



Geoheritage and resilience. Selected studies of volcanic geoheritage areas from different geographical environments and different levels of protection

Viktor Vereb

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**GEOHERITAGE AND RESILIENCE.
SELECTED STUDIES OF
VOLCANIC GEOHERITAGE AREAS
FROM DIFFERENT GEOGRAPHICAL ENVIRONMENTS
AND DIFFERENT LEVELS OF PROTECTION**

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‘és most már azt sem bánom, hogy nincsen semmi úgy, ahogy elképzeltem’

[‘and now I don’t even regret that there is nothing the way I imagined’]

[‘et maintenant je ne regrette même pas qu’il n’y ait rien comme je l’avais imaginé’]

Beck Zoltán (30Y): Ahogy elképzeltem (2014)

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β Abstract in English

Geoheritage is a rapidly emerging domain of geosciences, with the mission to evaluate and ensure effective conservation of the abiotical natural heritage and examining the potential of their broad-scale interpretation and popularization. Using an interdisciplinary approach, geoheritage encompasses not only the full toolkit of geology and geography, but also other domains such as disaster risk reduction and resilience to natural hazards. Geosites can be features exposed to hazards and can be hazards themselves, underlining the importance of dedicated geoconservation. Initiatives are emerging within the sphere of geoparks, but studies with these aspects are still in an early phase.

The thesis examines the geoheritage of three selected sites relating geoheritage to resilience. They are highly different areas, in terms of geographical conditions, the present level of geoconservation and interpretation, their socio-economical context, and consequent potential for development. State-of-the-art geoheritage assessment methods were used with two principal aims. The outcomes of each area function as direct output being shared with local stakeholders to enhance their ongoing or future geoheritage management initiatives. On the other hand, the thesis is an applied study using existing methods, especially the quantitative assessment of geosites. Instead of adding new methods to the plethora of existing ones, this work looks to help towards the standardization with the interpretation of selected, well-established methods.

In the first study area, the Chaîne des Puys – Limagne Fault natural World Heritage site in France, a dedicated inventory of geosites was created for the World Heritage property. A national and an international assessment method were used in parallel, including also the first experimental study in France on visitors' feedback in geosite assessment.

The second study area, the city of Clermont-Ferrand, is adjacent to the first study case, sharing the same geological background, but with a highly different context due to urbanization. The thesis addresses this scenario with a fine-scale geosite inventory of the city, using the French national workflow. Based on the results, a management proposal has been made which could be turned into a geodiversity action plan by the local municipality.

The third study is about Dallol in Ethiopia, connected to the French examples by having a continental rifting scenario, but encompassing a highly distinct socio-economical context for geoheritage management. It is a globally unique ensemble of a (proto)volcano, hydrothermalism and salt karst, however its study is still exploratory, especially in terms of monitoring. The thesis has taken a step in this direction with monthly satellite image monitoring, while carrying out the assessment of the outstanding geoheritage using a comparison of three methods. The two initiatives were synthesized into a preliminary resilient geoheritage management strategy, to be incorporated into local strategies to address the constantly increasing tourist pressure in this area of high risk.

The dissertation is put into context with an introduction, briefly summarizing the most important concepts of geoheritage and disaster risk reduction, and introducing the concept on geoheritage and resilience. Finally, a synthesis is given based on the outcomes of the three case studies, highlighting site-specific geoheritage management, the usage of comparative quantitative assessments, the need for the standardization of methods, and the importance of interdisciplinary approaches such as combining risk management and geoheritage.

γ Résumé en français

Le géopatrimoine est un domaine des géosciences en plein essor, qui a pour mission d'évaluer et d'assurer la conservation efficace du patrimoine naturel abiotique et d'examiner le potentiel de son interprétation et de sa vulgarisation à grande échelle. Grâce à une approche interdisciplinaire, le géopatrimoine englobe non seulement l'ensemble des outils de la géologie et de la géographie, mais aussi d'autres domaines tels que la réduction des risques et la résilience aux risques naturels. Les géosites peuvent être des éléments exposés aux risques et peuvent être eux-mêmes des risques, ce qui souligne l'importance d'une géoconservation spécifique. Quelques initiatives émergent dans les géoparcs, mais les études sur ces aspects sont encore à leurs débuts.

La thèse examine le géopatrimoine de trois sites sélectionnés en établissant un lien entre le géopatrimoine et la résilience. Il s'agit de sites très différentes, en termes de conditions géographiques, de niveau actuel de géoconservation et d'interprétation, de leur contexte socio-économique et du potentiel de développement. Des méthodes bien établies d'évaluation du géopatrimoine ont été utilisées pour deux buts principaux. Les résultats de chaque site sont à partager avec les acteurs locaux afin d'améliorer leurs initiatives de gestion du géopatrimoine en cours ou prévue. D'autre part, la thèse est une étude appliquée utilisant les méthodes existantes, en particulier l'évaluation quantitative des géosites. Au lieu d'ajouter de nouvelles méthodes à la pléthore de méthodes existantes, ce travail cherche à aider à la standardisation avec l'interprétation de méthodes sélectionnées et bien établies.

Dans la première zone d'étude - le site du patrimoine mondial naturel de la Chaîne des Puys - Faille de Limagne en France - un inventaire des géosites dédié au bien du patrimoine mondial a été réalisé. La méthode d'évaluation nationale et une méthode internationale ont été utilisées en parallèle, contient aussi la première étude expérimentale en France sur les avis des visiteurs dans l'évaluation des géosites.

La deuxième zone d'étude, la ville de Clermont-Ferrand est adjacente au premier cas d'étude, partageant le même environnement géologique, mais avec un contexte très différent en raison de l'urbanisation. La thèse aborde ce scénario avec un inventaire des géosites de fin échelle pour la ville, en utilisant le workflow national français. Basées sur des résultats, une proposition de gestion a été préparée, qui pourrait être transformée en plan d'action pour la géodiversité par la mairie locale.

La troisième étude concerne Dallol en Éthiopie. Elle est en relation avec des exemples français par un scénario de rifting continental, mais la contexte socio-économique est très distinct pour la gestion du géo-patrimoine. Il s'agit d'un ensemble unique au monde de (proto)volcan, d'hydrothermalisme et de karst salin, mais son étude est encore exploratoire, notamment en termes de surveillance. La thèse a fait un pas dans cette direction avec un surveillance mensuel utilisant des images satellites, tout en réalisant l'évaluation du géopatrimoine en comparant trois méthodes. Les deux initiatives ont été synthétisées dans une stratégie préliminaire de gestion du géopatrimoine en résilience, à intégrer dans les stratégies locales pour s'attaquer à la pression touristique dans cette zone à haut risque.

La thèse est mise en contexte avec une introduction, qui résume brièvement les concepts principaux du géopatrimoine et de la réduction des risques, et qui introduit le concept de géopatrimoine en résilience. Enfin, une synthèse est donnée sur la base des résultats des trois études de cas, mettant en évidence la gestion du géopatrimoine spécifique à un site, l'utilisation d'évaluations quantitatives comparatives, la nécessité de normaliser les méthodes et l'importance des approches interdisciplinaires telles que la combinaison de la gestion des risques et du géopatrimoine.

8 Magyar összefoglaló

A földtani örökségvédelem a földtudományok gyorsan fejlődő részterülete, melynek célja az élettelen természeti örökség felmérése és hatékony megőrzése, illetve megismertetése és népszerűsítése. Nem csak a földtan és a földrajz eszköztárát használja, hanem más területek kutatásait is beépíti, így a természeti veszélyforrások kezelését és az ezekhez való alkalmazkodóképességet. A geohelyszínek egyszerre lehetnek veszélyforrások, illetve más veszélyek okán sérülékeny elemek, ami hangsúlyozza a komplex örökségvédelemi törekvéseket. Ígéretes kezdeményezések már léteznek ugyan geoparkokban, ám az integrált megközelítésű tanulmányok még kiforrófélben vannak.

Jelen disszertáció három kiválasztott mintaterület földtani örökségét vizsgálja a földtani veszélyforrásokhoz való alkalmazkodás figyelembevételével. A példák a földrajzi adottságaik, a földtani megőrzés és bemutatás, továbbá a társadalmi-gazdasági környezet jelenlegi szintje szerint épp úgy eltérőek, mint ahogy jövőbeni fejlesztési lehetőségeikben. A földtani örökségvédelem kurrens módszereit alkalmazó vizsgálatoknak két célja volt. Az egyes mintaterületek eredményei a területileg illetékes szervekkel való megosztás után segíthetik a jelenleg futó, vagy tervezett örökségkezelési munkájukat. Másrészt már létező módszerek alkalmazásával – különösen az földtani értékleltárak területén – új eljárások kidolgozása helyett az eddigiek sokoldalú értelmezésével kíván hozzájárulni a tudományterület formálódó módszertani szabványosításához.

Az első mintaterület a Chaîne des Puys – Limagne Vetőzóna világörökségi helyszíne, melynek területére célzott földtani értékleltár készült. A nemzeti felmérési módszertan, továbbá egy nemzetközi metódus összehasonlító alkalmazása mellett a kutatás része volt a látogatók visszajelzését is beépítő földtani örökségi értékelés első kísérleti alkalmazása is Franciaországban.

A második helyszín, Clermont-Ferrand, földtani felépítése okán szorosan kapcsolódik az előzőhöz, ugyanakkor erősen eltérő, városi környezetről van szó. A disszertáció ezt a különbséget taglalja a város nagy részletességű földtani értéktárának elkészítésével, a francia nemzeti módszertan alkalmazásával. Az eredmények alapján megfogalmazott örökségvédelmi javaslatok a jövőben alapanyagként szolgálhatnak az önkormányzat földtani örökségkezelési tervének kidolgozásához.

A harmadik részterületet, az etiópiai Dallolt a francia példákkal összeköti a kontinentális riftesedés, mint fő geológiai kialakító folyamat, ugyanakkor a földtani örökségvédelem lehetőségei eltérőek a különböző természeti, gazdasági és szociális környezet következtében. Habár világszinten is kiemelkedő értékű területről van szó a (proto)vulkanizmus, a hidrotermális folyamatok és a sókarsztos jelenségek okán, a terület kutatottsága még mindig hiányos, különösen a földtani folyamatok rendszeres monitorozása terén. A disszertáció ez utóbbi irányba tesz lépést a terület havi rendszerességű távérzékeléses megfigyelésével, mindemellett elvégezve a földtani örökségi kiértékelést is, három módszer összehasonlító elemzésével. A két vizsgálat alapján felvázolt sarokpontok irányt mutatnak egy jövőbeni területkezelési terv felé, mely figyelembe veszi mind a jelentős földtani veszélyforrásokat, mind pedig a fokozódó turisztikai nyomást.

A disszertációt keretbe foglalja a bevezető, mely kitér a földtani örökség, illetve a veszélyforrás-kezelés történeti és elméleti hátterére, továbbá felvázolja a két részterület egységes megközelítésének lehetőségeit is. A mintaterületek eredményei alapján megalkotott és továbbgondolt összefoglaló pedig kiemeli a geohelyszínek sajátosságait figyelembe vevő kezelési tervek szerepét, az összehasonlító elemzések lehetőségeit, a módszertan egységesítésének fontosságát, és az interdiszciplináris megközelítések jelentőségét, például a földtani örökség és veszélyforrások kapcsán.

I RESEARCH FRAMEWORK AND INTRODUCTION

Geoheritage is a recent and rapidly evolving interdisciplinary domain of geosciences. Geoheritage researchers, decision makers, entrepreneurs and local people come together, using dominantly the approaches of geology or geography, but integrating social sciences, cultural heritage management, biodiversity studies or economics all for a common goal: to ensure the effective conservation of the Memory of the Earth (MARTINI & PAGES 1994) and raise the attention on the importance of abiotical values of the nature. This is vital as the lithosphere is the Earth's base for its biosphere, and thus the very existence of our society: The rock (lithos) is the record that helps us interpret the past and present and predict the future.

The inclusion of disaster risk reduction aspects in geoheritage, especially the concept of resilience – the capacity of systems to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner (UNISDR 2009) – is a relatively recent initiative in geoheritage. However, it is a growing trend, with some pioneering studies (such as CORATZA & DE WAELE 2012, FASSOULAS ET AL. 2018) and promising international commitments, like the ‘Shimbara Declaration’ (GGN 2012).

This thesis looks at geoheritage and geoconservation with respect to resilience to natural hazards. It has two principal goals. First, each case study was carried out to be practical, so that their results can be integrated into daily geoheritage management practices by the respective stakeholders and authorities, while still being research projects on their own right. The second goal was theoretical: with the selected case studies, using existing, state-of-the art geoheritage assessment methods instead of assembling new ones, the dissertation wishes to demonstrate the potential and challenges of geoheritage management, influenced by geographical conditions and constraints, both physical and human. The distinctive discussions of each topic and the global synthesis of thoughts therefore intend to add to the standardization of geoheritage management practices, especially to geosite inventories and some territorial management questions.

