii) an intermediate zone, 3.5-m thick, with lenticular jointing, and iii) an upper zone, less than one-metre thick, with columnar jointing again but with columns that are only 30 cm in diameter. The upper lava flow has four different zones, the first three, starting from the base, are each 5–9-m thick and have obvious columnar jointing, while the uppermost zone is about 9-m thick and has well-developed spheroidal weathering.

The medieval village of Castellfollit de la Roca was built on top of these lava flows using, above all, rocks and stones from the flows themselves as building materials.

Sant Joan Les Fonts lava flows

In the town of Sant Joan les Fonts there are two outcrops of interest (Fig. 13). Firstly, El Boscarró provides a vision of the relationship between well-developed columnar and lenticular jointing within a lava flow (Fig. 15b). Five layers can be distinguished here: the lowest has columnar jointing with 5- and 6-sided columns, 20–40 cm in diameter, and 2–3-metres high. The second and fourth layers have slab jointing, while between them in the third layer there is massive material with a few cooling cracks. The fifth and final layer, just below the soil level, is far more altered due to its proximity to the surface and has a marked spheroidal structure. North-west from the quarry face, a stream, La Riera de Bianya, flows along the contact zone between the volcanic materials and the reddish Eocene sedimentary materials.

At El Molí Fondo three lava flows are superimposed along the river Fluvià and are all visible and visitable: the oldest dates from 600,000 years ago (Araña et al. 1983), the second (150,000 years ago) exhibits lenticular formations and blisters, while the youngest (133,000 years ago) is characterised by a well-formed series of basaltic columns (Fig. 15c).

Quarry at El Cairat

A good example of a breccia generated by a phreatomagmatic explosion can be found close to the eruptive centre of the volcano El Cairat on the ridge of Serra Molera in the north of the natural park (Fig. 13). El Cairat is a maar-type volcano with a 120-m-diameter crater excavated in the Eocene substrate (Martí et al. 2011). It is one of the few examples in the studied area that is almost exclusively composed of phreatomagmatic deposits. The pyroclastic deposits that form this volcanic edifice were emplaced preferentially to the north and south of the crater. The observation point is an old quarry located at the base of the northern flank of the volcano. This outcrop has a 20-m-thick succession of pyroclastic deposits corresponding to lithic-rich explosion breccias and lapilli-sized fallout, and pyroclastic surge deposits (Fig. 15d). The main characteristic of this succession of deposits is the presence of abundant lithic clasts from the red sandstone Eocene basement, which range in size from a few centimetres to up to 5 m.

Montsacopa

This is one of the most representative and best-preserved volcanic cones in the area. Located inside the city of Olot, Montsacopa is a steep-sided cinder cone, 94 m in height and topped off with a circular, 120-m-diameter and 12-m-deep crater. On the south-eastern side of this volcano lie a series of Strombolian deposits resulting from the formation of a scoria cone, conformably above which there is a succession of pyroclastic density current (PDC) deposits caused by the interaction of the magma with a shallow aquifer (Fig. 15e). This outcrop reveals one of the most characteristic features of the La Garrotxa volcanism, namely, the co-occurrence of Strombolian and phreatomagmatic phases during a single eruption (Martí et al. 2011).

La Pomareda

The quarry at La Pomareda (Fig. 13), together with the two following outcrops (quarry at Croscat and the eastern flank of Santa Margarida), form part of one of the most recent eruptions in the area, which took place about 11–13 ka. In fact, La Pomareda, Croscat and Santa Margarida all lie on a 3-km-long eruption fissure oriented NW-SW, from where the eruption started at the southern end with a vent-opening phreatomagmatic phase, visible on the southern flank of the Santa Margarida outcrop. Subsequently, the eruption progressed to the central and northern sectors of the fissure extruding basaltic magma and generating massive spatter and occasionally rheomorphic, welded scoria agglomerates, visible at La Pomareda, and terminated in the centre of the fissure with an important cone-building event that formed the volcano of Croscat (Martí et al. 2011).

The outcrop at La Pomareda, located to the north of Croscat, is visible thanks to quarrying and corresponds to local black-to-reddish spatter deposits with welded blocks and bombs, covered subsequently by a layer of lapilli and a lava flow originating from the eruptive vent at Croscat (Fig. 15f). The scoria fragments are mostly flattened and are up to 1 m in width and, together with the welding, suggest a very proximal outcrop corresponding to the first stages of the purely magmatic eruptive activity along this eruptive fissure (Martí et al. 2011).

Quarry at Croscat

This quarry is located on the northern side of the volcano (Fig. 13) and was worked from the 1960s until the beginning of the 1990s. The excavations exposed an outcrop of pyroclastic materials, 150 m in height and 500 m in width, that today illustrate perfectly the different phases of the formation of a cinder cone generated by a violent Strombolian eruption phase (di Traglia et al. 2009).

On the right-hand side, the quarrying was executed in great terraced steps to help stabilise the volcanic material. However, the middle and the left-hand side are less stable and landslips are more frequent. The different layers of fallout scoria consist of irregular, highly vesicular juvenile fragments, for the most part lapilli-sized, and are very well exposed in this outcrop (Fig. 15g). At the base of the sequence, several bombs are visible. The materials are mostly dark grey or black, although in the area closest to the centre of the edifice they are reddish and ochre. In the lowest part of the quarry there is a reddish layer of welded scoria, which corresponds to the first episode in the cone-building phase of the volcano and is very similar to that observed at La Pomareda. On top of the Strombolian fallout succession there is a 2-m-thick laminated layer of finer pale-brownish material that corresponds to phreatomagmatic material deposited at the end of the volcano's explosive activity (Martí et al. 2011).

Eastern flank of Santa Margarida

On the eastern flank of the volcano of Santa Margarida (Fig. 13), crowned by a maar-type crater, there is a visible outcrop of PDC. On top of a silty soil, which corresponds to the pre-volcanic substrate, lies a layer of compacted phreatomagmatic ash followed by massive lithic-rich pyroclastic flow deposits and several well-stratified beds of medium-to-coarse-grained, dilute pyroclastic surge deposits and associated fine-ash deposits forming, in total, a 3-m-thick succession (Fig. 15h). On top of this there is a layer of black juvenile lapilli scoria fragments and fairly rounded reddish-brown lithics (Eocene red sandstones). This fallout scoria and the previous phreatomagmatic deposits correspond to the initial eruption phases from the Santa Margarida vent (Martí et al. 2011). Finally, at the top of the sequence there is a deposit – a fine-grained scoria deposit with no stratification – that closely resembles the previous layer but without any lithics, which corresponds to the airfall deposits originating from Croscat.

Quarry at Can Tia

Located on the western side of the volcano of Can Tia, this quarry is one of the few examples of basaltic ignimbrites (massive, scoria-rich, dense PDCs deposits), that are visible in this volcanic field (Martí et al. 2017). Can Tià is a maar-type volcano, with a 270-m-wide and 20-m-deep flat-bottomed crater. It is asymmetrical – its lip is higher to the south – and the sequence of materials that built this volcano, observable in the quarry next to Can Tia, consist only of pyroclastic deposits (Fig. 15i). There are four different units from base to top. The lowest unit corresponds to a 10-cm-thick, internally massive pyroclastic surge deposit, which rests unconformably on a palaeosoil. The second unit consists of a poorly stratified, non-welded, highly vesiculated lapilli scoria deposit, up to 6-m thick, with a few lithic clasts, some of block size. The third unit overlies conformably the previous one and consists of a 1.5-m-thick, thinly laminated, well-sorted, fine-grained scoria deposit rich in lithic clasts of red Eocene sandstones of variable size (<2–30 cm), with an interbedded ash layer in its upper part. The number of lithics increases gradually towards the top of this deposit, which is sheared by the emplacement of the uppermost unit. This final unit is a massive dense PDC deposit (basaltic ignimbrite), up to 3-m thick, that contains abundant Eocene lithic clasts and scoria, and highly vesiculated lapilli fragments, all contained in a lithic-rich, ash matrix that has been almost completely transformed into clay minerals, zeolites and iron oxides. The sequence of deposits displayed in this outcrop helps visualise the complex eruption dynamics of this monogenetic volcanism, in which magmatic and phreatomagmatic phases often alternated during the same eruption (Martí et al. 2011). This particular outcrop reveals how the explosive activity began with a short phreatomagmatic event, then changed immediately into a magmatic event (second and third units), and then changed back to a phreatomagmatic event (upper part of the third unit and fourth unit) during the course of the eruption.

Riera dels Arcs

This is another excellent outcrop for observing the full succession of a basaltic ignimbrite deposit (Martí et al. 2017). Located near Mas Carrer in Riera dels Arcs (Fig. 13), this outcrop is about 1.5 km from the vent of the volcano of Sant Jordi (Fig. 13). Two units are visible (Fig. 15j): the lower unit is consists of fine scoria lapilli fall deposits that hug the irregular pre-existing topography in the bottom of the gully. It is well sorted and thinly laminated, and mostly composed of highly vesicular, juvenile basaltic scoria clasts. Its total thickness is about 25 cm. The upper unit consists of a brown, massive, 15-m-thick ignimbrite deposit composed of dense-to-highly vesiculated, large lapilli-to-bomb-sized juvenile scoria fragments that are sometimes flattened, together with lithic lapilli and blocks of Eocene sedimentary rocks and previous lavas, all supported by an indurated ash and fine lapilli matrix. The base of the upper unit is mostly planar and corresponds to a fine-grained layer that gradually grades into a lithic-rich horizon, about 0.4-m thick, composed of dense fragments of Eocene sediments and older lavas up to 50 cm in diameter that are irregularly distributed. In the rest of the deposit, the lithic content varies vertically, and forms lithic-rich zones or lenses. Juvenile clasts tend to be concentrated towards the top. The top of the deposit has been partially eroded, reworked and transformed into a palaeosoil.

Torrent de Cal Bosquet

This outcrop is located to the north-east of the village of Santa Pau (Fig. 13). It exhibits a succession of dilute PDC deposits (surges) emplaced during the final explosive episode originating from Croscat (Martí et al. 2011). This outcrop lies atop a former fluvial terrace; its lower part is characterized by a succession of levels of fine lapilli fall deposits, while its upper part, which is clearly differentiated, has grain-supported levels of ash affected by tractive structures and by erosive and/or canaliform morphologies. This outcrop is exceptional due to the visibility of a large number of erosive canaliform strata, with an abundance of Type A dunes (Fisher and Schminke, 1984) that cross at low angles, and the presence of anti-dunes. These antidunes are eroded by reworked alluvial sediments that correspond to lahars provoked by the rainfall that accompanies this type of eruption.

Quarry at Rocanegra

The quarry on the northern flank of the volcano of Rocanegra, located 1 km to the west of Santa Pau (Fig. 13), is an excellent site for studying the formation of a cinder cone composed of lapilli scoria and bombs formed during a pure Strombolian magmatic eruption. The outcrop has a well-stratified succession of fallout deposits, dipping in equilibrium with the slope, that corresponds to a small cinder cone (Fig. 15l). All the deposits are grain-supported and well classified, with grain size varying from block size to medium-sized lapilli, and all are clasts of vesiculated basaltic scoria. Some bombs are also visible in some layers in this succession. Another interesting characteristic of this particular outcrop, which distinguishes it from the other volcanoes in the area, is the presence of a large number of enclaves of pyroxenite and gabbros, as well as partially melted granitic rocks (Neumann et al. 1999).

Table 5. The 12 outcrops (Fig. 16) that encompass a full spectrum of the eruptive activities occurring in the Catalan Volcanic Field and illustrate a very complete range of the deposits found in typical basaltic volcanic fields.