Three case studies are selected from three highly different areas in terms of physical and social geographical conditions, the current level and the future potential of geoheritage management.

- The *Chaîne des Pys – Limagne Fault* is a representative example of already developed geoconservation practices in the only natural World Heritage site in continental France, inscribed exclusively under criterion (viii). Stable economic conditions, developed tourist infrastructure, a temperate climate and relatively easy access help to attract a large influx of tourists, but overtourism has been so far avoided. Local management plans cover many geoconservation aspects already, but there is still a room for improvement, especially in site-specific management.

- The city of *Clermont-Ferrand*, the regional centre of *Auvergne* shares the same geological framework as the *Chaîne des Puys – Limagne Fault* area. This case study demonstrates that although the geoheritage in urban areas is shared with neighbouring rural areas, its management is connected both to the different context and so different challenges for geoconservation, and different potential for geoeducation and geotourism.
- *Dallol* in the *Danakil Depression* of Ethiopia is similar to the French examples with respect to the continental rifting environment, but it is radically different in all other aspects. It is one of the most extreme locations on Earth with its hyperarid climate and isolation in terms of infrastructure and socio-economic conditions. The area currently lacks any kind of legal and effective protection. The study of the unique hydrothermal processes and their risks is constrained to studies of short term expeditions, constant monitoring is missing. Meanwhile, the number of visitors in the hazardous, but stunning area has risen rapidly in the last years. Because of this, *Dallol* is an ideal exploratory lab for attempting a geoheritage management strategy, including resilience to natural hazards.

I/A Thesis outline

The thesis is organized into five principal chapters, centred on the three case studies which are framed by an introductory chapter on the principal concepts of this work, and a synthesis, summarizing key findings and some concepts for further reflection.

Chapter I gives a condensed, but comprehensive overview of geoheritage and resilience. After outlining the main goals, research areas and the structure of the thesis in this present section, the domain of geoheritage, is summarized briefly in two parts. *Chapter I/B* gives a short description of the history of the young domain of geoheritage, and a selected glossary of the most important terms of this field. *I/C* deals with a key area of geoconservation, geosite inventories. After giving their basic classification, four geosite assessment methods are introduced that will be used several times in the case studies. *I/D* is a condensed description of the growing domain of disaster risk reduction (DRR): following the structure of *I/B*, it gives a short historical lookback and a glossary that puts the concept of resilience into context. Finally, *I/E* gives the initial idea of the connection of geoheritage and resilience, outlining possible considerations on the links that geohazards have with geoconservation, geoeducation and geotourism, based on previous studies and own empirical considerations.

Chapter II presents the work carried out in the first case study area, in *Chaîne des Puys – Limagne Fault* World Heritage site. Underlining the importance of scale for geosite inventories, a dedicated inventory for the World Heritage property (~regional-departmental scale) is presented, an initiative that supplements the existing national inventory (DE WEVER ET AL. 2015, ARA DREAL 2020) and helps the geoconservation efforts of local stakeholders with a more in-depth view of local

geoheritage. An introductory part presents the geological-geographical background of the monogenetic volcanic alignment, the fault and the continental rifting context. This is followed by the conservation framework of the area, giving the French context as well. The inventory and assessment itself covers the parallel usage and comparative interpretation of two methods: DE WEVER ET AL. (2015) and VUJIČIĆ ET AL. (2011). Finally, the discussion of the dedicated inventory of the property is supplemented with a small-scale experimental study, including visitors' feedback in geosite assessment, using the method of TOMIĆ & BOŽIĆ (2014).

Chapter III about the urban geoheritage of *Clermont-Ferrand* is organically connected to the previous topic due to the geological background, but it draws on a different geoheritage context, the urban environment. The introduction of this chapter covers the interpretation of the local geology and geomorphology of *Clermont-Ferrand*, with a short overview on the domain of urban geoheritage. After presenting the methodology of local geosite selection, including geomorphological mapping, the results of the inventorying are presented, which used the French national workflow (DE WEVER ET AL. 2015). This part is concluded with a detailed discussion on local geoheritage management that could be a baseline for a municipal geodiversity action plan (DUNLOP ET AL. 2018) for *Clermont-Ferrand*, the first such initiative in France.

Chapter IV about the geoheritage and resilience of *Dallol* and the *Northern Danakil* is divided into four parts. The context of the area is given with a geological and geohistorical introduction. Then, the satellite image monitoring of *Dallol* and the *Black Mountain* is presented, giving the workflow from the methodological outline to the interpretation of current results, to a web publication initiative for improving visitors' resilience. The third part covers the geoheritage assessment of the area, using three methods (VUJIČIĆ ET AL. 2011, REYNARD ET AL. 2016, BRILHA 2016). Finally, a synthesis is given, drawing up some cornerstones of a resilient geoheritage management strategy for *Dallol*, integrating the monitoring and the geosite assessment results.

Finally, *chapter V*, the Synthesis gives some concluding thoughts. Issues such as scale-dependent inventorying, parallel usage of inventorying methods, integration of inventories with assessments of risk and other heritage elements (cultural, biodiversity), and the importance of resilient geoconservation strategies, are covered in this part.

I/B The domain of geoheritage

Geoheritage is a multi-disciplinary approach and a rapidly emerging, relatively new domain of geosciences. Its conceptual framework, and dedicated initiatives on geoconservation, have been mostly established from the late 1980s, but early initiatives are already traceable from the 19th century and even before as described in BROCX & SEMENYUK 2007, BUREK & PROSSER 2008, GRAY 2013, REYNARD & BRILHA 2018). In this chapter, a short description of the scientific history of geoheritage is given, and then the principal terms of the domain, used frequently through the thesis, are defined.

I/B/1 The historic development of geoheritage¹

I/B/1/a The early practices of geological awareness

Prominent rock formations, elements of hydrography such as springs or waterfalls, were part of local mythology throughout the world since human history began. They were counted as sacred places of worship, or taboo sites to be well avoided due to religious beliefs. A good example of this is the sandstone inselberg of *Uluru (Ayers Rock)* in the Northern Territory of Australia (TWIDALE 2010). Mythological “dreamtime tracks” are associated with the hilltop and climbing was a taboo for the *Pitjantjatjara* people. As a popular tourist attraction since the 1950s, it was possible to reach its top with a chain supported track, but since 2019, the ascent is banned again. Besides the respect of spirituality, an important consideration was the prevention of further erosion along tracks. Therefore, the past taboo and the present regulation on it is now functioning as a tool for preserving the integrity of the site.

A different geological appreciation is connected with minerals, ores and rock types. Amber was used as a jewel for thousands of years in the *Baltics*, obsidian as a tool was widespread in distinct cultures of *Catal Hüyük* in *Anatolia* or the Mesoamerican civilizations. Greeks and Romans selected their building materials such as the marble of *Pentelikon* or *Carrara* with a very fine sense (DOUGHTY 2008). For the Mercury Temple on the *Puy de Dôme*, they avoided using the volcanoes’ stone and extracted building material from non-sacred local sites (PAILLET & TARDY 2012).

The exploitation of these resources changed the original topography and landforms, but many of these ancient mining sites are now considered as geosites. During the time of their operation, they were important and strategic parts of local infrastructure, and their geological importance was appreciated in a figurative sense. Their legacy is now excellent outcrops with beautiful rock.

¹ Section I/B/1 is the compressed, modified version of the essay, submitted to the doctoral course of ‘*History of geography*’, as part of the Hungarian PhD curriculum in 2017/2018.

A further step of awareness appeared with the Renaissance, where there was a tendency among aristocrats to be fascinated by natural history and heritage (WORTON 2008). The personal collection of natural objects called “cabinets of curiosity” often contained minerals and rocks, they could be considered as early predecessors of modern museums (WORTON 2008). The first, documented (indirect) geoconservation act is also connected with this era at *Baumannshöhle* in the *Harz Mountains*. To control the growing number of visitors, Duke Rudolf August issued a regulatory decree in 1668 (ERIKSTAD 2008). Dud Dudley’s ‘Metallum Martis’ from 1665 is considered as the first geological map of the world, while Robert Plot has compiled the primordial systematic inventorying of important geological features with the natural description of the counties of the *Midlands* in England (WORTON 2008).

I/B/1/b The birth of modern geosciences and the first traces of environmental protection

The Age of Enlightenment in Europe from the 18th century and the era of first and second industrial revolutions of the 19th century created the independent disciplines of the traditional geosciences of geology and geography. Scientific methods and concepts were introduced, such as geological mapping or new exploitation techniques that made possible the massive extraction of resources, such as coal or petroleum, propagated by the growing demand for raw materials by industry. Industrial revolution was soon not just confined to its cradles in Europe and Northern America, but it started to spread over the world over the colonisation period of the 18th to 20th century. Colonisation was often led by new, westernized geographical explorations.

The United Kingdom was not just the starting point of the Industrial Revolution, but the birthplace of modern geology as well. ‘Founding fathers’ like James Hutton, the author ‘Theory of the Earth’ William Smith, the creator of the first geological map of Great Britain or Charles Lyell, the author of the influential ‘Principal of Geology’, based their theories and works on the observation of British landforms. Places like the *Siccar Point*, discovered and described by Hutton or the *Wren’s Nest*, are protected now for their significance in the history of geology (BUREK & PROSSER 2008).

Scientific progress was also accompanied by growing popular interest. Previously, visiting spectacular landscapes was the privilege of the upper classes, but the new transportation technologies, specifically the railways, opened a new horizon for travelling, making it available for the great masses. With the industrialization, the opportunity and demand for free-time also appeared. Even for the low-income or working class, short getaways became possible, especially in the second part of the 19th century. The *Peak District* in the *Midlands* or the *Isle of Wight* became popular spots in England. For the growing demand, tourist infrastructure was built such as paths, viewpoints, shelters. According to HOSE (2008), *Bowder Stone* in *Lake District* is probably the first

developed ‘geo-attraction’, with a touristic infrastructure of fencing and ticketing and a stair-system for an easier ascent.

Public attention meant threat and a potential for protection as well. Easily reachable fossil sites include *Cromarty* beach, which was virtually out-collected by amateurs and professionals only 20 years after its exploration (THOMAS & WARREN 2008). In contrast, *Hutton’s Rock*, a hematite vein in *Holyrood Park, Edinburgh*, was protected by one of the earliest legislative acts with the direct purpose of geoconservation. James Hutton raised attention about its value, and citizens brought legal action to preserve it. In 1831 and the court decided against the Earl of Haddington, the owner of the land, saving the landform from destruction. (THOMAS & WARREN 2008). Museums and geological collections have been acting as places for ex-situ geoheritage, being safe repositories for the findings of excavations and grasping public attention with precious minerals and fossils. The Museum of Practical Geology was established in 1837 and geological specimens were exhibited in the newly opened museums country-wide, such as the Dudley Museum (THOMAS & WARREN 2008, WORTON 2008).

USA is the other cradle of geoconservation. Most of the legislative acts followed a holistic approach for natural conservation, but geological values were also appreciated, marking the roots of local geoconservation. *Yellowstone National Park* (1872), the first of its kind in the world, became protected partially for its geothermal features, and *Yosemite National Park* (1890) was the second with its distinctive landforms. The *Devil’s Tower* in *Wyoming* was the first site to be declared a National Monument under the ‘Act for the Preservation of American Antiquities’ of 1905, becoming the first legally protected geological site worldwide. The petrified logs of *Arizona* were also given the same title, making the territory the first ever protected paleontological site (THOMAS & WARREN 2008).

The first national parks of Europe (*Abisko* and *Angsö*) were established in Sweden in 1909, but selected areas, such as *Drachenfels* (1836) or *Totenstein* (1844) were already legally protected in Germany in the 19th century, while a first inventory of natural monuments in Prussia took place in 1906 (WIEDENBEIN 1994).

I/B/1/c The way to dedicated geoconservation: from environmental awareness to national and international legislative acts

The end of Second World War was followed by a significant economic boom and by the rapid increase of global population, especially in regions of decolonization, like Africa or India. Excessive exploitation of natural resources with mining or intensified agriculture, along with urban sprawling and pollution of an unprecedented scale, has resulted in a progressive decrease and destruction of natural habitats. This has begun to raise attention to the fact that this kind of growth is not

sustainable. From the 1960s a growing amount of researches and publications pointed out the dangers, such as CARSON (1962) or MEADOWS ET AL. (1972) and environmental movements emerged such as Greenpeace. They made a huge step in calling public attention on the problems of sustainability and influencing decisions such as ‘National Environmental Policy Act’ of USA in 1969 or the Rio de Janeiro Earth Summit in 1992. Although they followed a holistic approach for natural protection, overwhelmingly the measurements were connected with biotic factors, the protection of flora and fauna elements. Lithosphere, the geological and geomorphological elements, were largely ignored.