Name	**Location** UTM31N - ETRS89	**Exposed deposits**	**Number of visitors**
Cliffs at Castellfollit de la Roca	X 461812 Y 4667201	Lava flow and columns	More 10,000
El Boscarró former quarry	X4 59608 Y 4673798	Lava flow and columns, and lenticulars forms	More 10,000
Molí Fondo	X 459551 Y 4673674	Three lava flows, blisters, columns and lenticular forms	More 10,000
Former quarry at Can Barranc on El Cairat	X 460809 Y 4673538	Phreatomagmatic fall	Less 100
Former quarry on El Montsacopa	X 457706 Y 4670571	Phreatomagmatic PDC with volcanic lithics	More 10,000
La Pomareda	X 461203 Y 4667462	Spatter	Between 1,000 and 10,000
Former quarry NE of El Croscat	X 461824 Y 4667203	Strombolian fall deposits	50,000
Track to El Cros	X 462725 Y 4665701	PDC with sedimentary lithics	Between 1,000 and 10,000
Former quarry on Can Tià	X 462476 Y 4663391	Basaltic ignimbrites	Less 100
El Carrer	X 465875 Y 4664562	Basaltic ignimbrites	Less 100
Torrent de Cal Bosquet	X 464132 Y 4667400	PDC with volcanic lithics	Less 100
Former quarry on El Rocanegra	X 463181 Y 4665613	Strombolian fall deposits	Between 1,000 and 10,000

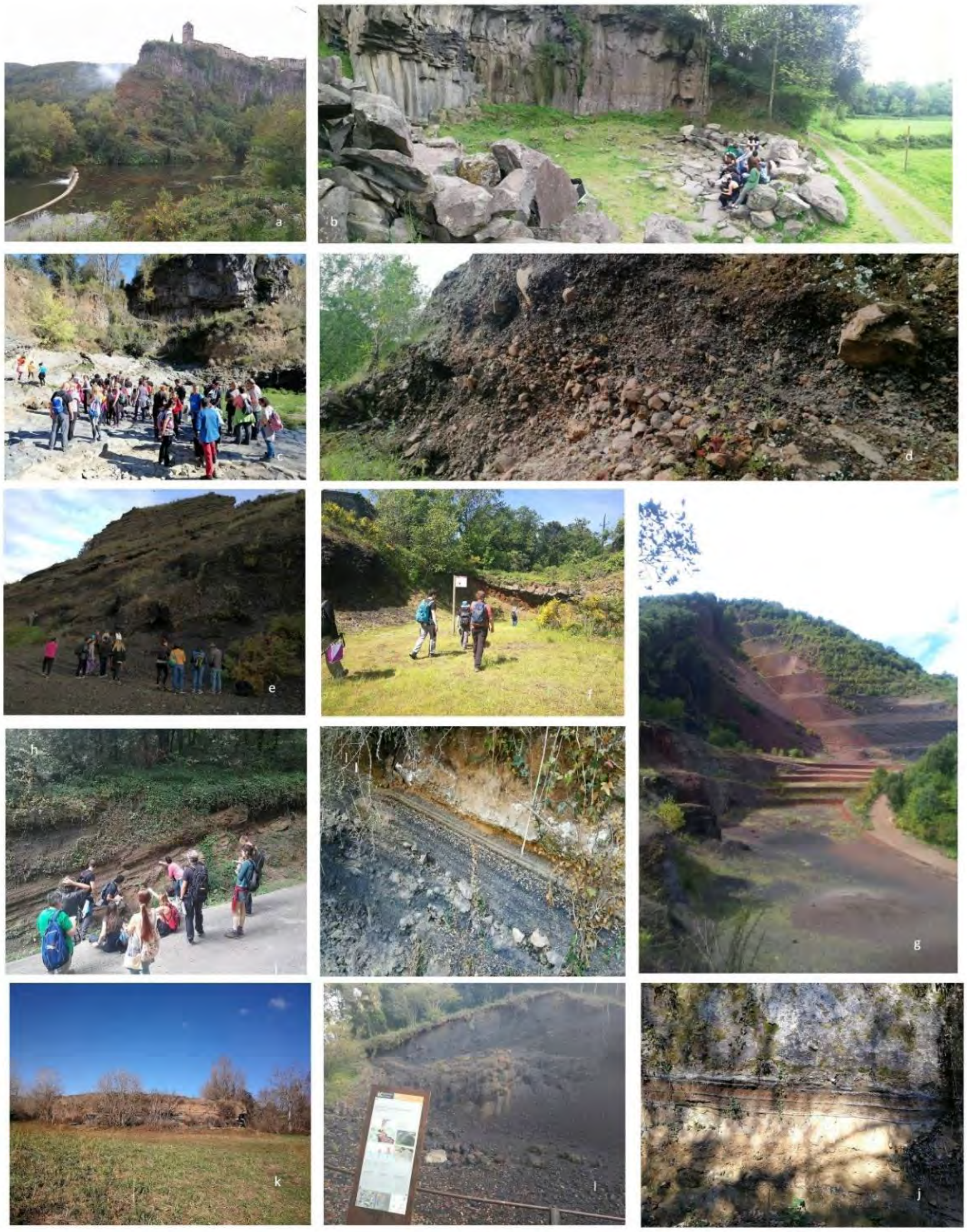

Figure 15. . Photographs of the outcrops of greatest interest. a - Cliffs at Castellfollit de la Roca (columnar jointing in lava flows), b – Quarry at El Boscarró (columnar and platy jointing in lava flows). c – Molí Fondo (columnar and platy jointing in lava flows), d - Quarry at Can Barranc (lithic breccias and scoria deposits). e – Quarry at Montsacopa volcano (succession of Strombolian and phreatomagmatic deposits), f- La Pomareda (succession of Strombolian agglomerate, scoria (lapilli) fallout deposit, and lava flow), g - Quarry NE of El Croscat (full succession of the Croscat Strombolina deposits), h - Track to El Cros (dilute PDC deposits and scoria fallout deposits), i– Quarry at Can Tià (transition between Strombolian -scoria fallout deposit- and phreatomagmatic -lithic rich fallout and basaltic ignimbrite- phases in the same eruption), j - Torrent de Cal Bosquet (succession of dilute PDC (surges) deposits), k – Quarry at El Rocanegra (Strombolian (scoria) fallout succession), l - El Carrer (basaltic ignimbrite),

Figure 16. Photographs of the outcrops of less interest. 1 & 2 – little use for illustrating geological processes (scoria fallout deposits) duet to extensive vegetation coverage, 3 – Problems with landowner, 4 – Poor observation (lava flows) possibilities, 5 – Poor state of conservation (former quarry used now as illegal dump), 6 – Inaccessible or only observable from long distance (columnar jointing in a lava flow)

Discussion

In order to preserve and disseminate the volcanological knowledge of an area, it is crucial to carry out a thorough study of its main geological and volcanological values (geodiversity), and accordingly identify its geoheritage and define and undertake appropriate conservation actions. Part of this management must consist of determining which sites are most interesting from a geological standpoint and which are the most suitable for visiting. To complete a full inventory of the outcrops to be protected, a full analysis of the conservation status of each site of interest is essential: Is it geologically relevant? Can it be easily observed? Is it on public or private property? Is there good access? Might it become eroded due to over visiting? Thus, using the various proposed criteria (Table 2), it is possible to catalogue the sites of greatest geological interest in the zone that should be conserved and managed as key places for visitors.

In the La Garrtoxa Volcanic Field, over the past two decades most of the efforts aimed at conserving and describing the region's volcanic heritage have been centred on the outcrops described above. Currently, they are all well conserved and are easily visitable. Taking them as a whole, visitors can obtain a complete picture of the most important volcanic processes that have occurred in this volcanic zone. Each of these selected outcrops is now equipped with information panels in which the main features to be observed are outlined. In addition, these descriptions and detailed indications on how to reach each one, along with a general introduction to volcanism and to La Garrotxa Volcanic Field, are included in a field guide that helps visitors appreciate more fully the geoheritage of the area (Martí et al. 2000). This field guide has become an essential tool for raising awareness of these 12 sites of great geological interest and helps visitors interpret the volcanic features of the natural park through careful observation.

The criteria to be considered for preserving the volcanic outcrops like those described here should include the following aspects: (i) the potential loss of sites of geomorphological interest and the difficulties in viewing geological processes due to changes in land use as forests encroach and swallow up pastureland and cropland; (ii) the potential loss of visibility of some outcrops due to landslips and rock falls that occur relatively frequently in this type of volcanic material; (iii) the potential impact caused by over-frequentation – i.e. the erosion of paths, increased noise levels, and the loss of the peace and quietness required for ensuring the quality of visits – that implies the need to regulate public access; and (iv) the potential loss and possible destruction of outcrops and volcanic morphologies such as blisters due to urban growth and the building of new lineal infrastructures such as roads.

Thus, it is essential to take into account the following principles when attempting to restore, signpost and promote the protection of this type of geological outcrops: (i) good scientific knowledge of all relevant geological processes; (ii) all restoration work must blend in with the landscape and improve the possibilities of observing the geological processes; (iii) public use (i.e. car-parking, massification and interpretation) must be controlled; (iv) the risk of landslips and rock falls must be minimised; and (v) local bodies including town councils and citizen groups must be involved in all attempts to manage these outcrops.

These sites of geological interest are included in the La Garrotxa Volcanic Zone Natural Park management plan (*Pla Especial*), which is the main tool for territorial planning used in this protected area. It has established a series of regulations aimed at preserving and protecting the local geological heritage by prohibiting all activities that might either provoke or accelerate erosion, and by forbidding any activity that might lead to the degradation and deterioration of the protected area, or hinder the study thereof. This plan bans any excavations or earth movements unless their aim is to improve access to the volcanoes for scientific or educational purposes; permission must always be granted beforehand by the park's management team. As well, the spaces created by past excavations must be kept free of all buildings and all other features that might hamper views of the volcanoes. The plan also states that these sites of exceptional geological interest should be actively managed, that agreements should be sought with landowners to facilitate the management of these volcanic features, and that grants can be applied for if and when necessary (Table 6)

The relationship with local town councils and local people living in the park is one of the most interesting indicators of the correct management of these outcrops since in some cases they are co-managed by the Natural Park and local town councils. Of the 12 outcrops classified as 'of great interest', nine are actively managed by the park, of which six are co-managed by the park and local councils (Fig 17). This demonstrates how local authorities and local people are committed to the conservation of the geological heritage of the zone.

Finally, it is worth mentioning that these selected outcrops are the reference points used for training the Park guides and where they study and learn about local volcanism. This training is important for the correct transmission to visitors of geological and volcanological knowledge and for making them more aware of the need to conserve the geological heritage of this area. This program has been run since 2000 and to date 400 guides have been trained.

Figure 17. Photographs before and after the restoration of the outcrop at Molí Fondo (platy and columnas jointing in lava flows).

Conclusions

Sites such as La Garrotxa Volcanic Field harbour a great variety of volcanic features that illustrate a large number of eruptive processes, products and landforms. This makes them very attractive for geotourism and tourism in general and they are often heavily visited due to their bucolic, easily accessible, and gently rolling landscapes, and as such are ideal places for raising awareness about the importance of volcanism. However, we should not forget that the volcanic materials present in these areas are often inherently fragile and easy to erode, which means that unchecked public access could lessen their value as heritage sites.

The use of this methodology in La Garrotxa Volcanic Zone Natural Park enabled the most important outcrops in the area to be identified, which crucially, enabled the park to i) increase the efficiency of actions devoted to conserving the processes that characterize this type of volcanic activity for future generations; ii) manage public use for those who come to visit the volcanoes; and iii) ensure that the scientific knowledge of these sites provides a service from a ecosystemic and cultural point of view. The correct management of all these aspects will contribute

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Table 6. Catalogue of outcrop interest & value.

	Table 3 Catalogue of outcrop interest & value	Conservation state	Abundance/uniqueness	Useful for illustrating volcanic processes	Type locality	Other features of interest	Diversity of elements	**Total**	Public use and awareness-raising	Observation conditions	Accessibility	Private property	Surroundings	Space	Fragility	**Total**
1	CINGLERA TURONELL	1	1	2	2	3	2	**11**	2	3	3	3	3	2	3	**19**
2	CINGLERA FLUVIÀ N	2	3	3	3	3	1	**15**	3	3	3	3	3	3	3	**21**
3	CINGLERA TURONELL, S	1	1	1	1	1	1	**6**	1	1	1	2	1	1	1	**8**
4	CINGLERA CAN GRIDO-CAL SORDET	2	1	2	1	2	1	**9**	2	2	2	2	2	2	2	**14**
5	CINGLES DE LA CANOVA	2	1	1	1	3	1	**9**	2	2	2	2	2	3	3	**16**
6	MOLI FONDO	3	3	3	3	3	3	**18**	3	3	3	3	3	3	3	**21**
7	BOSCARRO	3	3	3	3	3	2	**17**	3	3	3	3	3	3	3	**21**
9	CINGLE DE FONTFREDA	3	2	2	2	3	2	**14**	3	3	1	2	2	3	3	**17**
10	TORRENT DEL SOLER	1	1	1	1	1	1	**6**	1	1	1	2	1	1	1	**8**
11	NOC D'EN COLS	2	1	1	2	3	2	**11**	1	1	1	2	1	1	1	**8**
12	CINGLE DE LES COLS	3	2	3	1	2	2	**13**	2	3	3	1	2	1	1	**13**

13	LES TRIES	1	1	1	1	1	1	**6**	1	1	2	1	1	1	1	**8**
14	MOLI DE LA TORRE	1	1	1	1	1	1	**6**	1	1	2	1	1	1	1	**8**
15	MOLI DE TIRABURRES	1	1	1	1	1	1	**6**	1	1	2	1	1	1	1	**8**
16	VOLCÀ GARRINADA	3	2	3	1	2	2	**13**	1	1	2	1	1	1	1	**8**
17	VOLCÀ MONTSACOPA (Gredera E)	2	1	2	2	1	1	**9**	1	1	2	1	1	1	1	**8**
18	VOLCÀ MONTSACOPA (Gredera S-W)	3	3	3	3	3	2	**17**	2	3	3	3	3	3	3	**20**
19	VOLCÀ RACÓ (Gredera N)	1	2	2	2	2	2	**11**	2	1	3	1	1	2	3	**13**
20	BARRANC DE GARROFÀS	3	3	3	2	1	2	**14**	1	1	1	2	2	1	2	**10**
21	LA POMAREDA	3	3	3	3	1	3	**16**	3	3	3	2	3	3	2	**19**
22	GREDERA S (Costat Carretera)	2	1	2	2	2	2	**11**	2	3	3	3	1	1	1	**14**
23	VOLCÀ CROSCAT (Gred N-W, abocador)	2	1	2	2	1	1	**9**	2	2	2	3	2	3	2	**16**
24	VOLCÀ CROSCAT (Gredera N-E, Tall)	3	3	3	3	3	3	**18**	3	3	2	3	3	3	3	**20**
25	V.PUIG DE MARTINYÀ (Gredera N-W)	2	1	1	1	1	1	**7**	1	2	2	2	1	3	2	**13**

26	V.PUIG SAFONT (Gredera N-W)	2	2	1	1	1	1	**8**	2	3	3	2	2	3	3	**18**
27	V.PUIG MARTINYÀ (Gredera N-E)	2	1	1	1	1	2	**8**	2	2	2	2	1	2	2	**13**
28	V.PUIG DE MARTINYÀ (Gredera W)	2	1	1	1	1	1	**7**	2	2	2	2	1	2	2	**13**
29	V.PUIG DE MARTINYÀ (Gredera W)	2	1	1	1	1	1	**7**	2	2	2	2	1	2	2	**13**
30	PLA DE LES FORQUES	2	1	1	1	1	1	**7**	2	2	2	2	1	2	2	**13**
31	TALÚS DE LES FORQUES	2	1	1	1	1	1	**7**	2	2	2	2	1	2	2	**13**
32	V.SANTA MARG- Talús pista vessant N-E	3	3	3	3	1	2	**15**	3	3	3	3	2	2	3	**19**
33	V.SANTA MARG- Flanc cràter N-E	2	1	2	2	3	1	**11**	2	3	1	3	3	2	2	**16**
34	V.SANTA MARG- Flanc cràter NW	2	1	2	2	3	1	**11**	2	3	1	3	3	2	2	**16**
35	V.ROCA NEGRA- Vessant N-W	3	3	3	3	1	2	**15**	2	3	1	3	3	2	1	**15**
36	RIERA DE SANT ISCLE I	2	3	2	1	2	1	**11**	1	2	1	2	1	2	1	**10**
37	RIERA DE SANT ISCLE II	2	3	2	1	2	1	**11**	1	2	1	2	1	2	1	**10**
38	V. TRAITER (Gredera N-E)	2	2	2	1	2	1	**10**	3	3	3	2	2	3	3	**19**

39	BARRANC DE MATABOUS	3	2	1	1	2	2	**11**	1	2	2	2	1	1	3	**12**
40	V.CAN TIA	3	3	3	3	3	2	**17**	3	3	1	3	3	2	2	**17**
41	CAN BARRANC del Corb	2	3	3	2	1	1	**12**	1	3	2	2	3	2	2	**15**
42	V. CAN SIMÒ	3	2	2	2	1	1	**11**	1	3	2	2	1	2	2	**13**
43	SALT DEL CLOT	2	1	2	1	2	1	**9**	2	2	2	2	1	1	2	**12**
44	VALL DELS ARCS	2	1	2	1	2	1	**9**	2	2	2	2	1	1	2	**12**
45	CINGLE DE CAN FORMIGA	2	1	1	1	2	1	**8**	1	2	3	2	2	2	2	**14**
46	RIU SER	2	1	2	1	2	1	**9**	1	2	2	2	1	1	2	**11**
47	TORRENT DE SANT MARTI	3	2	1	1	3	2	**12**	2	2	1	2	1	1	2	**11**
48	TORRENTMAL	3	3	2	1	1	1	**11**	1	1	1	2	1	1	2	**9**
49	EL CARRER (Riera dels Arcs)	3	3	3	3	1	2	**15**	2	2	2	2	1	2	3	**14**
50	CAN BARRANC	2	3	3	3	2	2	**15**	3	3	3	2	3	3	3	**20**
51	PEDRERA TURONELL	3	2	1	1	3	2	**12**	2	2	1	2	1	1	2	**11**
52	CINGLERA TURONELL III	2	3	3	2	1	1	**12**	1	3	2	2	3	2	2	**15**
53	CAN BARRANC DE BATET	3	2	2	2	1	1	**11**	1	3	2	2	1	2	2	**13**
54	GREDERA DEL PUIG JORDÀ	2	1	2	1	2	1	**9**	2	2	2	2	1	1	2	**12**

55	CINGLERA DE CAN XERBANDA	2	1	2	1	2	1	**9**	2	2	2	2	1	1	2	**12**
56	CARRETERA DE COLLTORT	2	1	1	1	2	1	**8**	1	2	3	2	2	2	2	**14**
57	GREDERA SANT MARC	2	1	2	1	2	1	**9**	1	2	2	2	1	1	2	**11**
58	PEDRERA PUIG ROIG	3	2	2	2	1	1	**11**	1	3	2	2	1	2	2	**13**
59	TRAVERTINS LA TORRE I	3	2	1	1	3	2	**12**	2	2	1	2	1	1	2	**11**
60	TRAVERTINS LA TORRE II	3	2	1	1	3	2	**12**	2	2	1	2	1	1	2	**11**

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8. EVALUATION OF THE CONSERVATION OF THE GEOLOGICAL HERITAGE OF VOLCANIC FIELDS: THE CASE OF LA GARROTXA VOLCANIC ZONE NATURAL PARK 20 YEARS AFTER THE APPROVAL OF ITS GEOCONSERVATION STRATEGY

Evaluation of the conservation of the geological heritage of volcanic fields: The case of la garrotxa volcanic zone natural park 20 years after the approval of its geoconservation strategy

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Key words

Volcanic field, geological heritage, geodiversity, protected natural area, awareness-raising

Abstract

This article evaluates the strategy approved in 2000 for managing the geological heritage of La Garrotxa Volcanic Zone Natural Park (PNZVG). The conservation of geodiversity and geological heritage provides a foundation for the conservation of other types of heritage, for example, in the fields of forestry, agriculture, industry and urban development. The human imprint on this natural park is patent, and most of the land it contains is privately owned and is commercially productive. Consequently, the management of its volcanic strata is a highly complex affair as preservation must be compatible with the types of land use that dominate in this protected area. The PNZVG's strategy for managing its geological heritage stems from the need to promote the efficient conservation of its values based on knowledge and greater awareness of this volcanic field. Quaternary volcanic fields such as this one – which may have experienced volcanic activity in the Holocene – are characterised by their excellent state of conservation, which ensures that their volcanic morphologies and the geological processes that have created them are fully visible. In 2000, the Natural Park became one of the first protected areas

in the world to put into practice a strategy for preserving the geological heritage of its volcanoes. Twenty years later, an accurate evaluation of this process will help other volcanic zones design their own strategies for preserving their geological heritage. To sum up, both challenges and objectives are necessary for ensuring good management of a protected area such as this.

Introduction

Currently, it is widely accepted that geoconservation benefits our human societies as it provides understanding that helps grasp the history of our planet (Gray 2019); in addition, geoconservation is also valuable as a tool guaranteeing many important ecosystemic services linked to our planet's geology that, for instance, afford support (soils, cliffs and caves), supply (minerals, energy and water), regulation (climate and flood control) and cultural advancement (scientific knowledge and geotourism) (Gray et al. 2013). The geoconservation of a site or area requires a thorough knowledge of its geodiversity, as well as awareness of how geological heritage can be conserved using the principles of sustainable management (Gordon 2018). Implicit in the protection of the most valuable elements of geodiversity is the task of safeguarding our geological heritage, the main motivation for which is scientific, although educational, cultural, aesthetical, spiritual and ecological components are also highly relevant (Gray et al. 2013; Crofts and Gordon 2014; Gordon 2018). The success in conserving the geodiversity of an area will depend on how well its natural geological heritage can be preserved (Németh et al. 2017); hence, the selection of geozones and geosites, and how they are to be managed and monitored, are pivotal aspects of geoconservation strategies at all levels (Carcavilla et al. 2008; Gordon 2019).

The study and the appreciation of the geodiversity of an area are crucial steps when attempting to identify and protect the geological values that best represent its geological heritage. First, it is essential to evaluate the geodiversity by selecting a series of criteria that will depend on factors such as the types of landscape present in the study area, their extent, the importance of the various different geological features to be preserved, and the availability of spatial data at an appropriate scale (Brocx and Semeniuk 2007). Once this evaluation has been performed, the next task is to identify the elements that best reflect the geological value of an area and most contribute to the understanding of its geological history. Finally, it is also necessary to decide what type of management and conservation policies – i.e. based on geotourism, geoconservation and/or geoeducation – are of greatest importance (Németh et al. 2017).

Habitually, both the management plans in protected areas as well as the people in charge of management on the ground take into account the importance of conserving a region's biodiversity. This aspect of conservation has for many years been regulated by international agreements such as the Convention on Biological Diversity (1992) and is generally accepted to be the *raison d'être* behind many protected natural areas. However, this focus on biodiversity tends to underestimate the significance of our geological heritage and geodiversity. It is important to remember that the rocks, sediments, soils, and geological processes and their evolution are all vital components of the future of our planet and our societies. (Gray 2011) has synthesized the key concepts in conservation, which include intrinsic, cultural, aesthetical, economic and functional values, as well as its importance for research and education. Today, the awareness of geoconservation has grown and now goes beyond purely educational and aesthetic considerations to embrace the role of geodiversity and geological heritage as providers of ecosystemic services (Gray 2019). Many protected areas created to conserve biodiversity or natural heritage also harbour elements of great geological significance; good examples include Yellowstone National Park in the United States, one of the first of its kind, and El Teide, one of the first protected areas declared in Spain (Fig. 18).

Today, there are many good examples of where the planet's geodiversity has been well preserved and of how this protection is based on the specific characteristics of an area, the geological values that require protection, and existing political and administrative requirements (Prosser 2013; Brilha 2016; Brilha et al. 2018). The efforts aimed at preserving these geological values led to the declaration of the UNESCO geoparks, the natural and national parks that protect geological landscapes, and the many other geosites and protected natural monuments throughout the world. The protection and preservation of geological sites of interest does not imply that they should be closed off to the general public. Provided that their conservation is safeguarded, protected geological sites must be made visitable and good-quality information regarding their significance in both general and local contexts must be made available. Thus, the protection of our geological heritage implies the search for the best possible management and conservation protocols, which will permit access to and the identification and study of all the key observation sites that reflect the history of a particular protected area (Planagumà and Martí 2018).

Figure 18. – Path at Roques de Garcia in El Teide National Park, one of the most walked paths anywhere in the world. In 2019, 4,330,994 tourists visited this Park.

The UNESCO geopark programme was set up in 1999 and contemplates geoconservation at different territorial levels: regional (< 10,000 km^2), large-scale (< 100 km^2) and local (<1 km^2) (Brocx and Semeniuk 2007). A central tenet of this programme is that each territorial scale should define the objectives, actions, indicators and types of assessment that will form part of its particular geoconservation strategies (Gordon 2019). The past 20 years are time enough to analyse and evaluate the conservation of the geological heritage at territorial scale; this period is also long enough for natural processes such as erosion to have visibly affected parts of our geological heritage (Palacio-Prieto et al. 2016) or for the impact of human-provoked changes such as building and infrastructure projects (Salamanca et al. 2014), the hyperfrequentation of tourist areas (Dowling and Newsome 2018), mining and wars (Kiernan 2012) to become apparent. Hence, it is important to evaluate and analyse the indicators and the state of our geological heritage in relation to the first conservation initiatives taken in this field; this is the case of the PNVZG, declared in 1982, and its geoconservation strategy implemented from 2000 onwards.

Volcanic zones exhibit complex but fascinating stratigraphic relationships (Cas, R., Wright 1988) and often possess geological heritages of untold value. Proof of this are the large number of protected volcanic zones that exist (Németh et al. 2017), whose conservation is essential given their soils that favour biodiversity, the beauty of their landscapes, and their intangible cultural and spiritual values. For instance, 80 of the sites that have been declared world heritage sites are of volcanic origin (Casadevall et al. 2019). One type of volcanic zone that has been protected in many different ways are the volcanic fields, since they generally boast rich soils, easily accessible sites of geological interest, and aesthetically pleasing landscapes (Németh et al. 2017; Casadevall et al. 2019). A good example is the European Rift, which contains nine volcanic fields with some type of protection (fig 19)(Planagumà and Martí 2020). In recent years, volcanic zones have begun to attract ever more geotourists in search of active and dormant volcanic landscapes, good food, adventure and pleasurable experiences. Consequently, just as occurs in the fields of biodiversity and threatened-species conservation, the preservation of local geological heritage can generate positive social and economic values in the site in question (Planagumà and Martí 2018).