The post-war period also brought tremendous changes into geosciences. The theory of plate tectonics from the 1960s implied a real shift of paradigm. In geomorphology, the extensive usage of quantitative methods also changed focus from the simple description of landscapes and landforms to a more complex approach to explain the processes of external and internal forces.

Although the growing number of national legislative acts mostly focused on biotic or landscape values, the inclusion of geosciences also started to gain place. In the United Kingdom, an early national level inventory, with a report on National Geological Reserves in England and Wales, was implemented in 1945 and ‘The National Parks and Access to the Countryside Act’ mentioned geological features in Section 23 (PROSSER 2008). A group on geoconservation was established in the Netherlands in 1969 and started a systematic inventory of scientifically or educationally important geoscience sites (ERIKSTAD 2008).

The formal international recognition on the heritage of Earth, both for cultural and natural values began with the World Heritage Convention in 1972. The importance of the Earth’s heritage is included among the inscription criteria (criterion viii) from the beginnings, just as is the superlative aesthetic value of (geomorphological) landscapes (criterion vii), although the number of natural sites, especially the ones inscribed or connected with the lithic factors, has always been well below the number of cultural sites (BOYLAN 2008, MIGOÑ 2018). Another international initiative on the recognition of universal outstanding geological sites was the definition of global boundary stratotypes from the 1977 (ICG 2020).

I/B/1/d A new domain of geosciences: geoheritage and geoconservation

Direct or indirect forms for the preservation and presentation of geoheritage can be detected throughout our history, and the growing human impact on the environment was followed with a growing awareness on environmental issues, especially after World War II. The importance of geosciences under natural heritage protection might have appeared in these initiatives to some extent, but a direct, comprehensive concept on geoheritage and geoconservation only started in the late 1980s. The field has rapidly emerging since that time.

The *Tasmanian Wilderness* in Australia was inscribed on the World Heritage list in 1982 with geological heritage being a key criteria for the inscription (HOUSEHOLD & SHARPLES 2008). The Geological Society of Australia (GSA) had already acknowledged the need for the protection of outstanding bedrock features as reference sites of geosciences. However, the World Heritage designation of the area called for a different, process-based conservation, instead of a predominantly site-based approach. In order to make a better adaptable conservation strategy and to create a new, consistent terminology, replacing the plethora of previously coined expressions such as 'Earth Heritage', 'geological heritage', 'Earth Science Conservation', the geoscientist team of the Tasmanian Forestry Service defined *geodiversity*, *geoheritage* and *geoconservation* as the best available terms (HOUSEHOLD & SHARPLES 2008). The first English usage of geodiversity is coined to SHARPLES (1993), almost at the same time as to the independent definition of WIEDENBEIN (1993) in German. From the initial simple mirroring of this term from biodiversity, a number of definitions were published in the 1990s and 2000s (see GRAY 2013), just like with other important terms, such as geoheritage, geosite, geomorphosite (e.g. PANIZZA 2001, REYNARD ET AL. 2004, BROCX & SEMENIUK 2007).

A great catalyst for the terminological discussions were the first dedicated, scientific meetings on the field of geoheritage and geoconservation. A thematic workshop was held in *Leersum* in 1988, where the participants from seven European countries created the European Working Group on Earth-science Conservation, becoming the first international (and European) organization on geoconservation. In 1991 they organized the 'First International Symposium on the Conservation of our Geological Heritage' in *Digne-les-Bains*, creating the 'Digne Declaration' (MARTINI & PAGES 1994), a powerful statement on the importance on geological heritage and the need for its conservation and calling for a global network on geological territories (JONES 2008).

The Division of Earth Sciences of the UNESCO acknowledged that geodiversity in international (and national) protection frameworks, in the World Heritage list, and in the Man and Biosphere Reserves Programme, was underrepresented (JONES 2008, BRILHA 2018B). As a response to the proposal of the 'Digne Declaration', the implementation of a UNESCO Geoparks program was started in 1997 (PATZAK & EDER 1998). Although it was rejected by the UNESCO Executive board in 2000 (JONES 2008), it still supported initiatives of state parties.

In 2000, four European territories (*Reserve Géologique de Haute-Provence* - France, *Natural History Museum of Lesvos Petrified Forest* - Greece, *Geopark Gerolstein/Vulkaneifel* - Germany, *Maestrazgo Cultural Park* - Spain) gathered in Lesvos and founded the European Geoparks Network, as a legal framework to preserve and promote geological heritage and sustainable development, addressing social and economic problems of the territories with the potential of geotourism (JONES 2008).

In February 2004 the Global Geoparks Network was founded in *Paris* with the members of the European Geoparks Network and the Chinese Geopark Network. Their operational guidelines were established, and in the same year in November, a World Geopark Office opened in *Beijing* after the First International Geopark Conference (JONES 2008). The following years showed a remarkable extension of the network both in Europe and the People's Republic of China, but also admitting members from other Asian states and Latin-America. Cooperation with the UNESCO deepened throughout the years, with an increased input from the International Union of Geological Sciences, culminating in the '38th General Conference of UNESCO' in 2015. The member states accepted the creation of the 'International Geoscience and Geoparks Programme' (IGGP), which replaced and enlarged the 'International Geoscience Programme' (IGCP), acknowledging internationally the need for geoconservation. They also created the label of UNESCO Global Geoparks, ensuring the same level of international recognition as the 'World Heritage Convention' and the 'Man and Biosphere Program'.

In 2016, the International Union for Geological Sciences set up its Geoheritage Commission, and the international formalisation of geological science assessment began with a working group, within the commission. This work is still in progress.

Geoheritage's broad acknowledgement at an institutional scale was also followed by a growing representation in scientific circles. From 2009, *Geoheritage*, a peer-reviewed journal by Springer and ProGEO, has become a central information forum on the scientific research on geoheritage, and numerous studies were published on these issues in other journals as well, such as *Acta Geoturistica*, *Questiones Geographicae*, *Geoconservation Research* or *Episodes* (MUCIVUNA ET AL. 2019). A number of text books and compilations were also published on the theoretical background of geodiversity (GRAY 2013), geoparks (ERRAMI ET AL. 2015) and geoheritage and geoconservation in general (REYNARD & BRILHA 2018). Geoheritage is represented in international conferences of geosciences like European Geosciences Union or the International Geological Congress, and the Global Geoparks Network and its regional networks are also organizing bi-annual conferences on the issues of best practices of geoconservation, education and geotourism in geopark.

I/B/2 Terminology

Numerous terms were already quoted from the domain of geoheritage in the historical development overview, and they will be used many times in the further chapters of the thesis. In order to have a consistent usage, and to help the reader, an overview is given on these terms in the form of a glossary. It gives references to the plethora of available definitions, and highlights the actual one that is used throughout this thesis, if a specific interpretation is defined in the respective chapters later.

I/B/2/a Geodiversity

Biodiversity is a widely used and accepted term, appearing not just in official documents of UN and scientific publications, but more and more frequently in everyday language as well. Geodiversity appeared slightly later in the 1990s, and its recognition is still somewhat lagging behind biodiversity: under natural diversity or ecosystem services, most of the documents still mean biodiversity, the biotic aspects, not regarding the abiotical aspects, associated with geodiversity (GRAY 2018).

Geodiversity was first defined almost independently and in parallel by SHARPLES (1993) and WIEDENBEIN (1993) after the example of the use of biodiversity at the ‘Earth Summit of Rio de Janeiro’ in 1992. A wide range of definitions has appeared since then, arguing the exact content of the term, or even its ‘raison d’être’. This historical evolution and the exact citations can be followed up in BROCX & SEMENYUK (2007) and GRAY (2013). This thesis relies on the definition of DINGWALL ET AL. (2005), which is as follows:

‘The natural range (diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes. Geodiversity includes evidence of the past life, ecosystems and environments in the history of the Earth as well as a range of atmospheric, hydrological and biological processes currently acting on rocks, landforms and soils.’

From a conceptual viewpoint, here, the interpretation of GRAY (2013) and GRAY (2018) is also followed, summarized in *Fig. 1.1*. In this sense, geodiversity is the broadest term, of which geoheritage is its identified part, selected for geoconservation.

I/B/2/b Geoheritage

Geoheritage is often used as an umbrella term for the applied discipline or domain of geosciences that deals with the scientific research on the preservation of Earth’s Heritage. In this sense, it is frequently used parallel or synonymously with geoconservation. It is one of the most often referenced elements of the nomenclature according to the citation analysis of SCARLETT & RIEDE (2019). The references to geological heritage (e.g. ANDRASANU 2006), Earth(‘s) heritage (such as DOYLE ET AL. 1994) virtually cover the same phenomena.

From the first references to geological heritage of ANON (1991) and BRADBURY (1993), with a direct usage on geoheritage in a shortened form, numerous definitions were published. The exhaustive collection of these is given by BROCX & SEMENYUK (2007) until the mid-2000s, and further examples can be found in REYNARD & BRILHA (2018). Here, the geoheritage definition of

BROCX & SEMENYUK (2007) is used, with a note that geology is meant in its broadest sense (according to the description) as a synonymous term to geosciences:

‘Globally, nationally, state-wide, to local features of geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, palaeontologic, geomorphic, pedologic, and hydrologic attributes, at all scales, that are intrinsically important sites, or culturally important sites, that offer information or insights into the formation or evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference.’

In this thesis, geoheritage is frequently used in the general form as well, meaning the discipline of geosciences, whether in a standalone form, or together with the term of geoconservation.

I/B/2/c Geoconservation

In terms of natural conservation, the abiotical elements or geological references are often overlooked – often only meant to be wildlife conservation -, just like the still limited awareness on geodiversity in natural diversity, or geoheritage in the broader framework of natural heritage (GRAY 2018). According to the conceptual framework of GRAY (2013) and GRAY (2018), geoconservation can be considered as the set of actions, or the endeavour to conserve geodiversity and geoheritage. The timeline of definitions can be followed up in BROCX & SEMENYUK (2007), with further references in REYNARD & BRILHA (2018). Highlighting the laconic, yet complete designation by ANON (2000), the more detailed description of BUREK & PROSSER (2008) is used here:

‘Geoconservation can be defined as action taken with the intent of conserving and enhancing geological and geomorphological features, processes, sites, and specimens. As successful conservation depends on understanding, valuing, the actions taken often include promotional and awareness raising activities.’

When it is not referenced together with the term of geoheritage, all the conservation and enhancement efforts mentioned should be considered under the umbrella of geoconservation, including geoheritage inventories, geodiversity action plans (DUNLOP ET AL. 2018) related to resilience, geotourism, etc.

I/B/2/d Geotourism

Referring back to the historical description of geoheritage in I/B/1, it is clearly visible that the appreciation of landscapes and geological features have a long tradition and even the early episodes of modern tourism quickly explored such sights. However, its dedicated forms and scientific

research on it is relatively recent, just as with the previously mentioned terms in this chapter. The collection of principal citations, containing definitions from the first use of geotourism in HOSE (1995) is available in NEWSOME & DOWLING (2010) and RUBAN (2015). This thesis relies on the most frequently quoted version, by NEWSOME & DOWLING (2010):

‘Geotourism is a form of natural area tourism that specifically focuses on geology and landscape. It promotes tourism to geosites and the conservation of geo-diversity and an understanding of earth sciences through appreciation and learning. This is achieved through independent visits to geological features, use of geo-trails and viewpoints, guided tours, geo-activities and patronage of geosite visitor centres.’

It is important to note that this aspect and the ones available in geoheritage publications on this topic (see RUBAN (2015)) are different from the viewpoint of National Geographic’s similar initiative (NATIONAL GEOGRAPHIC 2020). The latter is defined ‘as tourism that sustains or enhances the distinctive geographical character of a place - its environment, heritage, aesthetics, culture, and the well-being of its residents’ therefore underlining a spatial aspect in tourism. The domain of geoheritage rather focuses on the utilisation of geosciences in tourism.

I/B/2/e Geosite

Geosites are basic units and direct physical representations of geoheritage that are being subjected to geoconservation initiatives and could be used for geoeducation and geotourism purposes. The several different concepts can be grouped into the categories of restricted and broad definitions (REYNARD 2009).

Sensum stricto, geosites are only those representations of geodiversity that have scientific importance for understanding the Earth’s history. Sensum lato, each geological object could be considered as a geosite that presents a certain value due to human perception or exploitation, either by aesthetic, cultural, historical or economic importance (REYNARD 2009). BRILHA (2016) even proposed a different terminology for these two concepts: *geosites* are only the most relevant sites that are representative of the history of the Earth and its evolution, while *geodiversity sites* are elements of geodiversity that do not have a particular scientific value, but which are still important resources for education, tourism, or cultural identity of communities.

Here, the broader sense is used, based on the definition of REYNARD ET AL. (2004), but the importance of a certain level of distinction between sites of high and limited scientific relevance as BRILHA (2016) is emphasized in several paragraphs throughout this manuscript.

‘Geosites are portions of the geosphere that present a particular importance for the comprehension of Earth history. They are spatially delimited and from a scientific point of view clearly distinguishable from their surroundings. More precisely, geosites are defined as geological or geomorphological objects that have acquired a scientific (e.g. sedimentological stratotype, relict moraine representative of a glacier extension), cultural/ historical (e.g. religious or mystical value), aesthetic (e.g. some mountainous or coastal landscapes) and/ or social/ economic (e.g. aesthetic landscapes as tourist destinations) value due to human perception or exploitation.’

In countries under German and French influence, geotope is often used as a synonym to geosite or the equal, established term (REYNARD ET AL. 2004). Geomorphosite is often frequently quoted in scientific papers as a narrower set of geosites, *‘as landforms with particular and significant geomorphological attributions, which qualify them as a component of a territory’s cultural heritage’* (PANIZZA 2001).

I/B/2/f World Heritage Site / Convention

The ‘World Heritage Convention’, adopted in 1972, is probably the most acclaimed framework for safeguarding the unique cultural and natural heritage of Earth. As of 2020 June, 189 State Parties of UN have signed the convention and 1121 sites are inscribed on the World Heritage list, of which 869 are cultural, 213 are natural and 39 are mixed (cultural – natural) sites.

The primary concept for the justification of a site to be inscribed on this list is the ‘Outstanding Universal Value’ (OUV). According to paragraph 49 of the Operational Guidelines, OUV *‘...means cultural and/ or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole...’* (UNESCO-WHC 2017). A property is having OUV if it meets one or more of the ten criteria, of which criterion (i) – (vi) represents cultural aspects and (vii) – (x) deals with natural heritage, and which has met the criteria for management and protection.

Geoheritage is directly addressed under selection criterion (viii) (UNESCO 1972, MIGOÑ 2018):

‘The property be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.’

Although not so explicitly and not exclusively, the criterion (vii) also represents Earth sciences and issues of geodiversity, especially geomorphoheritage (UNESCO 1972, MITCHELL ET AL. 2013, MIGÓN 2018):

'The property contains superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.'

Sites inscribe under criterion (viii) and/or (vii) should be considered therefore the representations of geodiversity on the World Heritage list. However, it must be noted, that a site might not reach the level of OUV in these aspects, to be inscribed under other natural or cultural criteria, but it might still have significant geoheritage value. Examples are *Bingvellir* (Iceland) of criteria (iii) and (vi), which is on the boundary of the divergent Atlantic plates, or the *Blue Mountains* (Australia) with dissected sandstone tablelands, represented under criteria (ix) and (x) (MIGÓN 2018). Furthermore, many historical buildings have a significant heritage stone potential among cultural properties.

Natural heritage is generally underrepresented compared to cultural assets, but elements of geodiversity are even more deficient. The studies of DINGWALL ET AL. (2005), BADMAN (2010) and MIGÓN (2018) all indicated that it is a common drawback of the World Heritage list that while certain themes are well represented, such as volcanism or karst systems, others such as elements of the Wilson cycle in tectonics (VAN WYK DE VRIES ET AL. 2018) are still scarce or even missing. It is partially related to the fact that OUV is exclusive in supporting only the judged 'best' global example of a phenomena, and valuable elements of geodiversity often have a similar origin (although slightly different physical representation) due to the uniformity and ubiquity of geological processes on the Earth.

I/B/2/g (UNESCO Global) Geopark

According to the definition of Statutes of the International Geosciences and Geoparks Programme (UNESCO-IGGP 2015):

'Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development.'

Being the official definition of UNESCO, this is associated principally with the UNESCO Global Geoparks, but virtually the same concept is the guideline in national geoparks that might apply for a UNESCO label as an aspiring geopark.

The appearance of the geopark movement is connected with the birth of dedicated geoheritage research studies, as summarized in *section I/B/1/d*. Since adopting the ‘International Geosciences and Geoparks Programme’ in 2015, the UNESCO Global Geopark has become the third international framework for preserving the natural heritage, besides the ‘World Heritage Convention’ and the ‘Man and Biosphere Programme’, with a direct, ‘*holistic concept of protection, education and sustainable development*’ in areas of ‘*geological heritage of international value*’ (UNESCO-IGGP 2015).

As of 2020 June, there are 161 geoparks in 44 State Parties. The four regional geopark networks (European Geoparks Network, Asia-Pacific Geoparks Network, Latin America and the Caribbean Geoparks Network, African Geoparks Network), together with the national network of the Canadian Geoparks Network, represent all permanently inhabited continents, leaving out Australia and Oceania so far. Besides the more and more extensive spatial representation, the majority of principal time units from Proterozoic to Quaternary and geological frameworks (e.g. volcanism, palaeontology) are well represented in the current UNESCO Global Geoparks (RUBAN 2016, BRILHA 2018).

It must be noted that the UNESCO Global Geopark label is not a protected area category, legislative protection of geosites in a geopark area must come from national regulations / legislation (BRILHA 2018). The holistic approach of geoparks ensures that other elements of our heritage, such as tangible and intangible cultural heritage and biodiversity, are also appropriately included in the conservation and management plans, and they are integrated in the education and geotouristic mission of the geopark.

I/B/3 The conceptual framework of geoheritage

In the scientific literature of geoheritage, a number of concepts are available that consider the connection between the key terms slightly differently (e.g. GRAY 2013, BRILHA 2016). The conceptual framework which is used in this thesis relies on the definitions given in *I/B/2* and especially on the remarks of REYNARD & BRILHA (2018). It is summarized in *Fig. 1.1*, which is based on the modified McKelvey box of GRAY (2018).

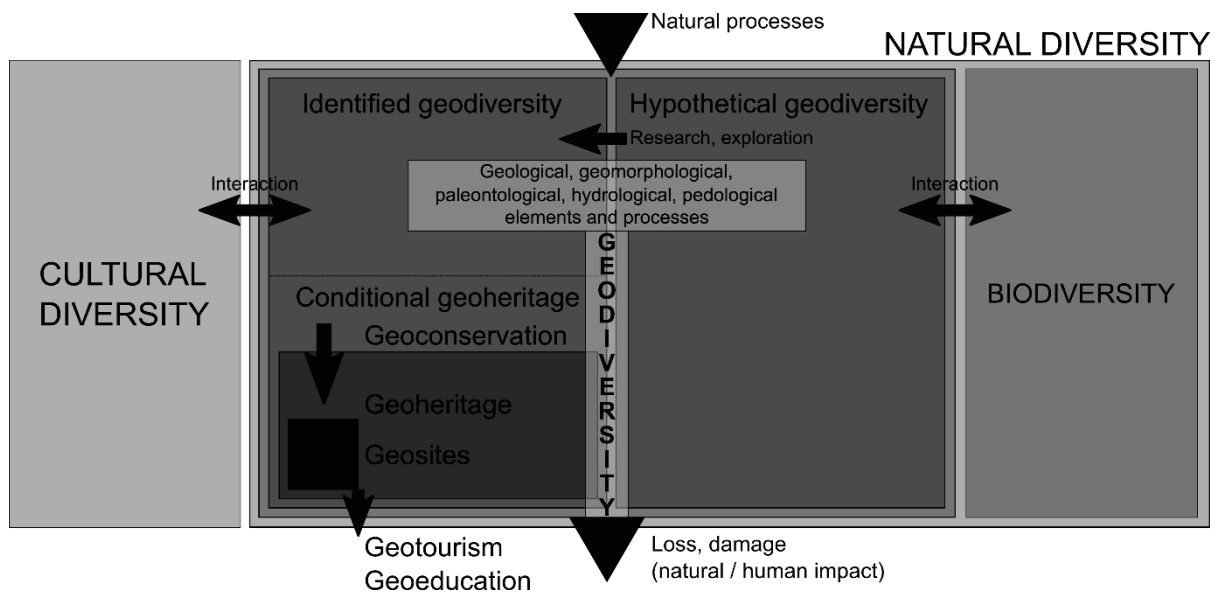


Fig. 1.1 The conceptual connection of the terms of geoheritage in this thesis

Geodiversity contains all abiotic (lithic) aspects of **natural diversity**, like geological or geomorphological processes, their physical elements and their interconnections. This diversity is constantly changing, increased by natural processes, decreased by loss of natural or human-induced processes. Geodiversity is almost all the time in interaction with the elements and processes of biodiversity. Due to the increasing human presence in every corner of our Earth, geodiversity is often in contact with cultural diversity as well. Only a limited part of the globe's geodiversity is known, the rest is **hypothetical**, that could become identified with research, exploration, etc. From the **identified** elements of **geodiversity**, some have the potential of becoming part of geoheritage (**conditional geoheritage**), according to future set of actions of geoconservation. **Geoheritage** covers only those elements of geodiversity which were selected for **geoconservation** due to their scientific importance/value, eventually taking into consideration their education or touristic potential as well.

Geosites are direct physical representations of geoheritage, often identified in connection to geoconservation frameworks, such as inventories of geoparks, World Heritage sites, national protection designations. These identified and well-described elements of geoheritage could be used for further purposes as well, such as **geoeducation** or **geotourism**, which is a form of ecotourism, often connected with the elements of cultural- and biodiversity as well.

I/C Inventorying geoheritage

In order to fulfill the needs and requirements of geoconservation and associated domains such as geotourism, the systematic collection and management of information about the geoheritage is required. Inventories of geoheritage are classification systems for identifying and listing sites with geoheritage significance (BROUX & SEMENYUK 2007), they are a practice of data collection used

extensively in geosciences during field work or laboratory focused studies (BRILHA 2016). The knowledge of geodiversity values, and the existence of inventories collecting these sites, are inevitable, as geodiversity should be considered as a non-renewable resource, and its destruction or mismanagement could lead to definitive disappearance of features, at least on the human timescale (BRILHA 2016).

I/C/1 Overview of methodologies and inventories

LIMA ET AL (2010) defined four principal considerations for inventorying: the **topic**, the **scope**, the **scale** and the **values**. The context of geosite inventories is presented here with this structure, adding a technical consideration as well.

I/C/1/a The importance of scale

One of the most important considerations for a geosite inventory is the level, the scale where it is taken, as this highly affects the detail, its purpose and the methodology used during the process. The majority of the inventories are ordered, implemented and maintained by well-defined organizations and their extent matches an administrative category from a national level to regional-departmental (mezo-scale), to even municipal or local scale (micro-scale) inventories.

A work on listing the key sites of geosciences with a global importance started in the 1990s, parallel with the emergence of geoconservation. The Global Indicative List of Geological Sites (GILGES) was a preliminary compilation of internationally outstanding sites by the joint Working Group on Geological and Palaeobiological Sites of UNESCO and the International Union for Conservation of Nature, the IUCN (COWIE 1993, DÍAZ-MARTINEZ ET AL 2016). The initiative further evolved to the IUGS GEOSITES, later commonly known as ‘Global Geosites Programme’. The Global Geosites Working Group started its work in 1995 with the joint support of UNESCO, IUCN and ProGEO (the European Association for the Conversation of the Geological Heritage). An intensive work started through laying down the criteria for selection, discussions in a number of workshops and submissions from several national committees (WIMBLEDON ET AL 1999, DÍAZ-MARTINEZ ET AL 2016). The program became defunct, inactive by 2003, however its purposes are still valid, and national efforts have still continued to create inventories that could help with the resumption of this initiative. The results of the European working groups were published in a book (WIMBLEDON & SMITH-MEYER 2012) and the list of assessed sites are summarized on the website of the IUGS International Commission on Geoheritage (IUGS-ICG 2020). A short-lived continuation, the GEOSSEE, was created in 2003 to promote ‘*activities demonstrating the value of geological heritage and the beauty of landscapes to the public*’, but it ceased to exist by 2006 (DÍAZ-MARTINEZ ET AL 2016, IUGS-ICG 2020). Global Geoheritage Areas is a new

initiative of the IUCN Geoheritage Specialist Group that at writing is in the discussion phase (WOO & BRILHA 2019).

The Global Geoparks Network (from 2004) and the ‘International Geoscience and Geoparks Programme’ (from 2015) is the current worldwide organization for geoheritage and geoconservation. Although the list of geosites from the member geoparks could not be considered as a tendentious global geosite inventory, certain items definitely have outstanding universal value. The list of natural or cultural / natural World Heritage sites, inscribed by criteria (viii) or indirectly supporting values of geoscience through other criteria, could be regarded as type of global level catalogue of selected geosites (areas) as well.

National geosite inventories aims at reflecting the best examples of geological phenomena that could be considered the key sites of geosciences on a national level and could eventually provide geosites for an international inventory. *Sensum stricto*, only catalogues dedicated to geoconservation should be considered national geosite inventories. Listing of geological heritage items as part of broader databases of heritage and protection, or inventories of geological phenomena, such as drill holes or mines are not direct, structural geoconservation catalogues. However, some of them could be an input of national geosite inventories, and in several countries without dedicated geoconservation recording programmes, they could be considered the only database of geological phenomena with a potential scientific and heritage value.