In this article we examine the results of the indicators that assess the strategy that was designed 20 years ago by the PNZVG to manage its geological heritage. Currently, after 20 years of implementation, no framework exists for analysing whether or not its geoconservation aims and policies have worked as planned, or how they could be improved. Two decades later, the impact of erosive processes, vegetation growth and educational programmes, for example, can be analysed, and the results used to improve geoconservation and, above all, provide tools for conserving geological values in other volcanic areas.

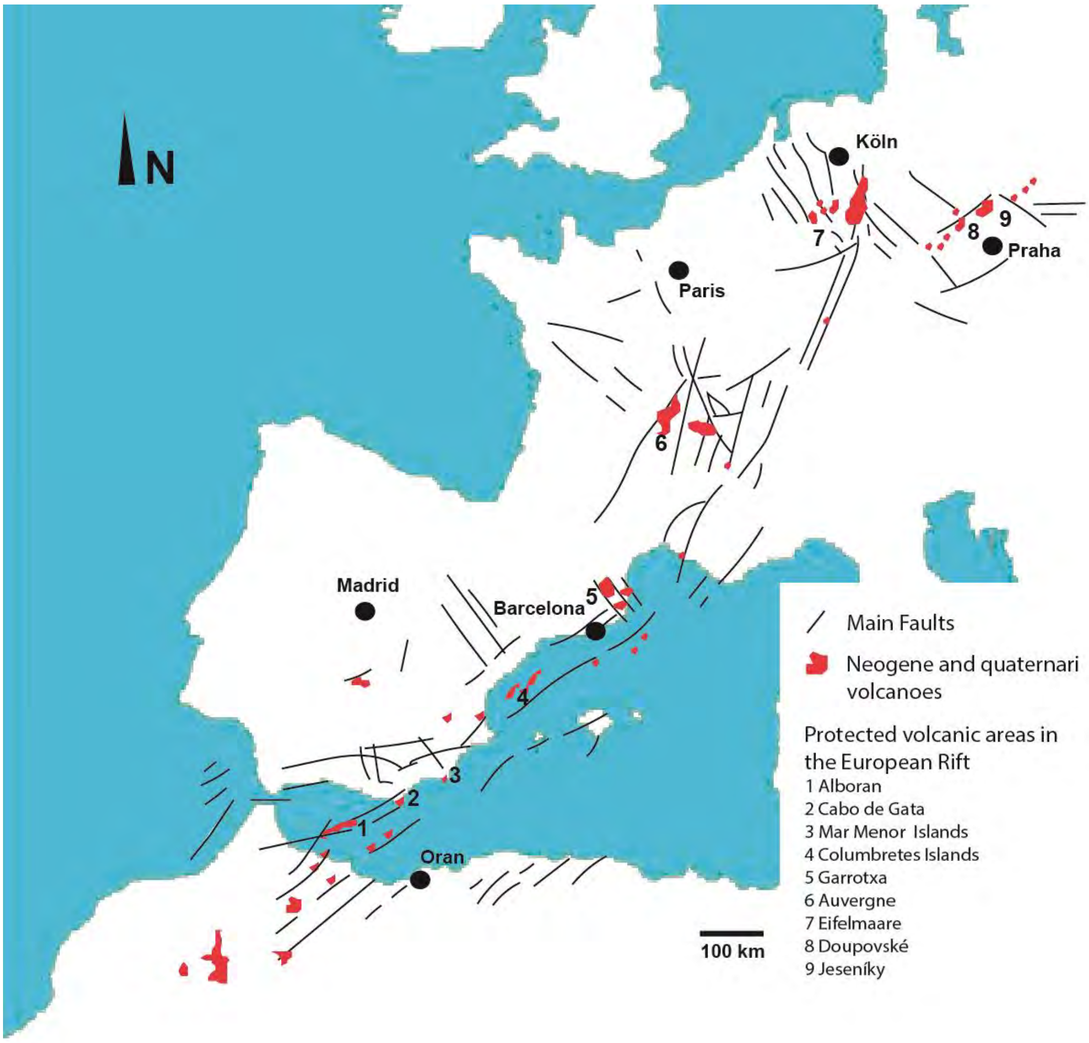

Figure 19. The European Rift with its associated volcanic areas, and the nine zones that enjoy some degree of protection according to the International Union for Nature Conservation.

Situation

La Garrotxa Volcanic Zone lies in the north-east of the Iberian Peninsula and is part of the Neogene-Quaternary Catalan volcanic province of the European Rift (fig 19) that extends from the Alborán Sea into central Europe (Martí et al. 1992). This rift originated during the Neogene distension that began 20 Ma as the alpine orogeny affecting southern Europe slowed. The associated volcanic activity is alkaline in nature and has given rise to a number of different volcanic zones (fig 19). La Garrotxa Volcanic Zone, covering around 600 km^2 and lying between the cities of Olot and Girona, is one of the youngest. It harbours around 50 volcanic cones, lava flows, tuff rings and maars dating from the Middle Pleistocene (0.12–0.78 Ma) and beginning of the Holocene (0.01 Ma) (fig 20). Its volcanic features lie atop Eocene sedimentary formations folded during the alpine orogeny, and Quaternary alluvial deposits. The magma that originated this field is both basaltic and basanitic (a mixture of basanites with nepheline crystals and basalts with olivine crystals) (Cebría et al. 2000). In many cases, the magma ascended directly from the mantle and was not differentiated or contaminated by materials from the crust.

Most of the volcanic activity in this field was strombolian and gave rise to cinder cones formed by fall deposits (lapilli and blocks). Many of these monogentic cones (e.g. Rocanegra, Montolivet, Sant Marc and L'Estany volcanoes) are characterised by horseshoe-shaped craters. Nevertheless, if the magma came into contact with the aquifer, the resulting eruptions were more complex and freatomagmatic phases occurred that produced gas explosions and emitted fragments of the substrate (lithics) as pyroclastic flows and breccia. (Martí et al. 2011). Combined with the strombolian fall deposits, these other types of deposits created a complex variety of eruptive sequences that in some cases include maars and tuff rings (e.g. Santa Margarida, La Garrinada, El Racó and Can Tià volcanoes) (Martí et al. 2017).

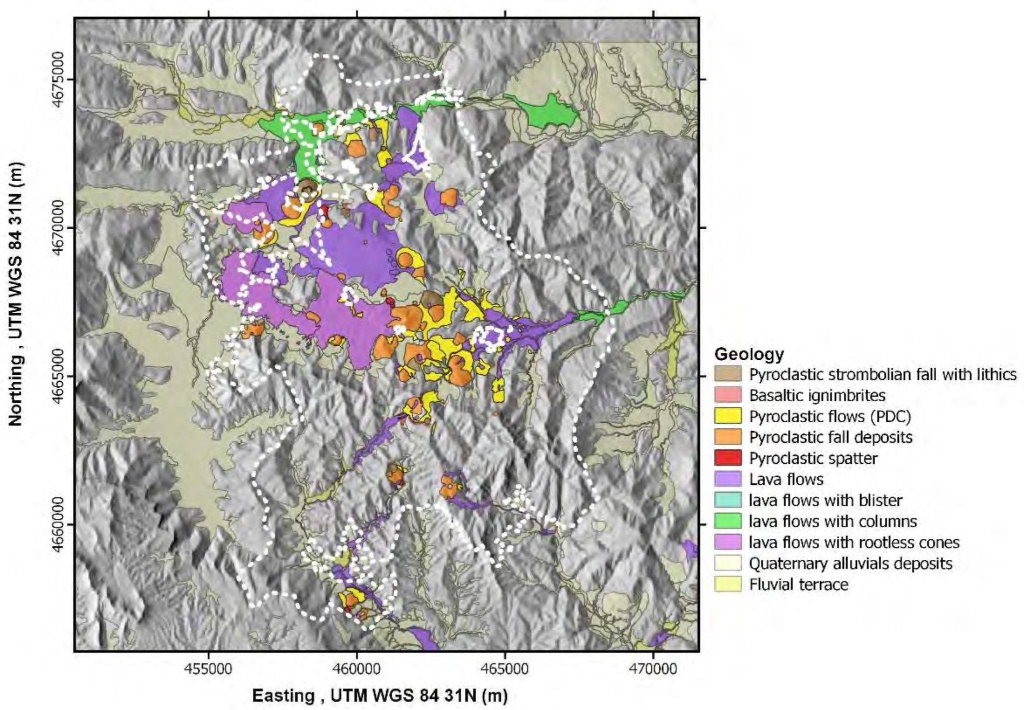

Figure 20. Map of the geodiversity in and around La Garrotxa Volcanic Zone Natural Park.

The excellent state of conservation of these volcanic cones, the rich soils of their associated fields and the biodiversity they generate were the main factors prompting the declaration of the PNZVG in 1982, the first natural park (IUCN category V) to be established in Catalonia since Spain's return to democracy. The management of protected areas in the Spanish state was handed over to the autonomous communities, the only exception being the national parks that are run jointly by regional and state authorities. In Catalonia, the planning mechanism that oversees its network of protected areas is the 1992 Areas of Natural Interest Plan (PEIN). Most of these areas were incorporated in 1997 into the European Natura 2000 network, the legal framework that guarantees the conservation of much of Europe's natural heritage.

The PNZVG covers 15,000 ha and lies in the centre of the county of La Garrotxa in northern Catalonia. It contains 40 monogenetic volcanic cones, of which 28 are protected as natural reserves (IUCN category IV), and it is regarded as the best preserved volcanic field in the Iberian Peninsula. The human influence is notable in this natural park since within its boundaries live 33,000 people. In all, 98% of its land area is private property owned by many different landowners, a fact that complicates enormously the running of this park (fig 21).

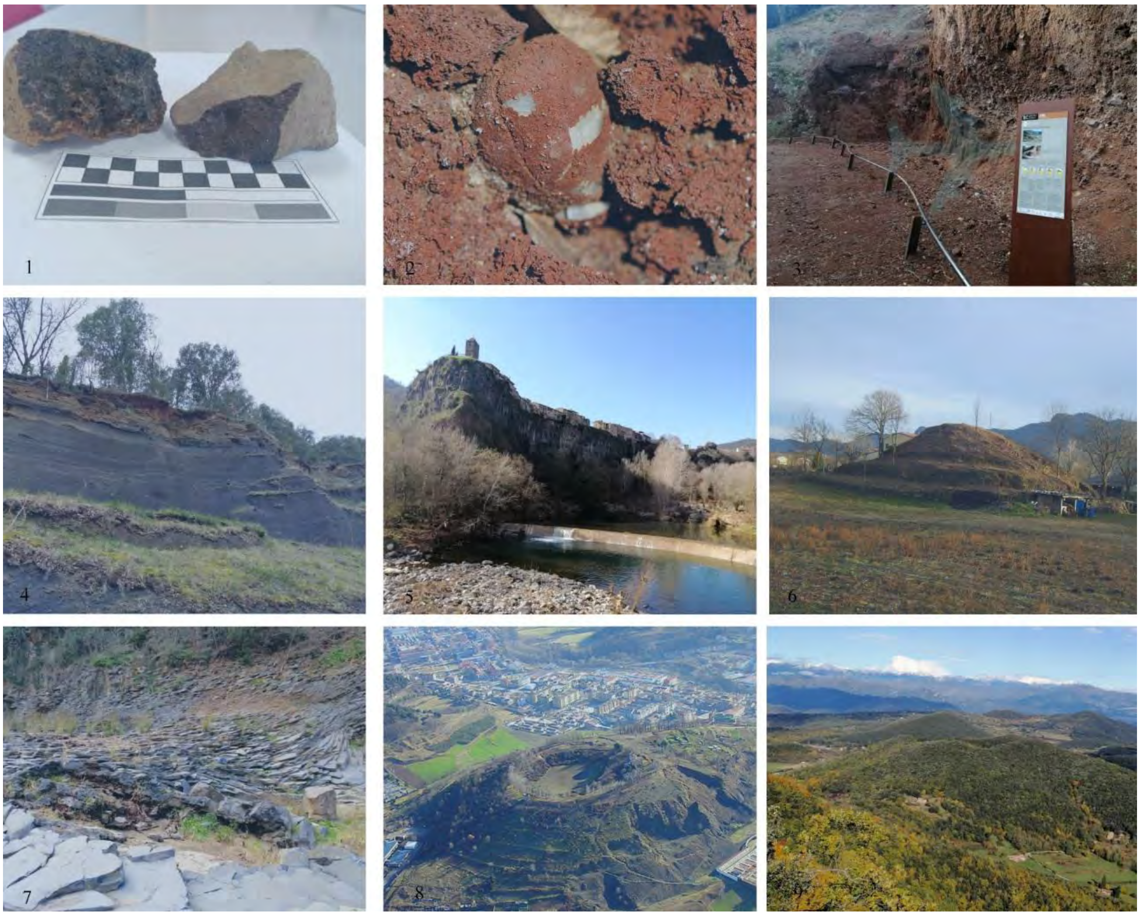

Figure 21. Elements of the geological heritage of La Garrotxa volcanic field. 1- Example of pyroxenite from the earth's mantle; 2- Sanidine; 3 – Former quarry in the Sant Marc volcano; 4 – Strombolian and phreatomagmatic fall deposits in the former quarry in the Croscat volcano; 5 – Cliff at Castellfollit de la Roca composed of two lava flows; 6 – Rootless volcanic cone (tossol) on the Bosc de Tosca lava flow; 7 – Blister at El Molí Fondo; 8 – Cinder cone and circular crater of the Montsacopa volcano; 9 – Craters of the Santa Margarida and Croscat volcanoes.