Currently (as of 2020), only a fraction of countries has a dedicated national geosite inventory program, with a satisfactory coverage. The IUGS Heritage Sites and Collections Subcommission maintains a list, where national inventories published online are collected (IUGS-ICG 2020). A preliminary study on potential national geosites with a full or a partial spatial coverage was carried out in some countries. An example is the inventory of São Tome and Príncipe (HENRIQUES & NETO 2015) that could eventually be an input for a future national inventory, maintained by a local responsible authority, such as a geological society, museum or an environmental planning agency.

The highest number of geoheritage inventories with a huge variety of purposes (scientific research, geotourism potential, management policy) have been created for smaller, restricted areas. These could follow political boundaries and administrative units like regions or municipalities (such as FUERTES-GUTIÉRREZ & FERNÁNDEZ-MARTÍNEZ 2009, DEL MONTE ET AL. 2013), or they could focus on a well-defined landscape, a geomorphological or geological unit (e.g. COSTA-CASAS ET AL. 2015, MAUERHOFER ET AL 2017).

I/C/1/b The values of geoheritage, used in inventories

In most cases, from the abundant choice of potential sites in an area, only certain ones should be selected and included in a geosite inventory. The exceptional nature of a location, the reason

why it was considered as the most representative example, is manifested through the assessment of its values. The terminology of values used in inventories may differ by authors, but there should be an overlap between the contextual frameworks, and not all the methods utilize the same aspects, the same values. According to BRILHA'S (2018A) classification, the following values are the most widely used in the presently existing geoheritage inventories:

- Scientific value: considered as a key value for choosing a geosite. BRILHA (2016) proposed only to name geosites as such with a high scientific value, regardless the outstanding nature of associated values. Considerations such as its representation in scientific literature, or proposal as a key site for geosciences by its geohistorical importance, or as a stratotype sections are assessed under scientific values.
- Educational value: interpretative potential of geological phenomena for students at different levels (primary school to university)
- Aesthetic value: considered as one of the main factors by the visitors, but a spectacular feature might not be considered outstanding for other values, therefore not meeting properly the requirements for a geosite
- Cultural value: the additional value of a geosite, as part of intangible heritage by its religious importance, or its function as a connection to a cultural landmark / heritage
- Touristic value: all the considerations connected with the geotourism potential of the site (accessibility, level of interpretation by guides, panels, interpretation centres, etc.)
- Functional value: the potential usage of the geological phenomena as a local resource, such as habitat, water source, etc.
- Economic value: partly overlapping with functional and touristic values, these factors should describe what kind of exact revenues a geosite could offer to communities (e.g. exploitation of natural resources vs. their preservation, potential revenues from geotourism).

I/C/1/c The scope and the topic

The scope, the objective of carrying out the inventorying process strongly affects all the other considerations. It defines the choice of the method, and restricts an area and the topic which is examined. A clear definition of the chosen inventory objective does not exclude the other standpoints, but emphasis would be put on the principal purpose. From the variety of typical inventory needs by public or private institutions or research projects, the following ones are the most widely defined objectives:

- Geoconservation: recording of geological values primarily by their scientific importance, their vulnerability, creating an input for their strategy of conservation and management
- Geotourism: surveying of the chosen territory is focusing on the touristic potential, how the sites could be exploited as potential sights, what type of infrastructure is available and needed for interpretation
- Outreach and geoeducation: the main consideration during recording geosites is to demonstrate which ones, and how, could be used in educational activities (on different levels), or for popularization of geosciences.

The topic for certain projects might focus on the general description of geoscientific values, while others are restricted to certain subjects or geological contexts such as volcanology (e.g. SZEPESI ET AL 2017), alpine environment (REYNARD ET AL 2011), or mineralogy.

I/C/1/e The way of evaluation: quantitative or qualitative inventory

From the practical viewpoint, one of the most important questions is the structure of the assessment. Quantitative and qualitative are the main approaches for this consideration. Certain methods combine the two, and can be referred to as semi-quantitative methods. It must be noted, that in each case, the methods should be backed up by sound cartographic material, figures and photographs.

Potential geosites could be evaluated textually, describing their attributes through a number of fields. Qualitative evaluation methods has been used since the beginning of direct geoconservation attempts (e.g. the UK Sites of Special Scientific Interest – WIMBLEDON ET AL 1995). They are often made specifically for defined reasons and areas, therefore they are highly adapted for local conditions. On the other hand, textual description bears a certain level of subjectivity.

Quantitative assessment numerically evaluates the relevance of geoheritage values. One of their main aims is to reduce the inevitable subjectivity of each inventorying attempt. The usage of indicators could be adapted to the purposes of the inventory, but the numerical values facilitates interoperability of the selected method in other researches or territories, making the results comparable. Also, the ease of repetition of such methods raises the possibility of reducing subjectivity. Quantitative evaluations are generally faster to be implemented than textual descriptions, therefore a higher number of participants could fill in the same survey for a potential geosite, whether they are professionals, experts or visitors (TOMIĆ & BOŽIĆ 2014). For a large area or a high number of sites to be evaluated, it is certainly a more viable choice, while for limited territories, either qualitative or quantitative methods could meet the requirements (BRILHA 2018A).

Since the pioneering methods of GRANDIGARD (1999) or REYNOLDS (2001) focusing on scientific values, a number of methods were published and used in case studies adding more indicators (e.g. BRUSCHI & CENDRERO, 2005, PRALONG & REYNARD, 2005, ZOUROS 2007, PEREIRA ET AL 2007, RYBÁR 2010, FASSOULAS ET AL 2012). Published methodologies often build on previous systems, incorporating certain elements, updating frameworks with new considerations (e.g. REYNARD ET AL 2007 – REYNARD ET AL 2016).

Semi-quantitative assessments are an intermediate solution, incorporating both techniques for recording the information. *Sensum stricto*, pure quantitative methods do not exist as every method includes a basic, textual description of sites (e.g. name, owner, area). Those methods should be considered semi-quantitative, in which the textual indicators significantly outnumber, or equal to, the numerically assessed values. A good example of this category is the French National Geosite Inventory (DE WEWER ET AL 2015), where 9 numerical indicators were used besides a significant number of textual evaluation fields.

I/C/2 Considerations of choosing the inventories of the PhD research

With the current lack of globally acknowledged and usable inventory methods, universally adaptable for various scales and purposes, four distinct methods were chosen and used in the research areas of the present thesis. Not all the methods were applied to each project, but in most cases, multiple methods were used parallel, and their results were compared in order to give an overview of their performance as well as the geoheritage area itself. The present thesis does not give an extensive comparison of the numerous, available methods, but relies on previous comparative studies. The results of KUBALIKOVÁ (2013), STRBA ET AL. (2015) and SZEPESI ET AL. (2018) were used to choose the two principal workflows of the thesis.

The inventory methods of VUJIČIĆ ET AL. (2011) and BRILHA (2016) were compiled with the intention of synthesizing previous assessment techniques. Being quantitative techniques with a reasonable number of indicators and questions, the assessment is easily done, repeatable, and the obtained results can be well-summarized in a textual and visual form as well. The majority of the questions were not scale-dependent, nor optimized for any particular national geoconservation framework, therefore they could be used well in different geological and geographical contexts as well.

The method of REYNARD ET AL. (2016) was used in the case study about *Dallol*, as the first quantitative geosite inventory of the country in the *Simien Mountains* (MAUERHOFER ET AL. 2017) had been carried out using this workflow. Even if it is not officially selected as a national inventorying method, the comparability with the previous study calls for the application for this method. This was also a consideration for the utilization of the French national workflow by DE

WEVER ET AL. (2015). It allows the future integration of results to the national system, and also ensures putting the results of this thesis in the French context.

I/C/3 VUJIČIĆ ET AL. 2011

This entirely quantitative method (Geosite Assessment Model aka. GAM) uses 27 indicators, each evaluated with a grade between 0-1. The indicators have two groups, the *Main Values* (MV) and the *Additional Values* (AV), summarized in *Table 1.1*. Results are represented on a matrix, where MV on the horizontal axis is plotted against AV on the vertical one. The matrix can be further divided into 9 zones, by trisecting both axes, where $Z(i,j)$ ($i,j=1,2,3$) and i represents the horizontal and j the vertical axis zone number. Each zone could give an overview of the present situation of a geosite and a quantified justification for future conservation and tourist development. For example, $Z_{(3,1)}$ indicates that main values are significant, but additional values are low, implying sites with high scientific and/or aesthetical values; a low score of AV indicates that the geosite is not exploited yet by geotourism and/or development could be recommended.

TOMIĆ & BOŽIĆ (2014) published an extended version of GAM, the M-GAM (Modified Geosite Assessment Model), which includes the opinion of tourists concerning the importance of indicators in the assessment process. Each respondent rated the *importance* (Im) of the 27 GAM sub-indicators on a scale of 0 – 1. The M-GAM values were calculated by the multiplication of the GAM values, generated by previous expert elicitation (TOMIĆ & BOŽIĆ 2014)

Table 1.1 Synthesis of the geosite assessment method of VUJIČIĆ ET AL. (2011) and TOMIĆ & BOŽIĆ (2014)

MAIN VALUES (MV)			ADDITIONAL VALUES (AV)	
Scientific/Educational (VSE)	Scenic/Aesthetic (VSA)	Protection (VPr)	Functional (VFn)	Touristic (VTr)
Rarity	Viewpoints	Current condition	Accessibility	Promotion
Representativeness	Surface	Protection level	Additional natural values	Organized visits
Knowledge on geoscientific issues	Surrounding landscape	Vulnerability	Additional anthropogenic values	Vicinity of visitors center
Level of interpretation	Environmental fitting of sites	Suitable number of visitors	Vicinity of emissive centers	Interpretative panels
			Vicinity of important road network	Number of visitors
			Additional functional values	Tourism infrastructure
				Tour guide service
				Hostelry service
			Restaurant service	
MV = VSE + VSA + VPr			AV = VFn + VTr	
Each sub-indicator marked on a rank of 0 - 1 (0.25 Likert-scale). Some indicators limited to 0, 0.5, 1 values (Vujić et al 2011)				
Modified Geosite Assessment Method (M-GAM) by Tomic & Božić (2014): each sub-indicators importance (Im) assessed by individual visitors in the following way				
$MGAM = Im \star GAM = Im \star (MV + AV) = \frac{\sum_{k=1}^K I v_k}{K} \star ((VSE + VSA + VPr) + (VFn + VTr))$				

where Iv_k is the score of one visitor for each subindicator and K is the number of total visitors

I/C/4 REYNARD ET AL. 2016

The method of REYNARD ET AL. (2016) is an updated version of REYNARD ET AL. (2007), a predominantly quantitative geosite assessment method. From its two main groups, *Central* or *Scientific Values* are always assessed numerically, while this is optional for the *Additional Values* in the updated version of the method (REYNARD ET AL. 2016). Each criterion is evaluated on a scale from 0 – 1, and the sub-criteria are averaged using an arithmetic mean (Table 1.2). The *Central Value* of a site could be an average of its criteria (REYNARD ET AL. 2007), but they could also be weighted according to the research purpose (REYNARD ET AL. 2016).

Table 1.2 Synthesis of the geosite assessment method of REYNARD ET AL. (2007) and REYNARD ET AL. (2016)

SCIENTIFIC VALUE (SV)	ADDITIONAL VALUE (SV)		
	Ecological Value (ECOL)	Aesthetic Value (AEST)	Cultural Value (CULT)
Integrity (Int)	ecological impact (Ecl)	viewpoints (VP)	religious importance (REL)
Representativeness (Rep)	protected site (PS)	contrasts, vertical development and space structuration (STR)	historical importance (HIS)
Rarity (Rar)			artistic and literature importance (ART)
Paleogeographic value (PgV)			geohistorical importance (GEO)
			economic value (ECON)
$SV = \frac{Int + Rep + Rar + Pgv}{4}$	$AV = \frac{ECOL + AEST + CULT}{3}$		
Each criterion is marked on a rank of 0 - 1 (0.25 Likert-scale)			
Quantitative assessment of AV is facultative in Reynard et al (2016), weighting of indicators are possible			

I/C/5 BRILHA 2016

Four set of indicators are defined in this quantitative method (Table 1.3), where *Scientific Values* (SV) and *Degradation Risk* (DR) should be assessed in all cases, since scientific importance is the crucial requirement of a geosite and the characterization of degradation is a minimum requirement for any conservation and management plan. Assessment of *Potential Educational* (PEU) and *Touristic Values* (PTU) can also be evaluated for geotouristic or geoeducational development plans, and these values are inevitable for geodiversity sites which do not possess scientific significance. For the two latter sets of values, 10 indicators are common and should be assessed from both educational and touristic viewpoints and they contain 2 and 3 standalone criteria. Each indicator is marked on a scale of 1 to 4, with two remarks: score 3 is omitted at SV in order to better distinguish the score 4 sites from lower scoring ones, and 0 can be given as a value where it is irrelevant. Each indicator is weighted by its importance, summing up to 100 per set of values. The final value is given by

multiplying the scores of each criterion by these weights, and it should total in 400 in each case (SV, PEU, PTU, DR).

Table 1.3 Synthesis of the geosite assessment method of BRILHA (2016)

SCIENTIFIC VALUES (SV)		POTENTIAL EDUCATIONAL VALUE (PEU)		POTENTIAL TOURISTIC VALUE (PTU)		DEGRADATION RISK (DR)	
Criterion	Weight	Weight	Criterion	Criterion	Weight	Criterion	Weight
A. Representative-ness	30	10	A. Vulnerability		10	A. Deterioration of geological elements	35
		10	B. Accessibility		10		
B. Key locality	20	5	C. Use limitations		5	B. Proximity to areas/activities with potential to cause degradation	20
C. Scientific knowledge	5	10	D. Safety		10		
		5	E. Logistics		5		
D. Integrity	15	5	F. Density of population		5	C. Legal protection	20
E. Geological diversity	5	5	G. Association with other values		5		
		5	H. Scenery		15	D. Accessibility	15
F. Rarity	15	5	I. Uniqueness		10	E. Density of population	10
G. Use limitations	10	10	J. Observation conditions		5		
		20	K. Didactic potential	K. Interpretative potential	10		
		10	L. Geological diversity	L. Economic level	5		
				M. Proximity of recreational areas	5		
<i>Each criterion assessed on a rank of 1-4. 0 values are permitted. Value of 3 is omitted at SV</i>							
<i>Maximum points of 400 per each sets of values (SV, PEU, PTU, DR), with the multiplication of criterion points with the weighting</i>							

I/C/6 Inventaire National de Patrimoine Géologique (INPG)

The *Inventaire National de Patrimoine Géologique* (INPG) is the comprehensive framework that controls and guides the assessment of geoheritage, as well as the collection, processing and publication of geoheritage data in France. The conceptual background and the description of the methodology was first published by DE WEVER ET AL. (2006), and updated later as ‘Géopatrimoine en France’ (DE WEVER ET AL. 2014). A publication in English summarizes this work and addresses its global relevance (DE WEVER ET AL. 2015).

The INPG is a predominantly qualitative assessment form, with numerous fields for text description, but also includes some quantitatively assessed criteria. Information is grouped into fields, namely *Identification*, *Localization*, *Physical Description*, *Geological Description*, *Interests*, *Status*, *Vulnerability/Need for protection*, *Documentation and Sources*. Textual fields appear as a list of options (e.g., *Accessibility*, *Actual State*), while in other cases, a detailed, free text description is permitted or required (e.g., contact information, itinerary for access, justifications for the scoring of *Pedagogical Interest*, *Natural hazards*, etc.).

Quantitatively assessed criteria are organized into two groups (Table 1.4). The first, *Geoheritage Interest* (*‘intérêt patrimonial’*), consists of *Primary* and *Secondary Geological Interest*, *Rarity*, *Preservation Status*, *Educational Interest*, and *Importance for the history of geology* (Geohistorical Importance). Each of these criteria is scored on a scale of 0 to 3, and then the values are multiplied by a coefficient (weighting) and summed up, 48 points being the maximum total score. According to their total score, geosites receive an importance grade marked with a number of so-called ‘geoheritage interest stars’ (from 1 to 3) that can be used to compare between similar sites in order to assess their regional, national or international importance. The total score of the second group, the *Vulnerability and need for protection* is calculated separately (Table 1.4). *Natural Vulnerability*, *Anthropic Threats* and *Effective Protection* are measured here as individual criterion, also on a scale of 0–3. The number of ‘geoheritage interest stars’ is also used as a fourth criterion. Values for each criterion are summed without a weighting, with 12 points being the maximum score.

Table 1.4 Synthesis of the national geosite inventorying method of France, the INPG, based on DE WEVER ET AL.. (2015)

GEOHERITAGE INTEREST					VULNERABILITY AND NEED FOR PROTECTION	
Criterion	Scale	Coefficient	Geoheritage interest rating		Criterion	Scale
Primary geological interest	0 (Minimal interest) – 3 (Remarkable)	4	≤ 10	0 star	Heritage interest	0 - 3 (geoheritage interest stars)
Secondary geological interest	0 (No interest) – 3 (Remarkable)	3	11 - 20	1 star (*)	Natural vulnerability	0 (no threat) – 3 (extreme threat)
Educational interest	0 (No interest) – 3 (Remarkable)	2	21 - 30	2 star (**)	Anthropic threats	0 (no threat) – 3 (extreme threat)
Interest on the history of geology	0 (No interest) – 3 (Remarkable)	2	31 - 48	3 star (***)	Effective protection	0 (maximum) – 3 (complete lack)
Rarity of the site	0 (Common) – 3 (Rare)	3			Summation	12 points in maximum
Preservation status	0 (Poor) – 3 (Good)	2				
Summation	48 points in maximum (scale*coefficient)					

I/D Disaster risk reduction and resilience

Hazard, *risk*, *danger*, *disaster*, words that are used more and more frequently not just in administrative documents and scientific literature, but in the news as well. They are often quoted as synonyms, although they cover different aspects of a concept that is also connected with rapidly emerging terms, like *resilience* or *mitigation*. In the following chapter, after a brief historical overview of natural disasters and their management, the definition and the conceptual relations of the most important terms will be provided.

I/D/1. A brief historical overview of disaster risk reduction*I/D/1/a Roots and early forms of mitigation*

Natural processes of Earth have been always connected with events that affected all elements of its system, e.g. global flora and fauna were severely hit by the asteroid impact that led to the Cretaceous–Paleogene extinction event. Humans have also been affected, since their appearance, and with each of our technological breakthroughs, our infrastructure, such as buildings and agriculture, also became exposed to hazards. Human changes have also altered the environment, both locally and globally, leading to human-induced disasters.

There are numerous accounts on disastrous events, related to nature- or human-induced catastrophes, such as the eruption of *Vesuvius* in AD. 79, the great plague of the 14th century in Europe, or the 1556 *Shaanxi* earthquake, the latter with an immense death toll of 830,000 people. Communities, exposed to certain well-known hazards, adapted successfully and used resilient solutions, such as the earthquake-resistant baroque churches of the Philippines or the equally earthquake-resistant houses of the Inca Empire (BANKOFF 2003). Improved techniques and institutionalization of effective disaster responses and mitigation were especially associated with the period of the industrial revolution, such as the appearance of official fire services.

I/D/1/b Institutionalization

The rapid expansion in population and a dramatic increase in global infrastructure after the Second World War and the growing awareness of environmental issues, including climate change, were all propagating factors for initiating a broad-scale set of actions on disaster management worldwide. In 1971, the United Nations Disaster Relief Office was set up, with the purpose of promoting the study, prevention, control and prediction of natural disasters and providing advice to governments on pre-disaster planning (UNDRR 2020). National frameworks for disaster management were also set up, often instigated by distinct destructive events. A good example of this is the Philippines, one of the most hazard-affected country on Earth. Based on isolated cataclysms like the 1991 eruption of *Pinatubo* and recurrent events like earthquakes and the yearly series of typhoons, the Philippines set up a number of institutions, such as PAGASA for hydrometeorological, or PHILVOLCS for volcanic and seismic hazard assessment and monitoring, or legislative acts, such as the ‘Philippine Disaster Risk Reduction and Management Act’ of 2010 (UNDRR 2019), and most recently the Resilience Institute of the University of the Philippines.

The 1990s were named as the ‘International Decade for Natural Disaster Reduction’ with the first World Conference on Disaster Reduction in *Yokohama*, Japan in 1994. It raised the awareness of the international community to the major threats of natural disasters and that a global culture of

prevention is required (UNDRR 2020). It took its official form in the ‘Hyogo Framework’ in 2005 that was improved and replaced by the ‘UN Sendai Framework for Disaster Risk Reduction 2015-2030’. This functions as the current set of common standards, a comprehensive framework with achievable targets, and a legally-based instruments for disaster risk reduction (UNDRR 2015).

Although YIU & MOORE (1985) noted that disaster risk reduction cannot afford the luxury of theoretical debates, due to the frequent and immediate need of response in the management of disasters and mitigation of risks, this theoretical background has also advanced, and is more and more being applied to the practical. This is especially true of the terminology noting that basic concepts such as *hazard*, *risk* or *resilience* are still often differently interpreted and used in documents. The scientific literature of the domain is flourishing with dedicated journals such as *Natural Hazards* or *Risk and Resilience*, and a plethora of studies on conceptual questions, the interpretation of past and future disasters, hazard, vulnerability and risk assessments. This can help dealing with disasters, but it should not be forgotten that practical response and basic preparedness is worth a ton of scientific papers (VAN WYK DE VRIES: personal communication).

I/D/2 Terminology

In the following section, the principal terms of disaster risk reduction and resilience are defined and interpreted. The definitions are based on the terminology of the ‘United Nations International Strategy for Disaster Reduction’ (UNISDR 2009), where not marked otherwise.

I/D/2/a Disaster risk reduction

The term, mostly used in official documents, such as the ‘Sendai Framework’ (UNDRR 2015) or the United Nations Office for Disaster Risk Reduction, should be considered the synthetic name of the domain, focusing on identifying and managing hazards, risks, disasters and the preparedness for them. Here, in this thesis, it is also used as a collective term.

‘The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster.’

I/D/2/b Hazard

‘A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.’

Hazards can be grouped principally into human-induced types, such as epidemics (in the sense that they can be generated and transmitted by humans), technological hazards, conflicts and those related to natural processes. This latter can be further divided into geological hazards related to internal earth processes (seismic activity, mass movements, volcanic activity) and hydrometeorological hazards (e.g. floods, droughts, extreme temperatures, tornadoes, etc.), related to the outer Earth processes.

I/D/2/c Risk / disaster / disaster risk

Risk is frequently used in common parlance as a synonym of hazard, although the latter is considered rather as an element of risk, not an equal term of it. According to the UNISDR (2009) definition, risk is:

‘The combination of the probability of an event and its negative consequences.’

Alternatively, it is often quoted with the equation terms, as risk is equal to relevant hazard(s) combined with the vulnerability (UN DHA 1992), or even adding exposure (see *I/D/2/f*) as a third element of risk (e.g. BLONG 1996). A detailed, selected list of definitions can be found in KELMAN (2003) and BROOKS (2003)

Disaster is often used as synonym of risk in popular articles or even in reports and study materials (such as VSO 2019). However, according to UNISDR (2009) terminology, disaster is:

‘A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.’

In this sense, disaster can be interpreted as those risks (combination of hazards, exposure and its vulnerability) in which the capacity to cope or reduce the impact of an event and its negative consequences (~ the resilience) was insufficient. The term *disaster risk* (see below) also reflects this concept, i.e. disasters are outcomes of continuously present conditions of risk:

‘The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.’

I/D/2/d Stress, shock

According to BROOKS (2003) hazards can be I) discrete, recurrent events, II) discrete, singular events that only appear for a relatively short time with changes in conditions (e.g. related to volcanic events), III) continuous hazards (effects of climate change on temperature, rainfall, etc.). The present conditions of hazard(s), considering the vulnerability of exposed elements, could be affected by continuous influx of impacts that after a certain point might lead to a disaster. Stress is (VSO 2019):

‘A long-term trend that undermines the potential of a given system and increases the vulnerability of actors within it.’

On the contrary, short-term impacts, which overcome the resilience of a system, could also lead from a present condition of risk to a disaster. Shock is (VSO 2019):

‘A sudden event that impacts on the vulnerability of a system and its components.’

I/D/2/e Exposure, vulnerability

These two terms are mostly quoted together, sometimes with overlapping definitions, having a different interpretation from a biophysical or social viewpoint (see ADGER 1999, BROOKS 2003). In this thesis, the concept and definitions of UNISDR (2009) is followed. Here, exposure is a given set of elements (e.g. people, natural objects) that might be affected by a hazard:

‘People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.’

The term vulnerability encompasses those factors (physical, social, economic, environmental) that make the exposed elements susceptible to a hazard:

‘The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.’

To give some actual examples on the relationship of the two terms: I) a building (exposure) of inadequate design to withstand certain hazards (vulnerability), II) a community (exposure) living in a hazardous area with lack of information and awareness (vulnerability).

I/D/2/g Resilience

A term, originally used in mechanics, and coined from the 1970s in ecology and social sciences, has become an important, yet sometimes debated concept of disaster risk reduction (ALEXANDER 2013). Resilience is (UNISDR 2009):

'The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.'