The urban and industrial growth in Spain and in Catalonia that took place in the 1960s and 1970s provoked a series of impacts that seriously threatened the country's natural – and, by extension, geomorphological – values (Zorrilla and Vila 2010). The most obvious case was the quarrying of lapilli from Croscat volcano, to which we can add the threat of mining for radioactive minerals, the continued pollution of the river Fluvià and its tributaries by sewage, the proliferation of fly-tipping including the tip at Fontfreda (Sant Joan les Fonts) underneath a basaltic cliff of exceptional patrimonial value, the building of residential areas and associated service infrastructure on the very volcanoes, and the growing urban and industrial sprawl of the area as a whole (Zorrilla and Vila 2010). These abuses led to the organisation of a series of protest campaigns, which culminated in 1976 with the creation of the highly active Commission for the Protection of the Volcanic Zone and, subsequently, a year later, the setting up of Campaign for the Protection the

Natural Heritage of the Catalan Countries organised by the Congress of Catalan Culture. Finally, on 3 March 1982, the Catalan Parliament approved Law 2/1982 on the Protection of La Garrotxa Volcanic Zone, which declared this volcanic zone a Natural Site of National Interest with the avowed aim of conserving its highly singular flora, geomorphological character and outstanding beauty (Bassols Isamat 2008). This law also established a series of integral reserves of geobotanical interest that would counteract any future action liable to destroy, deteriorate, transform or disfigure the area's geomorphology and flora.

Initially, the management of the PNZVG's geological heritage focused on the conservation of the geomorphology of its volcanic cones, the restoration of the quarry in Croscat, and the mitigation of the degradation of certain hyperfrequented cones and craters (e.g. Santa Margarida and Montsacopa). In 2000, a management strategy for the park's geological heritage was mapped out to analyse the state of knowledge, conservation and awareness of the volcanoes, and to institute future strategic objectives and lines of work. This new strategy was incorporated into the Parks' Special Plan, approved in 2010, that is today the mainstay of its territorial and resource-use planning.

The strategy for managing the geological heritage

The geological heritage of the PNZVG contains many points of interest, ranging from volcanic elements just a few centimetres in size (the enclaves of rocks from the Rocanegra volcano and the sanidine crystals of the Pomareda volcano), through outcrops that illustrate unique geological sequences and processes, to geomorphological features such as rootless volcanic cones, lava flows, craters, cinder cones, and large extensions of terrain that help us interpret complex eruption clusters such as those of Santa Margarida-Croscat. All these elements are of geological importance at scales that vary from the local and regional to the international (fig 22).

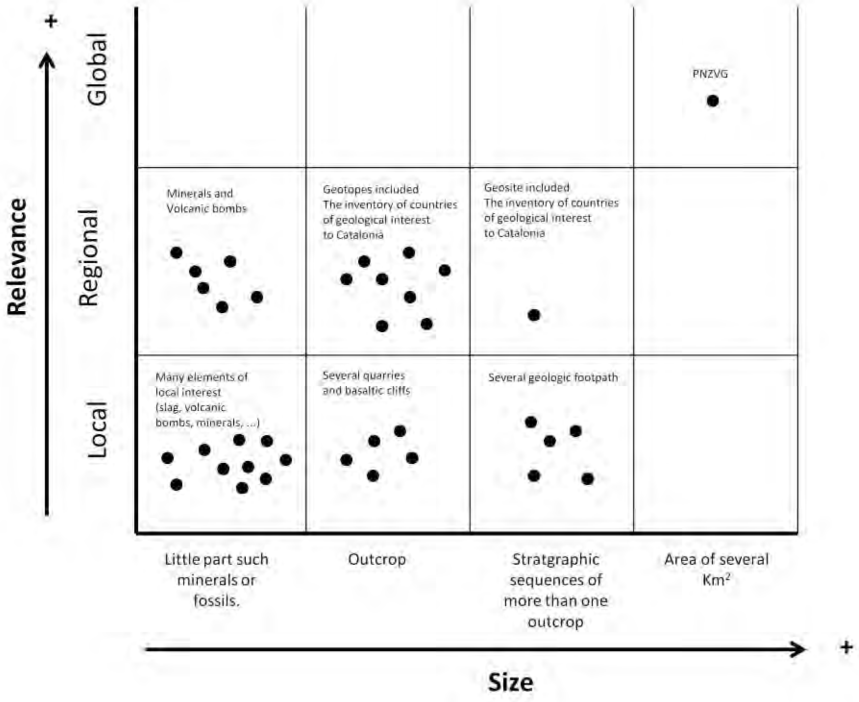

Figure 22. Relationship between the local, regional and international relevance and the size of the site of geological heritage. In the study zone, no single outcrop, either volcanic or mineral, is of international importance. The international relevance of the area is due to the diversity of eruptive sequencies and their relationship with the region's natural, cultural and intangible heritage (Martí and Planagumà 2017). Adapted with permission from an original idea by Enrique Díaz-Martínez and Luis Carcavilla.

In 2000, 18 years after the declaration of the natural park, the overriding idea was that the geomorphology of the volcanic cones was no longer under threat given that the quarrying had ceased, and a number of restoration projects fostering the conservation of the area's geological heritage were underway. Nonetheless, it was also clear that in many cases the management of land use in the park had not been completely successful in highlighting the morphology of the cones and craters and, as a consequence of the fly-tipping, landslips and vegetation encroachment, the visiting conditions of many of the park's most significant outcrops and their overall visibility had been negatively affected. Fortunately, these processes are generally reversible and can be remedied if appropriate measures are taken.

The Park's conservation strategy comprises three general objectives: (i) improve knowledge of vulcanism in the PNZVG; (ii) conserve the geological and scenic values of the vulcanism in the PNZVG; (iii) educate the local population to appreciate the importance of conserving their geological heritage. In addition, there are a series of more specific objectives that depend on these three general aims (table 1). This strategy also proposes ways of evaluating the park's work via a series of quantitative indicators that include the number of scientific articles in which the monitoring of ephemeral outcrops is mentioned and the number of places of geological interest that have been conserved and restored; likewise, it is important to evaluate certain qualitative indicators that analyse participation by local groups and citizens and the Park's educational programmes and the impact they have had.

Table 7. List of objectives stated in the Park's geoconservation strategy and their degree of fulfilment.

	Objectives	**Fulfilment** (yes / no / partially)
	Improve knowledge of the geological heritage of La Garrotxa Volcanic Zone Natural Park	
1	Create a database of geological heritage sites that can be integrated into the Park's GIS.	Partially
2	Characterise the eruptive behaviour of the 12 most singular volcanoes in the area.	Partially
3	Promote collaboration with universities and other research centres.	Partially
4	Propose ways of integrating studies of volcanic and seismic risk into territorial planning.	No
5	Define research priorities in the fields of petrology, geochemistry, palaeoclimatology and tectonic-structural studies.	Yes
6	Create 1:25,000 geological maps.	Yes
7	Plan and monitor the incorporation of new data obtained from the study of ephemeral sites and bore-holes.	Yes
	Conserve the geological and scenic values of volcanic landscapes	
8	Restore and conserve the meadows and crops sown in craters and around the base of cones to facilitate the observation and geomorphological study of the volcanoes.	Partially
9	Restore and conserve well-preserved outcrops, create a network of points of geological interest and aim for quality viewing experiences.	Yes
10	Integrate the areas and outcrops of interest into municipal planning.	Yes
11	Programme on an annual basis the activities and measures required to conserve the volcanic heritage.	Yes
12	Draw up catalogues and 1:5,000 maps of the most interesting volcanic features.	Partially
13	Review every five years the Park's volcanic heritage and protect those elements of greatest interest.	No
	Educate the local population in the importance of the conservation and protection of the Park's geological heritage.	
14	Review and update if necessary existing educational recourses.	Yes
15	Design activities and create resources (publications and infrastructure) that can be used to promote the importance of the volcanoes.	Yes
16	Design and place informative signage for the network of points of geological interest.	Yes

Evaluation

A series of indicators aimed at measuring how the strategy's objectives have been implemented were designed. These indicators determine whether or not the objectives have been fulfilled and, additionally, provide quantitative data that can be analysed and used in future work aimed at improving geoconservation in the PNZVG.

In this article we highlight five indicators that illustrate the state of the geoconservation in this volcanic zone and directly quantify certain relevant aspects; moreover, these indicators also shed light on improvements in the environmental services that geology provides our societies.

i) Information of interest derived from the monitoring of ephemeral outcrops (ecosystemic cultural services). Dynamic economic activity implies the need to dig into the subsoil to carry out work on buildings and infrastructures (Fig. 23). In volcanic fields, these ephemeral sites, which are otherwise often completely covered by vegetation, are of great interest given the opportunities they provide for improving knowledge of local vulcanism. These outcrops vary greatly in terms of the type of deposits they reveal (Martí et al. 2011), some of which are fairly limited in size.

Figure 23. Photographs of ephemeral geological elements and outcrops exposed by building work, bore-holes or the construction of large infrastructures. 1 – Pyroclastic flow deposits in a building site in Olot; 2 – Cinder cone deposits in the centre of Olot that enabled us to map a new volcano; 3– Work on a new car park that enabled us to characterise new lava flows; 4 – Lava flow and deposits that filled a lava tunnel exposed during work on a new water deposit ; 5– Dyke revealed during the construction of a new football pitch; 6 – New lava flows exposed during the building of a dual-carriageway; 7 & 8 – Aragonite and spherical calcite found during the drilling of a bore-hole, both caused by hydrothermal activity occurring after an eruption. Both are now deposited in the Geological Museum of Barcelona; 9 – Lava flows and palaeosol exposed during the construction of a warehouse in an industrial estate.

Thus, since 2004 the PNZVG has promoted the inventory and description of these ephemeral outcrops and, from the onset of this programme up to 2019, a total of 154 points – including sites exposed by geological survey work, the digging of wells and construction projects – have been studied (PNZVG report). The information that has been gathered has broadened our knowledge of the volcanic features of the area and provided invaluable data for scientific articles and maps (table 8), as well improving our understanding of the overall geodiversity of the area and its volcanic deposits.

Table 8. Published scientific articles and the contribution made by the Park's database of ephemeral outcrops to each one.

Year	Article / Publication	New geological contribution
2007	The geological chart of the Volcanic Zone of La Garrotxa Natural Park. (Losantos M et al. 2007)	New lava flows and volcanoes
2009	Changing eruptive styles in basaltic explosive volcanism: Examples from Croscat complex scoria cone, Garrotxa Volcanic Field (NE Iberian Peninsula) (Di Traglia et al. 2009)	New phases of Croscat volcano
2010	Complex interaction between Strombolian and phreatomagmatic eruptions in the Quaternary monogenetic volcanism of the Catalan Volcanic Zone (NE of Spain). (Martí et al. 2011)	More stratigraphic sequences
2014	Volcanic stratigraphy of the Quaternary La Garrotxa Volcanic Field (north-east Iberian Peninsula). (Bolós et al. 2014)	The relative age of the stratigraphy
2015	Volcano-structural analysis of La Garrotxa Volcanic Field (NE Iberia): Implications for the plumbing system. ((Bolós et al. 2015))	New fissure eruptions
2017	Basaltic ignimbrites in monogenetic volcanism: the example of La Garrotxa volcanic field. (Martí et al. 2017)	New pyroclastic flows

ii) Production and updating of geological maps. The strategy has also promoted the taking of geological inventories and geological mapping. Volcanic and other types of cartographic work reveal how a volcanic zone or a volcano has evolved and so further understanding of local vulcanology (Branca et al. 2011).

Over the past 20 years, some of the most important maps of this volcanic area that have been drawn are those that illustrate its volcanism (Losantos et al. 2000; Bolós et al. 2014; Pedrazzi et al. 2014), tectonics (Bolós et al. 2015), eruption risk (Bartolini et al. 2015), and its rootless volcanic cones (Fig. 24). Nevertheless, few have been published anywhere other than in scientific journals and so the information they contain has largely remained within the realm of scientific study.

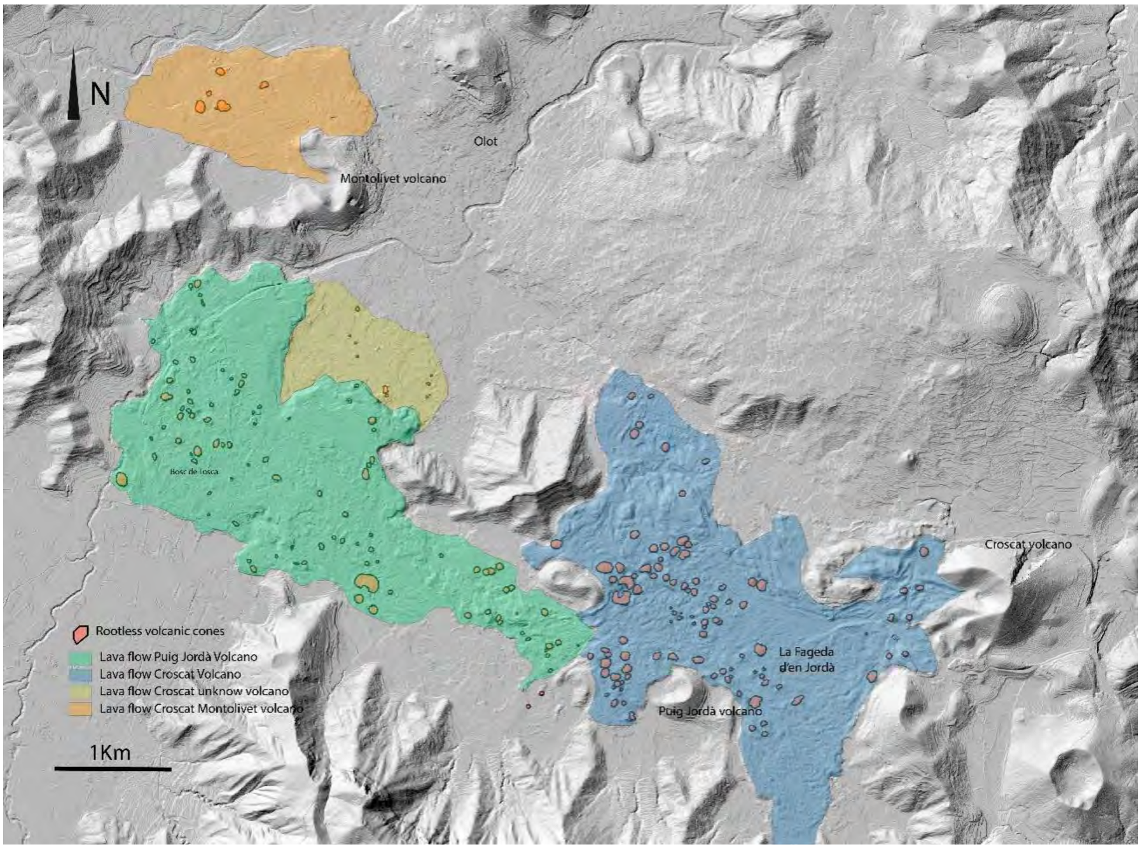

Figure 24. – Map of the distribution of the rootless volcanic cones on the lava flows in the La Garrotxa Volcanic Zone Natural Park. This map was made possible by the participation of local people.

iii) Characterisation of the volcanoes in the PNZVG. Knowledge of the volcanoes is essential if they are to be conserved and promoted as a resource for sustainable tourism (Planagumà and Martí 2018). The Park's strategy centres on the study of the most visited volcanoes and the most significant cones in the volcanic field as a whole. In all, six articles have been published focussing on the characterisation of the volcanoes in general, and improving our understanding in particular of Croscat, Santa Margarida, Rocanegra, La Pomareda, La Garrinada and El Montsacopa volcanoes. The sites studied are the natural reserves in this volcanic field that receive most visits (355,000 visitors annually[1]). According to oral visitor surveys conducted by the Park, at least 315,000 people (local people and visitors) visit one or other of the Park's volcanoes every year, of which 125,000 head for the Croscat lava flow (Fageda d'en Jordà), 50,000 the former quarry in Croscat, 65,000 the crater of Santa Margarida and 75,000 El Montsacopa.

[1] *Economic and social impact of protected natural areas.* Institut Cerdà. Departament de Territori i Sostenibilitat de la Generalitat de Catalunya (2015).

iv) Conservation of outcrops of geological interest. The main factors that influence the vulnerability of the outcrops of geological interest in the PNZVG are the erosion caused by visitors walking along paths and on poorly consolidated pyroclastic deposits (Fig. 25), and natural erosion provoked by rain. These types of impacts in the much visited former quarry in Croscat can damage up to 50 cm of an outcrop annually and affect 450 m^3 of deposits in a year of high rainfall (Geyer et al. 2015). Of the sites included in the PNZVG's inventory of outcrops of geological interest, the number that are actively managed has risen from two to seven over the past 20 years, of which six are now managed in conjunction with other local entities.

Figure 25. Example of the erosion caused by visitors to the outcrops in the former quarry in Croscat volcano. 1 and 2 are holes that have been dug by hands; the arrows indicate where the wall has collapsed after the continual scratching at the surface of the lapilli by visitors.

v) Interpretation material. Over the past 20 years a series of resources aimed at interpreting the volcanoes have been produced for a variety of different publics. One of the indicators used is how these resources evolve in the wake of fresh scientific knowledge. They are constantly being updated and this indicator measures how they are maintained and revised, since one of the biggest problems that the visitor centres and the Park's publications have is ensuring that the material it offers visitors is kept fully up-to-date (table 9).

Table 9. Educational material relating to the Park's geological heritage, how often it is revised, and whether or not it has incorporated new data on the Park's geological heritage.

	Maintenance and revision	**Has it incorporated new scientific material?**
Exhibition in the Croscat Natural Reserve	First – 1995 / second – 2009 / third - 2020	Yes
Guide to the Park's Vulcanism	First edition - 2000	No, second edition
Vulcanological map	First edition 1986 / Second edition 2007	Yes
Park brochures	Renewed every 3–4 years	Yes
Itineraries	Temporary modifications	Yes
Interpretation panels	Modified every 8–10 years to incorporate new data	Yes
Educational programmes	Reviewed every 5–6 years	Yes

vi) Observation of the volcanic features (loss of the agroforestry mosaic). One of the most pressing problems in volcanic fields is the way cones and craters are lost to view due to forest encroachment provoked by the abandoning of traditional agricultural methods. This process can easily be monitored using aerial photographs (Woo and Worboys 2019) and appropriate management work can be taken as a result. In the natural reserve of Santa Margarida volcano (Fig. 26) the crater has become less visible, thereby hindering the correct interpretation of the circular geomorphology of this maar. Since 2000, the surrounding forests have encroached into the agroforestry mosaic on account of the decline in cultivated land in upland areas.

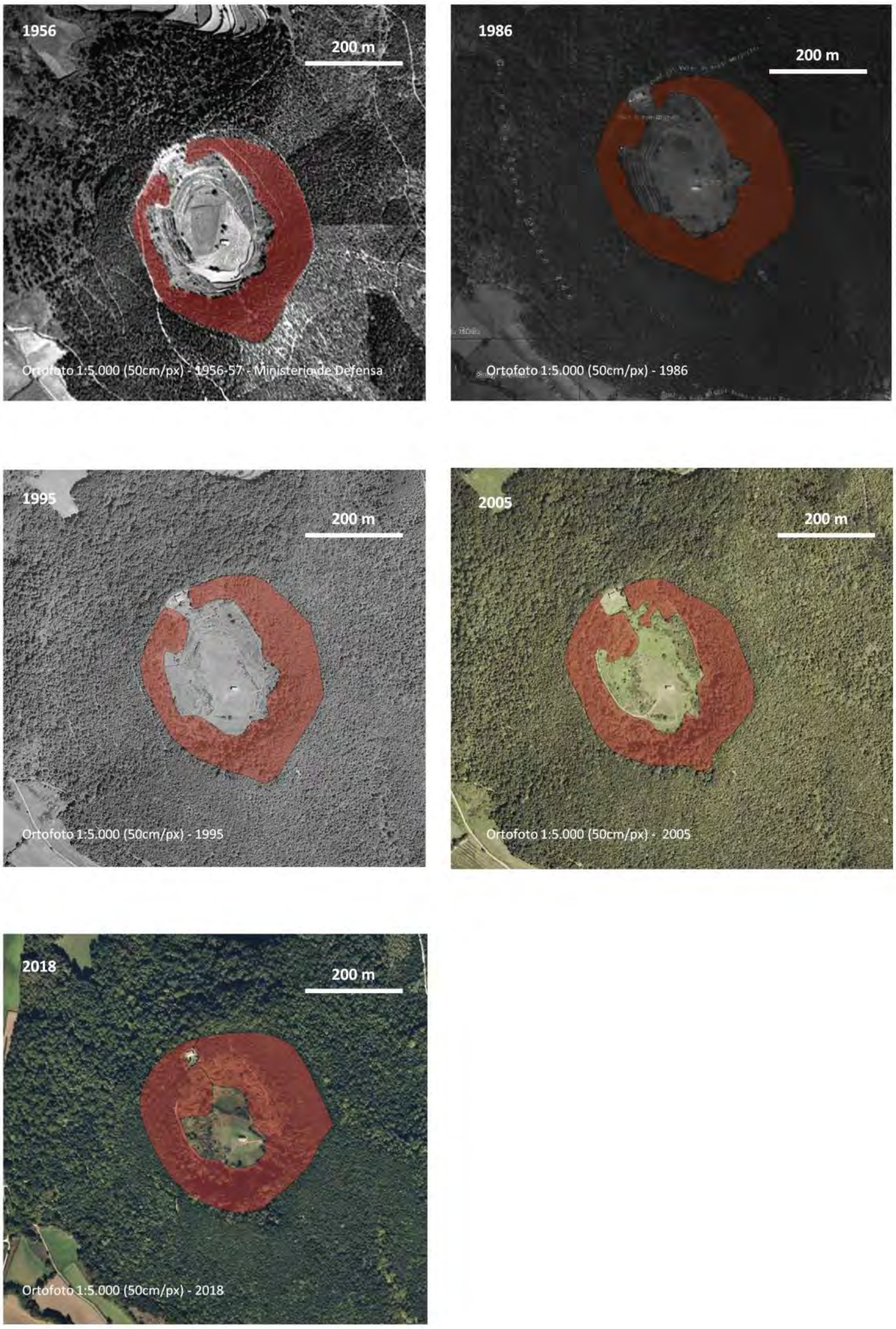

Figure 26. Images showing the evolution of the forest in the crater of Santa Margarida volcano.

vii) Training of local guides and environmental educators

The main resource in any interpretation or education strategy is the guide or educator empowered with the task of inculcating a sentiment for a region's geological heritage in the people who live there or just visit. Thus, it is important to analyse the Park's training programme, which imparts scientifically rigorous knowledge and regularly offers refresher courses to the guides and educators working in the protected area. The PNZVG has to date run 20 annual training courses for guides and educators, as well as over 30 refresher sessions aimed at encouraging awareness of new scientific findings. In all, around 200 guides and educators have been trained, of whom around 100 have found work guiding local people and visitors. Today, on average, these guides have five years' work experience in the Park.

viii) Geodiversity in 2021 compared to 1982

The most singular geological sites in this volcanic field (Planagumà and Martí, 2018) can be contrasting archive images and modern aerial photographs. This exercise reveals how the visibility of the geological processes present in these sites has improved, remained the same, or worsened due to erosion or vegetation encroachment (table 10). In the nine sites of greatest interest, at least one element has worsened in five, at least one has improved in three, and the overall conditions of conservation have remained stable in one. The visibility of other sites classified as outcrops of interest such as the former quarries in Rocanegra and Sant Marc volcanoes have improved over the past 20 years.

Table 10. Comparison between 1982, the year in which La Garrotxa Volcanic Zone Natural Park was declared, and 2021 of the state of the sites of greatest geological interest.