The resilience of a system principally relies on its full capacity to act, *'the combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals'* (UNISDR 2009). These capacities can be I) absorptive, using predetermined coping responses to preserve and restore essential basic structures and functions (CUTTER ET AL. 2008, BÉNÉ ET AL. 2012, UNISDR, 2009), II), adaptive, adjusting, modifying or changing a system's characteristics and actions to moderate potential, future damages (IPCC 2012, BÉNÉ ET AL. 2012) and III) transformative, the ability to create a fundamentally new system when ecological, economic or social structures make the existing system untenable (WALKER ET AL. 2004).

I/D/2/b Mitigation

The concept of mitigation is closely connected to prevention, as it is a proactive measure. It is:

'The lessening or limitation of the adverse impacts of hazards and related disasters.'

The scale or severity can be eliminated or reduced by various mitigation strategies and concrete actions, such as hazard-resistant constructions, environmental policies or raising public awareness.

I/D/3 The conceptual framework of disaster risk reduction and resilience

This thesis principally relies on the definitions of UNISDR (2009), but for establishing a more solid context for terms, it also takes into account the concepts of other authors, as described in section I/D/2. Based on this terminology, *Fig. 1.2* summarizes the relation between the terms of disaster risk resilience.

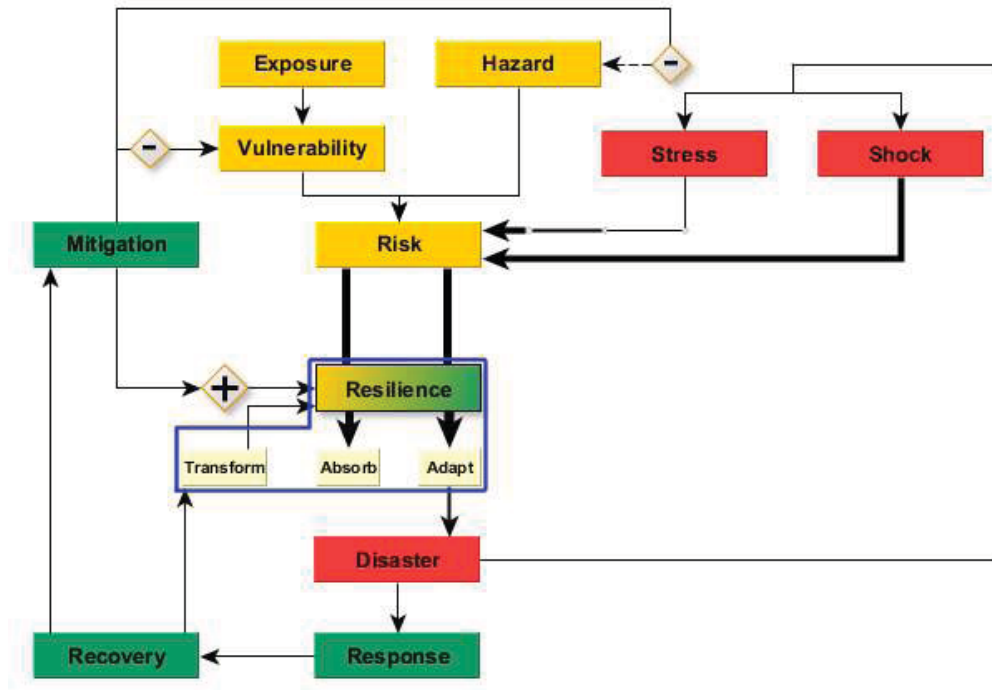


Fig. 1.2 The concept of disaster risk reduction and resilience in this thesis

Communities, elements of infrastructure or natural systems are the **exposure** of a system that have certain characteristics that define their **vulnerability** towards different hazards. **Hazards** are potentially dangerous phenomena that may cause a disruption or damage to exposed elements. With this connection, the present hazards multiplied with the vulnerability of exposed elements are the **risks**, which are present in a certain area for a certain time (continuously, recurrently, once). The risk is a probability/eventuality that only becomes a **disaster** if affected by a one-time significant event (**shock**) or a long-term trend that overrides the capabilities of a system (**stress**). The capacities of the system are its **resilience** that could absorb (prevent) certain events, or they will define the conditions how the exposed elements could react, adapt to a risk, when it becomes an event.

A disaster, on one hand, might be followed by new events (shock, stress) that could lead to a new disaster. On the other hand, the exposed elements give certain immediate **responses** to a disaster followed by a longer **recovery** process.

Mitigation, as a form of preparation for risks, could reduce the presence or severity of hazards, or the exposure (e.g. moving communities, enforcing infrastructure) in certain areas. This also leads to an improved resilience as well, that helps tackling of future events more effectively. A desirable recovery process is also connected with mitigation efforts that also transforms the resilience of a system in accordance with the new conditions after disaster events.

I/E The connection of geoheritage and resilience

In the previous sections, the most important aspects of geoheritage, inventories and assessment of geoheritage and disaster risk reduction (often referenced later as DRR) and resilience were summarized. Geoheritage can play a significant role in improving the resilience of communities and visitors in various ways, such as reducing exposure and vulnerability, raising awareness on hazards, propagating more effective means of mitigation, or even responding to disaster risk. In the next section, the most important aspects of the role of geoheritage in resilience will be discussed through the current objectives of international frameworks and considering the potential of the three main aspects of geoheritage: **geoconservation**, **geoeducation** and **geotourism**.

Currently (2020) a detailed summary about the role of geoheritage in resilience is not available, and this short summary principally relies on selected case studies and considerations that could be later transformed with a broad-scale geoscience community contribution to a comprehensive framework.

I/E/1 The commitment of international frameworks

Section I/B/1 has already pointed out that early traces of geoconservation practices are visible in human history and some dedicated steps were taken starting from the 19th century. However, the international recognition of geoheritage is still lagging behind cultural heritage, or biodiversity in its inclusion in key documents and protection frameworks (LARWOOD 2013, BRILHA 2018B, GORDON ET AL. 2018). Although direct references are still limited, geoheritage can be read into statements about biodiversity or cultural heritage, opening a direction of future update and compilation into international policies.

I/E/1/a Disaster risk reduction frameworks: Hyogo (2005) and Sendai (2015)

Geological factors only appear directly in the ‘Hyogo Framework’ (UNISDR 2005) in the context of being hazards that should be mitigated (see points 2, 18/o, 19, 30/g). In terms of heritage, the ‘Sendai Framework’ (UNDRR 2015) mentions cultural heritage elements as exposures (e.g. I/5). Natural heritage is not directly mentioned, but the vulnerability and exposure of ecosystems appear in the same section. The ‘Hyogo Framework’ mentions in paragraph 18/i/a (UNISDR 2005) the provision of ‘... *understandable information on disaster risks and protection...incorporate relevant traditional and indigenous knowledge and culture heritage...*’. The ‘Sendai Framework’ expands this with ‘...*ecosystem-based approaches with regard to shared resources...to build resilience and reduce disaster risk...*’ in 28/d and ‘...*preserving ecosystem functions that help to reduce risks...*’ at 30/g (UNDRR 2015). Although geoheritage is not directly mentioned in the recent DRR frameworks, its potential in resilience building can be traced through ecosystem approach and cultural heritage applications. Taking into

account geodiversity as a key element of ecosystems (no ecosystem can exist without its geosystem base), it could contribute to reducing risks (e.g. flood-planning, carefully considering the hydrological regime of river systems), and knowledge on geoheritage (e.g. historical accounts and the memory contained in physical sites of past disasters) could effectively contribute to risk management.

I/E/1/b World Heritage

The original text of the ‘World Heritage Convention’ (UNESCO 1972) does not contain any references to risk or resilience as the domain of DRR, as its acknowledgement in UN policies was just beginning when the convention was drawn up. However, importance of educational activities and the role of World Heritage sites to raise awareness was explicit from the start. The roles and responsibilities of the World Heritage Committee and its sites in terms of DRR was addressed in the ‘Strategy for Reducing Risks from Disasters at World Heritage’ properties in 2007. It acknowledges that ‘*Cultural and natural heritage...can play an important positive role in reducing risks from disasters at all phases of the process (readiness, response and recovery)...*’ (UNESCO-WHC 2007). Among its five objectives, the role of knowledge and education in building a culture of disaster prevention, the identification, assessment and monitoring of risks, and reduce underlying risk factors (aka mitigating) are all considerations that could contribute to the resilience of World Heritage properties and people associated with them (local communities and visitors). A special publication on *Managing disaster risks for World Heritage* (UNESCO 2010) was issued, and a similar, dedicated summary on the management of natural World Heritage sites (UNESCO 2012) also contains references on the importance of effective risk management at sites with practices of mitigation.

On the level of policies, the commitment for endorsing mutual cooperation between natural World Heritage properties and the domain of DRR is well established, but they are not fully implemented in practice. CORATZA & DE WAELE (2012) noted for some Italian examples that the clear interpretation on the connection of geosites and their underlying or past risks is often missing or only moderately expressed. Another concern is that disaster mitigation plans for World Heritage properties are still not always implemented (UNESCO 2010), which might affect several sites with geoheritage values.

I/E/1/c UNESCO Global Geoparks

Geoparks, with their mission on the broad scale valuing of Earth's geodiversity, have had a commitment to understand and interpret geohazards in their territories since the early stages of the geoparks movement. This dedication was officially declared during the 5th UNESCO Global Geoparks Conference in the 'Shimbara Declaration'. It states that '*Education ... is the most effective way to help our local communities understand how to coexist with nature which occasionally generates geohazards*' and '*geoparks hold records of past climate change and, as such, we must be at the forefront of the debate on climate change with our local communities and stakeholders...should be educators on climate change*' (GGN 2012). The guidelines of the International Geosciences and Geoparks Programme also underlines (ref. 3/ii) that '*UNESCO Global Geoparks should use that heritage...to increase knowledge and understanding of: geoprocesses; geohazards; climate change...*' (UNESCO-IGGP 2015).

There is abundant literature on the practices of raising awareness on geohazards in geoparks, such as LIMA ET AL. (2014) or ZOUROS ET AL. (2011). The interpretative practices described in the latter paper about faults and earthquakes had proven their positive effect on improving the resilience of local communities, as during the June 2017 earthquake in *Lesvos*, where there were no casualties and many schoolchildren knew how to react in the disaster situation, benefitting from the educational activity of the geopark.

I/E/2 Geoconservation

Similar to that geodiversity covers the full range of formations and landscapes with different characteristics, management and protection practices are also diverse, often highly adapted to local, special circumstances. This section gives a general overview of the most important issues; specific cases can be found in relevant journals and books, such as REYNARD & BRILHA (2018).

Geosites should be considered almost universally as exposed elements, as they are vulnerable to natural processes, whether those associated with their creation (i.e. endogenic processes: earthquakes, faulting, volcanism,), or other natural hazards that might affect them, like hydrometeorological hazards. A recent, symbolic example of this is the *Azure Window* in Malta, an abrasional arch that collapsed in 2017 due to the same processes that were responsible for its appearance (SATARIANO & GAUCI 2019). They could be vulnerable to human influence as well, from erosion of paths and disruption connected to massive visiting or to unauthorized collection of rocks and or fossils until the partial or total destruction of sites by construction works.

On the other hand, sites with geoheritage values themselves might be hazardous as well. Elements of infrastructure, people or flora and fauna elements are often situated in the vicinity, permanently or just temporarily (e.g. visitors at a site). Outcrops could produce landslides or

rockfalls, active volcanic areas with high aesthetic values are related to several potential or continuously present hazards (ERFURT-COOPER 2011), changes of hydrological regimes (floods or droughts on the contrary) could have serious impacts.

In this way, geoconservation practices have two main objectives: protecting the site itself for its intrinsic values (as exposed elements), and protecting the associated exposures as well. These initiatives are generally connected to each other and both of them could improve the resilience of the geosite's environment as a system. Hazards could be minimised at well-maintained sites, where the natural landscape forming processes predominate, are monitored and / or guardedly regulated, and where anthropogenic influence is limited. In this way, they should function with their highest possible integrity and for the longest time as important elements of the ecosystem (e.g. a landform crucial in a hydrographical regime of an area, or geosites as habitats for flora and fauna). From the anthropogenic viewpoint, geosites of lowered or limited hazards could be used for further purposes in this way such as geoeducation, geotourism. If hazards are too significant, their potential negative effects should be mitigated, but only making sure the intrinsic values are not compromised.

From the plethora of available geoconservation practices, here are some examples that could help with reducing the exposure and hazards at sites of geoheritage values.

I/E/2/a Identification

The key point of any resilience management plan in areas of geoheritage is to identify risks (hazards, exposures and their vulnerability) at geosites and as a counterpart to identify geosites in areas of risks. Inventorying and assessment of the geoheritage areas should include references to this issue, whether in the form of textual description or numerical assessment, as described at the selected methods of *section I/C*. Risk assessment of certain areas is often created for different purposes (e.g. geological exploitation, construction projects), but they could help identifying valuable elements of geodiversity as well. For example, by mapping underground cavities to identify dangers of collapse in urban environments, new geosites can be found. It would be desirable in the future to bring closer the following two aspects: I) carrying out the risk assessment of geoheritage areas which has already started for some natural World Heritage sites (UNESCO 2010) and geoparks (FASSOULAS ET AL. 2018), and II) properly underline the importance of geodiversity in risk assessments. For example, geodiversity could be assessed in development plans of construction sites, mining activities, etc., something already done for biodiversity or cultural heritage, both in terms of mentions in planning documents or employing experts during decision making.