Place		State
Croscat volcano	Quarry	Similar interpretation conditions
Santa Margarida volcano	Crater	Vegetation growth has worsened viewing possibilities
	Quarry	Improved
Castellfollit de la Roca	Cliff	Vegetation growth has worsened viewing possibilities
Boscarró y Molí Fondo	Outcrops	Improved
Montsacopa volcano	Crater	Vegetation growth has worsened viewing possibilities
	Quarry	Improved
Can Tià volcano	Outcrop	Similar interpretation conditions
La Pomareda volcano	Outcrop	Vegetation growth and erosion have worsened viewing observation possibilities
La Fageda	Lava flow	Similar interpretation conditions
Bosc de Tosca	Lava flow	Vegetation growth has worsened viewing possibilities

Discussion

When analysing the indicators proposed as tools for evaluating the Park's geoconservation strategy it becomes clear that both intrinsic and extrinsic factors have to be taken into account. Examples of the former linked to current conservation efforts include the correct visualisation and better knowledge of points of geological interest, the incorporation of new sites as a result of fresh geological research, the development and management of new itineraries for visitors, and the promotion of local groups implicated in geoconservation. The extrinsic issues affecting the Park include large-scale territorial dynamics produced by socio-economic change, public policy leading to important changes in land use, rural-urban drift, and the evolution of urban areas.

Intrinsic factors in management

One of the key findings of the analysis of the indicators is that the Park has been successful in linking scientific advances to the creation and revision of its educational material. Almost all of its educational material incorporates new data and it has shown its willingness to update this material periodically; this has established the PNZVG as a benchmark in the popularisation of geoscience for both the local population and visitors. This is due to the fact that, to disseminate information correctly, the most important assets are not large, expensive-to-run interpretation centres but, rather, policies committed to educating people and producing resources that can be easily brought up-to-date. On the other hand, it is important to recognise that the average number of years of work experience of the guides in the zone – five years – is improvable as the stability of the workforce in the mid- and long-terms is an important component of any set of human and material resources. If this average stands at only five years rather than the 10 years of an experienced guide, efforts still need to be made to establish a more stable workforce with, for instance, an average of 10 years of experience in the Park, to guarantee the quality needed to achieve optimal results (Bonet 2017)

Improvements in the sites of geological interest are a key part of the work to conserve the geological heritage. In this facet of the Park's work the results are uneven. Thanks to its geoconservation strategy, although the active management of elements of geological interest has increased, the conservation and visualisation of the whole of the Park's geodiversity is not as yet assured. One of the most critical actions undertaken is the move towards the co-management of the Park's geological heritage, which ensures that conservation work is less likely to suffer the effects of changes in political policies (Planagumà and Martí 2018).

Extrinsic factors: the territorial model

During the 20 years that the Park's geoconservation strategy has been operating, certain extrinsic factors have inevitably played their part. Despite the active management that has taken place during this period, the geological heritage of this volcanic field has suffered from the changes triggered by the loss of an agricultural mosaic due to the decline in traditional agricultural methods in upland areas. The overarching causes are both the abandoning of the land and the growth in the service industry centred increasingly on satisfying the needs of the tourist sector. Consequently, the vegetation has begun to encroach in some of the craters and on lava flows and, as Table 4 shows, over half of the sites of geological interest in the Park are now suffering from problems of this kind.

Construction work in the area has meant that many deposits of volcanic materials have appeared momentarily. The protocol for gathering information from these ephemeral sites has generated good on-the-ground knowledge of this volcanic field that a number of researchers have been quick to take advantage of.

A final extrinsic factor to take into account is climate change, which could lead to an increase in the rate of erosion of the volcanic deposits due to the increasingly frequent episodes of heavy rain (Sánchez et al. 2004).

Conclusions and future challenges

The management of the geological heritage of volcanic fields is complex and challenging as their cones and fragile deposits, prone to erosion and degradation, are often found in densely populated areas. Yet, they also represent an excellent opportunity for popularising geoscience and increasing awareness of the need for territorial planning. If we incorporate the conservation of our geodiversity and geological heritage into our land management, we will strengthen our territory by adapting it to potential geological risks and local types of production; likewise, we will be able to build our infrastructures to suit the geological context and create greater awareness in the local population about the need to conserve their surroundings (Crofts and Gordon 2014).

For all these reasons, it is important that in these volcanic fields, the geological heritage should be conserved, not only through active management but also via territorial planning that incorporates geodiversity and geological heritage; specifically, we should work to prevent the loss of the traditional agricultural methods that help maintain the landscape mosaic that so favours the aesthetic appreciation of the volcanoes. Finally, a positive step would be to legally oblige all building and infrastructure work to carry out inventories of the geological heritage they uncover, just as occurs regionally in the case of archaeological remains.

The conservation of the geodiversity of La Garrotxa volcanic field also requires the active management of elements of its geological heritage that lie outside the Park, which include the Crosa de Sant Dalmai, Puig d'Adri and Puig de la Banya del Boch volcanoes.

Another pertinent concept is the co-management of the geological heritage, a type of governability that will guarantee its long-term conservation. This idea can be extended to local geoconservation groups beyond the actual municipalities the volcanoes belong to, and will help stabilise the work of guides and educators who play such a significant part in the conservation of this heritage. As part of this co-management, the relationship between scientists, park staff and local population, as well as their decision-making abilities, must be taken into account and formalised.

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9. DISCUSIÓN GENERAL

La gestión del patrimonio geológico de los campos volcánicos monogenéticos es compleja y un gran desafío, ya que sus conos y depósitos piroclásticos son muy frágiles y vulnerables a la erosión y degradación y se encuentran a menudo en áreas densamente pobladas, a lo que hay que añadir el impacto creciente del cambio climático (Németh et al. 2017). Sin embargo, también representan una excelente oportunidad para popularizar las geociencias y aumentar la conciencia sobre la necesidad de una planificación territorial (Henriques y Brilha 2017). Si incorporamos la conservación de la geodiversidad y patrimonio geológico en la gestión urbanística, agrícola, de espacios naturales protegidos…, fortaleceremos nuestro territorio adaptándolo a los potenciales riesgos geológicos, amenazas antrópicas y tipos de producción local (figura 28). Asimismo, podremos construir las infraestructuras para adecuarlas al contexto geológico y paisajístico y crear una mayor conciencia en la población local sobre la necesidad de conservar su entorno y regular mejor las visitas y también el comportamiento y la experiencia de los visitantes.

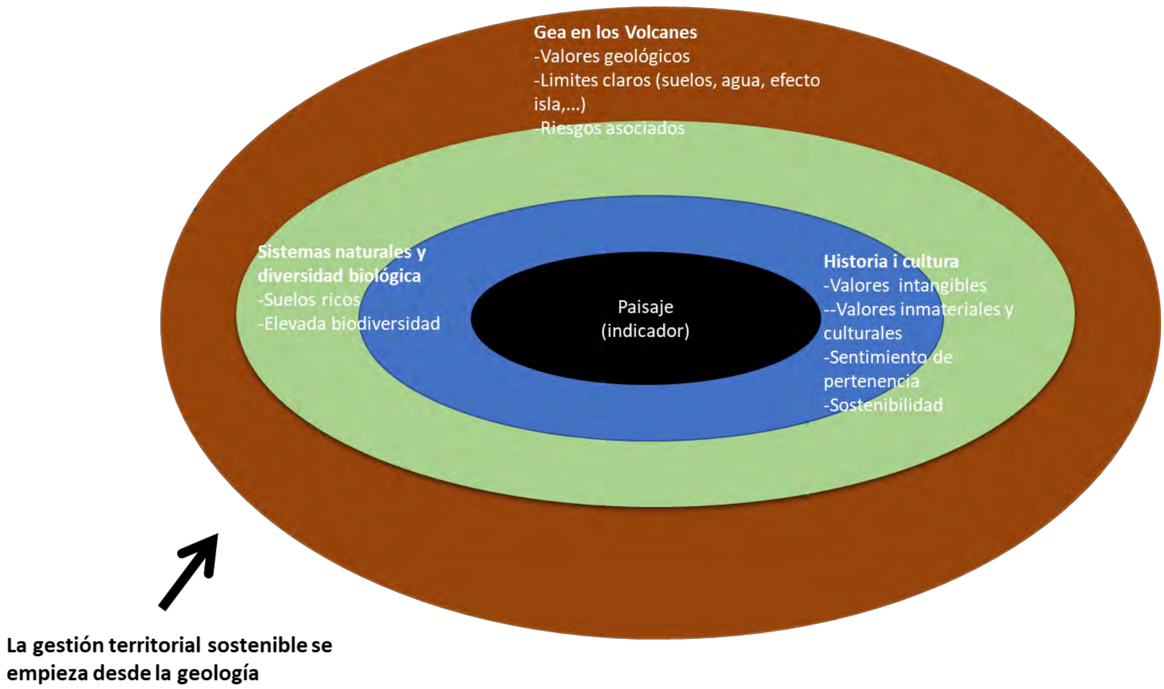

Figura 27. Relación entre la geología, los sistemas naturales y las sociedades en terrenos volcánicos.

Si desgranamos la figura 27 podemos considerar los territorios volcánicos como islas, aunque estén situados en lugares continentales. Esto se debe a las diferencias geológicas significativas que hay entre un terreno volcánico y otro que no es volcánico. En el caso de la ZVG, por ejemplo, se encuentran unos valores geológicos con interés regional e internacional, pero también unos acuíferos fluvio-volcánicos muy permeables que producen surgencias de agua espectaculares y, a la vez, son el sustento de una población de 50.000 habitantes. Sin los volcanes difícilmente se habría desarrollado una industria ya en el siglo XVIII. Estos volcanes también generan suelos fértiles tipo andosoles y relativamente llanos en una zona de montaña que han podido ser bien aprovechados históricamente. Todos estos condicionantes han influido en una biodiversidad de las más elevadas de Europa. En esta región se encuentra una gran diversidad de hábitats y flora, llegando a inventariarse hasta unos 1.400 taxones (Oliver 2016). Este substrato geológico diferente al del entorno y con particularidades bióticas ha generado una cultura y sociedad dinámica y muy arraigada al territorio (Peppoloni y Capua 2012). La zona por sus características geológicas, fue de las primeras en desarrollar una industria a pesar de su aislamiento, y sus suelos y aguas generan paisajes de gran belleza pintados y apreciados históricamente (Tresserras y Duran 2017). Como indicador de gestión y conservación, que al final es la suma de todos los factores geológicos, bióticos y socioeconómicos, está el paisaje (Nogué y Sala 2017): a partir de él podemos determinar si en el territorio se está desarrollando una gestión territorial sostenible.

9.1. Mejora económica y social al conservar los valores naturales de los volcanes y así ofrecer un servicio ecosistémico cultural

La Zona Volcánica de La Garrotxa demuestra claramente que utilizar la geoconservación como herramienta para una economía sostenible es una buena estrategia a seguir. Si se gestiona bien el patrimonio geológico, aporta ventajas económicas y sociales en la zona, no solo en turismo, sino también en la imagen global del territorio. Esta buena imagen que exporta el territorio se puede ver en esta zona en cómo los volcanes son utilizados ampliamente por la población (marcas, asociaciones, etc…). Desde la creación del Parque Natural el impacto social y económico positivo que ha tenido la conservación de los volcanes en la Garrotxa se basa en diferentes factores esenciales. Uno de ellos ha sido el conocimiento científico del área que se puede encuadrar como servicio ecosistémico cultural. Promover y generar investigación científica de alta calidad sobre los volcanes de la Garrotxa ha sido importante para evaluar los mejores lugares para promocionar, conservar y, a la vez, proporcionar información correcta y rigurosa a los visitantes. Por esta razón, la cartografía, guías de campo y bases de datos construidas en un adecuado sistema de información geográfica han sido fundamentales. Otro aspecto destacado ha sido agrupar el sector turístico para desarrollar a través del PNZVG un turismo sostenible a partir de la herramienta que representa la Carta Europea de Turismo Sostenible (Planagumà et al. 2017). Esta carta obliga a debatir entre todos los actores el futuro en relación con el turismo en la zona para que sea sostenible. Por otra parte, administraciones y entes de desarrollo económico centran el foco e impulsan el turismo como actividad económica de efecto multiplicador y con capacidad de generar un impacto económico directo e indirecto. Por ello, sin una coordinación del sector se pueden generar problemas ambientales irreversibles, como ha ocurrido en otros lugares geológicamente interesantes.

9.2. La cogestión de los espacios de interés geológico como herramienta eficiente para la conservación.

La implicación y la cogestión de actores locales como los ayuntamientos y entidades públicas o privadas para gestionar la red de puntos de interés geológico del PNZVG se ha demostrado una herramienta muy útil por dos razones. En primer lugar, para superar de manera puntual los cambios en las políticas ambientales y los recortes presupuestarios de la Generalitat de Catalunya, como sucedió durante la crisis económica del 2010 (Peñuelas et al. 2021), ya que la participación de estos actores significa que ha sido una presión eficaz para mitigar posibles recortes en conservación y para involucrarse en los déficits de gestión. Y, en segundo lugar, para generar una mayor participación y complicidad en la gestión del patrimonio geológico llegando a incorporar vecinos, escuelas, etc.… Aun así, se requiere una mejor cogestión de los valores geológicos para avanzar en la conservación de los volcanes, incorporando más espacios de interés e implicación de la población local para superar cambios políticos locales. Estos pueden llegar a degradar puntos de interés geológico al dejar de invertir recursos y, de los cambios locales, pasar a regionales en Catalunya y crear influencia a escala europea, como se ha visto en el caso de la CETS, en el que el PNZVG fue uno de los impulsores y ahora cuenta con centenares de adhesiones a través de la federación de Europak.

9.3. Programas educativos para mejorar la concienciación de la conservación del paisaje y el conocimiento social de las geociencias.

Durante estos 20 años se ha demostrado que el impacto ha sido positivo al integrar los volcanes como un elemento fundamental de la identidad hecho identitario local, con una amplia aceptación e identificación por parte de la población de la comarca de la Garrotxa. Esto ha sido la clave para poder transmitir la importancia del paisaje de la zona a los visitantes y a la población local, y así generar un espíritu crítico para seguir avanzando en políticas de sostenibilidad y evitar que el desarrollo económico tenga graves impactos ecológicos y sociales. En este sentido, los programas de formación y educación que han sido llevados a cabo durante décadas en la Garrotxa han sido significativos y deben mantenerse en el futuro como garantía para su conservación y gestión sostenible (Catana y Brilha 2020). Estos programas educativos, dirigidos no solo a escolares, sino también a personas adultas y otros segmentos de población, se han mostrado relevantes para difundir las geociencias, que dentro de en un marco de adaptación al cambio climático tendrán especial importancia en un futuro muy próximo.

9.4. Indicadores para la conservación del patrimonio geológico en los volcanes.

En los campos volcánicos se pueden dividir los indicadores para evaluar el estado de conservación en intrínsecos y extrínsecos. Los factores intrínsecos son los referentes a la propia conservación que, desde un organismo público, ayuntamiento o entidad se pueda hacer con recursos propios (Crofts 2018). Serían ejemplos de ello que se puedan visualizar correctamente los puntos de interés geológico, que estos se conozcan mejor, que se incorporen algunos inéditos a partir de nuevas investigaciones geológicas, diseño de los itinerarios y gestión de visitantes, promoción de grupos locales para la geoconservación, etc… Por otro lado, hay que considerar también los valores extrínsecos, como por ejemplo las dinámicas territoriales fruto de la evolución socioeconómica y de las políticas públicas que acaban provocando considerables modificaciones en la forma de cambios de usos del suelo, despoblamiento, cambios urbanísticos, etc.…

Factores intrínsecos a la gestión

a. Relación entre investigación científica y recursos educativos, guías y materiales para los visitantes. La buena comunicación entre los trabajos científicos y los recursos divulgativos que se han creado o renovado des del PNZVG ha generado impactos positivos en la conservación (Peppoloni and di Capua 2016; Catana and Brilha 2020). La capacidad de renovar los recursos elaborados incorporando nuevos datos es básica para la conservación del patrimonio geológico al convertirse un punto de referencia en la comunicación de las geociencias, tanto para la población local como la visitante. Un factor importante en esta estrategia, a diferencia de otros sitios de interés geológico, se debe al hecho de que, para divulgar correctamente, no es imprescindible la creación de grandes equipamientos de interpretación difíciles de mantener, sino una política fundamentada en aprovechar los recursos en formación a guías y actores locales y en renovar recursos fácilmente reeditables.

b. Mantener los puntos y zonas de interés geológico bien conservados. La mejora de lugares de interés geológico es clave en la conservación del patrimonio geológico. En este aspecto, se observan resultados dispares. Disponer de una estrategia ha incrementado la gestión activa de los elementos de más interés geológico, pero aun así no se garantiza la conservación y la visualización de toda la geodiversidad del PNZVG. Esto se debe a la enorme dificultad que conlleva mantener ciertos elementos de interés geológico y no solo en recursos, sino también en disparidad de criterios de conservación respecto al de la biodiversidad, como es el caso del risco basáltico de Castellfollit de la Roca. En el risco basáltico de Castellfollit de la Roca es difícil garantizar su correcta visualización de las dos coladas de lava que lo conforman a causa del mantenimiento y mejora del bosque de ribera.

c. La monitorización del patrimonio geológico en volcanes**.** En zonas donde los materiales geológicos son extremadamente vulnerables a la erosión y a la acción de los visitantes es necesario poder innovar en indicadores para ver la evolución de los afloramientos para poder determinar cuál es la mejor gestión en la conservación (Woo y Worboys 2019).

Factores extrínsecos – modelo territorial –

a. La pérdida de patrimonio geológico a causa del abandono del pequeño campesinado. El patrimonio geológico del campo volcánico de la Garrotxa, a pesar de tener una gestión activa no se ha salvado, en parte, de la dinámica que ha significado la pérdida de mosaico agrícola causado por el abandono de las tierras de cultivo y una progresiva terciarización de una economía comarcal cada vez más focalizada en la actividad turística (Zorrilla y Vila 2010). Esto ha provocado que los cráteres y determinadas lavas se cubriesen de masa forestal, generando la pérdida de la correcta visualización del elemento geológico a conservar.

b. La presión urbanística en el patrimonio geológico. La fuerte presión urbanística en la zona ha provocado que afloren muchos depósitos, aunque sea de manera efímera, y disponer de un plan de recogida de información geológica ha generado un mejor conocimiento del campo volcánico que diferentes científicos han sabido aprovechar. Por eso, bien gestionada toda obra o infraestructura no tiene por qué suponer un impacto severo para el patrimonio geológico, si esta no afecta al paisaje, morfologías o puntos de interés geológico, pudiendo ser incluso, en algunas ocasiones, una oportunidad y una fuente de conocimiento al poner de relieve una parte del patrimonio geológico y la geodiversidad.

c. El cambio climático. El cambio climático puede incrementar la tasa de erosión de los materiales piroclásticos en los conos volcánicos. Un cambio en el régimen de tormentas con más intensidad (Pascual 2006) y más frecuencia de estos periodos puede llevar a una degradación mayor de los puntos de interés geológico, como se pudo comprobar durante la tormenta Gloria en el 2020. Los lugares de interés geológico cerca del río se pueden ver muy afectados, pero también los diferentes afloramientos de piroclastos que por su poca consistencia son muy vulnerables a las grandes tormentas. En estos 25 años se ha podido observar bien la degradación del afloramiento de interés de les grederes del volcán del Croscat (Geyer et al. 2015).

Esto supone nuevos retos en la gestión del patrimonio geológico, como por ejemplo mejorar la monitorización, implementar medidas para evitar la erosión del suelo en la cima del afloramiento, etc.

10. CONCLUSIONES

En la Zona Volcánica de la Garrotxa y en los campos volcánicos muy humanizados es importante que se conserve el patrimonio geológico, no solo a través de una gestión activa sino también a través de una planificación territorial transversal que incorpore la geodiversidad y el patrimonio geológico como soporte del medio biótico y socioeconómico. Son zonas donde se pueden implementar como laboratorio estrategias de resiliencia socioecológica, donde la naturaleza y las sociedades se estudian y gestionan como un todo. Una correcta gestión en estos territorios debe plantear cuestiones fundamentales como la democracia, la salud, la pobreza, la desigualdad, el poder, la justicia, los derechos humanos, la seguridad y la paz que descansan en la capacidad de apoyo y resiliencia de la biosfera, pero también de la geosfera. Según Peñuelas et al. 2021, la biosfera proporciona las condiciones previas para lograr y mantener la dignidad en relaciones humanas. Por lo tanto, el enfoque de resiliencia socioecológica enfatiza que el ser humano y el bienestar descansan fundamentalmente en la capacidad de la biosfera para sostenernos, independientemente de si las personas reconocen esta dependencia. Pero es importante recalcar que la geosfera no forma parte de la biosfera, aunque su límite muchas veces no sea del todo claro al compartir los suelos edafológicos. La geosfera es el soporte vital de la biosfera y, por lo tanto, de las sociedades. Poner en el centro de la gestión del territorio la geodiversidad es prevenir riesgos naturales, alargar la vida de muchos materiales y analizar cómo adaptarse mejor a cambios como el climático o ecológico. Por eso, como afirman (Peñuelas et al. 2021), ya es hora de volver a conectar los enfoques y perspectivas sobre el desarrollo a la base de la biosfera como condición previa para la sostenibilidad de las personas en la Tierra. Por tanto, es necesaria una ciencia de la sostenibilidad basada en la biosfera, pero previamente se debe conectar con la geosfera, al menos en territorios geológicamente tan singulares como la ZVG.

Específicamente, debemos trabajar para evitar la pérdida de los métodos agrícolas tradicionales que ayudan a mantener el mosaico paisajístico que tanto favorece la apreciación estética de los volcanes. Finalmente, un paso positivo sería obligar legalmente a todas las obras de edificación e infraestructura a realizar inventarios del patrimonio geológico que descubren, tal como ocurre a nivel regional en el caso de los restos arqueológicos.

La conservación de la geodiversidad del campo volcánico de la Garrotxa requiere también la gestión activa de elementos de su patrimonio geológico que se encuentran fuera del Parque, entre los que destacan los volcanes Crosa de Sant Dalmai, Puig d'Adri y Puig de la Banya del Boch. Así se integraría todo el campo volcánico de la Garrotxa, ofreciendo coherencia en la gestión de todos los volcanes.

Otro concepto pertinente es la cogestión del patrimonio geológico, un tipo de gobernabilidad que garantizará su conservación a largo plazo. Esta idea se puede extender a los grupos de geoconservación local más allá de la cogestión que ya realizan los ayuntamientos a los que pertenecen los volcanes, y ayudará a estabilizar el trabajo de guías y educadores que juegan un papel tan importante en la conservación de este patrimonio. Como parte de esta cogestión, se debe tener en cuenta y formalizar la relación entre los científicos, el personal del parque y la población local, así como su capacidad de toma de decisiones.

En estos campos volcánicos se demuestra que es mejor priorizar la renovación de materiales y recursos para los visitantes y formar y estabilizar guías interpretes que crear grandes centros de interpretación. Por eso, un reto de esta zona protegida es mejorar la media de 5 años de estabilización de guías y educadores que ahora existe. Si el medio plazo se considera 5 años y el largo plazo 10, la estabilidad tendría que estar más cerca de los 10 que de los 5 para ofrecer la continuidad y la calidad necesarias para conseguir resultados óptimos.

Uno de los aspectos para tener en cuenta en estos volcanes es prevenir el cambio climático, ya que la vulnerabilidad de los depósitos piroclásticos se puede agravar en episodios de lluvias más intensas en el actual contexto de cambio climático. Un correcto seguimiento del grado de erosión y la identificación del grado de resistencia del afloramiento, con el fin de conservar la correcta visualización de los depósitos volcánicos.

Finalmente, se puede afirmar que aplicar políticas de geoconservación es una inversión que genera beneficios sociales y económicos para el territorio donde estas son establecidas. En este caso, se ha podido demostrar que el PNZVG transita hacia un territorio más sostenible y resiliente.

11. LÍNEAS FUTURAS DE INVESTIGACIÓN

Como futuras líneas de investigación se resumen los aspectos que se consideran interesantes para desarrollar trabajos complementarios y derivados de esta tesis doctoral. Estos trabajos y análisis deberían ser analizados próximamente, ya que su alcance escapaba de los previamente planificados y objetivos previstos.

- Analizar el impacto social y económico que tiene la promoción de la investigación científica en los campos volcánicos. A partir de la comparación entre investigación realizada y cómo esta se divulga de diferentes campos volcánicos o zonas de vulcanismo monogenético, se podrían determinar indicadores que analicen si en la población que convive con los volcanes se genera más capacidad crítica y de decisión, mejorando la gobernabilidad local. También podría analizarse si para los visitantes ofrecería una experiencia atractiva que fortalecería el sector turístico. Se podría analizar entre la Zona Volcánica de la Garrotxa, Lanzarote, La Chaine des Puys y vulcanismo reciente de Islandia.

- Comparar la geoconservación de esta zona volcánica con otras para establecer parecidos comunes de cara a poder sistematizar protocoles de conservación del patrimonio geológico en volcanes. Analizar susceptibilidades de los puntos de interés geológico entre Lanzarote, el Paricutin, Islandia y Zona Volcánica de la Garrotxa con contextos socioeconómicos diferentes para determinar indicadores de vulnerabilidad y líneas de conservación comunes y diferentes dependiendo del entorno climático, social y económico.

- Establecer una metodología de seguimiento periódica en los AIG compuestos por piroclastos para analizar el grado de erosión y degradación. Una de las dificultades para la conservación de los depósitos piroclásticos es lo vulnerables que son. Poder establecer una serie de indicadores de seguimiento en afloramioentos como les gederes del Croscat u otros de climas diferentes para poder tomar decisiones de conservación, se podría aplicar a otros campos volcánicos donde abundan los conos volcánicos tipo escoria.

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