I/E/2/b Monitoring

In order to identify changes in the number of exposed elements and their vulnerability, key factors of the system associated with geosites should be followed up. For example, natural processes like changes in hydrothermal activity (see *chapter IV* or VEREB ET AL. 2020B), the erosion rate of landforms or the hydrographical regime of waterbodies should be monitored regularly to detect ongoing or potential changes in the geoheritage values, or hazards associated to the property. Anthropogenic processes, like number of visitors and their behaviour at affected sites, temporal and spatial patterns of urbanization should be also followed up, as they could have an impact on the geosites themselves, but might change the interactions between the property and the associated exposures as well.

I/E/2/c Conservation / stabilization

Depending on the nature and quality of a geosite, it should be preserved from natural and human processes, or negative impacts on exposed elements should be prevented, such as mass movements, associated hydrometeorological hazards. Parts of the geo(morpho)sites could be modified, with adding or removing their certain elements or using techniques that could contribute to their integrity. One of the most typical examples of this latter is slope stabilization, in forms of reinforcing the walls of outcrops with adding protective elements or removing dangerous sections (see *chapter III* or VEREB ET AL 2020A), using erosion-resistant solutions for trails, ensuring the drainage of the site, etc.

I/E/2/d Management

A geoconservation plan of a certain geosite or a wider area should carefully consider the practices that ensure the protection and takes into account its usage as well, based on the vulnerability of its related exposed elements. In protected areas, such as World Heritage sites, geoparks or nationally designated properties, it could mean that (geo)touristic visits are strictly prohibited or limited at certain sites, or the flow of people is regulated with proposing alternative routes, guided tours. Generally, the legal protection of sites and areas (not just with geoheritage values, but similar initiatives of biodiversity and cultural heritage as well) could contribute to mitigating hazards with effective conservation actions (see previous point). It could also be helpful for permanent exposures by limiting urbanization and large-scale infrastructure projects. It must be noted that the visits at sites might mean a more significant temporal exposure based on the number of visitors, although it can be relatively easier to mitigate with limiting practices, as described before.

At geosites isolated from larger protected areas (and often lacking site-specific protection), especially in urban areas, a balance has to be found between human activities and infrastructure as

well as the remaining natural areas. It might include the incorporation of a site into the urban fabric (see *chapter III* or VEREB ET AL 2020A), reconsideration of development plans, or removing elements or the integrity of a site to preserve it as ex-situ geoheritage (e.g. fossils, minerals).

I/E/3 Geoeducation

Identified geosites or facilities like dedicated museums and visitor centres have a significant education potential, as underlined for example by CORATZA & DE WAELE (2012) or ZOUROS ET AL. (2011). With a well-developed concept of interpretative panels, exhibitions, educative programs, they could contribute significantly to improve the resilience of visitors by describing geohazards, explaining the vulnerability of natural systems, but also human society to natural and human-induced hazards and demonstrating some mitigation techniques as well.

Probably the highest education potential is associated with past disaster sites, where the impacts of a hazard and how the exposed elements reacted to that (i.e. how was their resilience) are clearly visible and well interpretable. CORATZA & DE WAELE (2012) and MIGOÑ & MIGOÑ (2019) collected some examples, demonstrating that many geohazards have very evident representations as geosites, where disasters with a serious impact on society can be well-examined. Examples include the viewpoints of the 1963 *Vaiont* landslide area or the interpretation site of the 1999 *Wufeng* earthquake in Taiwan. However, the level of their interpretation in practice greatly varies: at many cultural designated properties the responsible geohazards are only partially or not explained, such as at the site of *Tangiwai* rail disaster (New Zealand) or *Pompei* and *Herculaneum* (MIGOÑ & MIGOÑ 2019).

Another issue is the disappearance of these sites, either by natural processes or the recovery of the affected areas, potentially eradicating most of the evidence of the disaster event. Eradication may help with the treatment of the post-disaster trauma, but such disappearance from the common knowledge could reduce the resilience of the once affected communities (MIGOÑ & MIGOÑ 2019). This is the point where cultural heritage has a responsibility to preserve past geohazards through commemorative plaques, historical archives, etc., in cases when the original geosites are not available anymore.

Only a part of the geosites could be related to disasters that had a documented impact on human societies. The majority of sites were formed during significantly more distant eras of the geological timeline. Even at sites where significant hazards are present like mass movements, they are often not interpreted due to the lack of previous reports on disaster events. However, these properties also have a significant educational potential. A good example of this is the *Chaîne des Puys – Limagne Fault* natural World Heritage site in France (see *chapter II*). The iconic monogenetic volcanoes formed during the Pleistocene/ Holocene are not likely to reawake individually again, but the area

itself is still potentially active to the birth of new volcanoes. Therefore, selected geosites (different types of scoria cones, maars, etc.) could improve knowledge on the typical and probable eruption types that might happen in the future, and this way the affected communities could react to this with improved resilience.

Geosites could generally improve the awareness of the natural world and environmental issues. GRAY (2019) concluded the case of *Birling Gap*, a chalk cliff in England, which shows excellently the erosion rate of abrasion that now affects a hamlet, and where the scientific value was preserved rather than the affected private property after legislative decisions. Quarries used as geosites, or gullies, where some of them are formed due to human-induced deforestation (ZGŁOBICKI ET AL. 2015), could illustrate well the anthropogenic impact on our environment, contributing to social awareness to push decision makers to sustainable development practices, instead of projects with significant environmental impact.

Interpretation centres, museums and exhibitions, dedicated to the issues of geoheritage, could be the third spatial category to contribute to education, therefore building resilience as well. As conservation and preservation spots of ex-situ geoheritage (removed from its original locality), they could contribute to awareness on nature as described before. They also have the potential to placing these geoheritage ‘objects’ in a special context for interpreting a theme (e.g. risks connected to volcanism or floods, episodes of Earth History), that would be not or only partially feasible at in-situ geosites, due to their spatial distribution (significant distances between sites) and the lack of elements for interpretation (e.g. a karst phenomenon, not observable in a protected area, but placing it in the interpretation story with an imported ‘geoheritage object’).

The interpretation itself taking place at geosites, dedicated facilities or outreach channels are the core activities that could take through the message to communities about the importance of geoheritage in DRR. In its simplest form, interpretative panels placed at geosites or in exhibition facilities could inform not only about the visible geological phenomena, but also about associated risks. Unfortunately, this potential is not exploited at many sites (CORATZA & DE WAELE 2012) and the style of these explanations does not always help the outreach due to lack of understandable explanations or concluding figures and maps (MACADAM 2018). A strong message could be taken through with guided visits as well, especially at those sites where the vulnerability of a geosite or the hazards do not permit individual visits, for example at sensitive karstic domains or active volcanic areas (see *chapter IV* or VEREB ET AL. 2020B). In the case of any interpretative facility, a prerequisite is a well-defined educational concept, like the school visits on the seismology of *Lesvos Island* in the local natural history museum (ZOUROS ET AL. 2011). Finally, when elements of geoheritage come into spotlight, either due to growing interest on a tourist area or disaster events;

composed, well-understandable explanations from the scientific and geoconservation community to the channels of media could have a significant impact on present and future resilience as well. Evident examples of this are volcanic eruptions, such as the 2010 eruption of *Eyjafjallajökull* in Iceland, where the media coverage greatly influenced the society's reaction to the events even in distant areas (HARRIS ET AL. 2012), therefore aiding their long-term resilience to volcanic activity.

When geoeducation is discussed, it is mostly associated with schoolchildren and the way how geoheritage can be integrated into formal and informal education. It is true indeed, that students are the primary focus group of special educational activities. However, risk-related interpretation of geoheritage could not only improve the resilience of the students themselves, but it could have a further spreading effect on family members as well, just as it can be presumed from some successful examples from geoparks (LIMA ET AL. 2014, ZOUROS ET AL. 2011). Adults are best targeted through (geo)touristic activities through individual, group or family visits to geosites and interpretative facilities. In both discussed target groups, visits or activities could be directed to geosites that are crucial to improve knowledge on the risks of the local environment and the way how they can react to them. Visiting more distant sites with a (geo)touristic purpose could be educative with important 'take-home messages' that might be used well during travels to other areas with geoheritage and geohazards (e.g. how to react to certain situations in active volcanic areas generally) or they could improve natural awareness, as discussed before.

I/E/4 Geotourism

Certain aspects of geotourism were covered already in the previous section I/E/2 and 3. Geoconservation could not only contribute to identify geoheritage and associated geohazards, but it creates new touristic products as well, through protected areas and interpretative facilities. The issues discussed in geoeducation, such as the interpretative potential of risk related geosites, educational activities and outreach, mostly concern and coincide with geotourism itself.

One viewpoint which was not discussed previously was how geotourism could provide services that could contribute to the resilience of communities. Tourist developments focusing on presenting the geoheritage values of a certain site or a wider area could create new jobs, improve certain services and infrastructure elements and contribute to local economic conditions. A more resilient community from a social and economic viewpoint could be more resilient to natural hazards as well, allowing financial conditions to effective mitigation works, like investing in risk-resilient infrastructure, prevention campaigns in the society, etc. The importance of geotourism in sustainable local development is highly emphasized in the concept of geoparks (UNESCO-IGGP 2015), but its positive effects are traceable at other protected areas as well with developed (geo)touristic practices. On the other hand, the disappearance of tourism could make a community

even more vulnerable (especially from an economical viewpoint), as it was experienced during the recent COVID-19 epidemic in 2020. The concept of ecosystem services is often discussed under the auspices of geotourism, but can be interpreted in general terms of geodiversity. GORDON ET AL. (2018) discussed in details the domain of geoheritage from the viewpoint of ecosystem. Environment, besides the protection of biodiversity and geodiversity values for its own sake, could also provide a basis for human activities, culture and well-being. In the previous sections, the discussed geosites functioned as ecosystem services that could help with the well-being of communities by improving their resilience through geoconservation and geoeducation. Under geotourism, geoheritage – as the identified part of geodiversity with scientific and additional values – functions as an ecosystem service as well, where geosites contribute to tourism, therefore to the economic well-being of local communities and the socio-cultural conditions of visitors.

It exceeds the limit of this work to discuss in detail, but it must be noted that geodiversity in general, where no geoconservation actions are taking place, contributes to communities, and therefore improving socio-economical resilience, which has a link to resilience to natural hazards as well. Some examples are exploitable materials (rocks, ores, etc.) providing basis for economic activities, soils – the complex interactions of bedrock and biological processes – as the backbone of agriculture and nutrition, landforms as living places and habitats for humans, flora and fauna (with a certain resilience to hazards!). Although with no geoconservation, degradation of the environment is likely to happen.

I/E/5 The links of geoheritage and disaster risk reduction

Previously in this chapter, the links between geoheritage and disaster risk reduction and resilience to natural hazards have already been presented. Recalling sections *I/B, C* and *D*, especially to the summarizing *figures* of *1.1* and *1.2* and regarding the aspects discussed in the present chapter, the most important links are the following.

Geoheritage as a domain could contribute to effective mitigation by lowering hazards, exposures and vulnerabilities, therefore improving the resilience of systems connected to a geoheritage area. This was discussed through examples like identification of geosite-related risks or the educative potential of natural disasters. For this purpose, most aspects of geoheritage could contribute somehow: geosites as places of interpretation and awareness raising, geoconservation and geoeducation with their toolkits discussed before, geodiversity and geotourism through ecosystem services.

The identification of these links is not just important from the viewpoint of geodiversity, but also because abiotical factors provide the foundation for biodiversity and cultural diversity through

complex interactions, including through natural risks. This way, geoheritage helps to consider a wider context, improving resilience toward a wider global system.

II THE DEDICATED GEOSITE INVENTORY OF THE CHAÎNE DES PUY – LIMAGNE FAULT WORLD HERITAGE SITE

II/A Introduction

The *Chaîne des Puy* is the youngest volcanic domain of the *Massif Central* (between 95 – 8.4 ka), situated in the heart of France (Fig. 2.1). Together with the *Limagne Fault* and the *Montagne de la Serre*, it has been inscribed on the World Heritage list since 2018. It is currently (2020) the only natural heritage property nominated exclusively for geological values (criterion viii) on the list in metropolitan France. The globally outstanding value is justified by the range of more than 80 juvenile, well-preserved monogenetic volcanic landforms (scoria cones, lava domes, maars, basaltic to trachytic and trachy-andesitic lava flows and their microforms) and the chain's relationship to the classic example of continental rifting, the *Limagne Fault* and the inverted relief of the *Montagne de la Serre*.

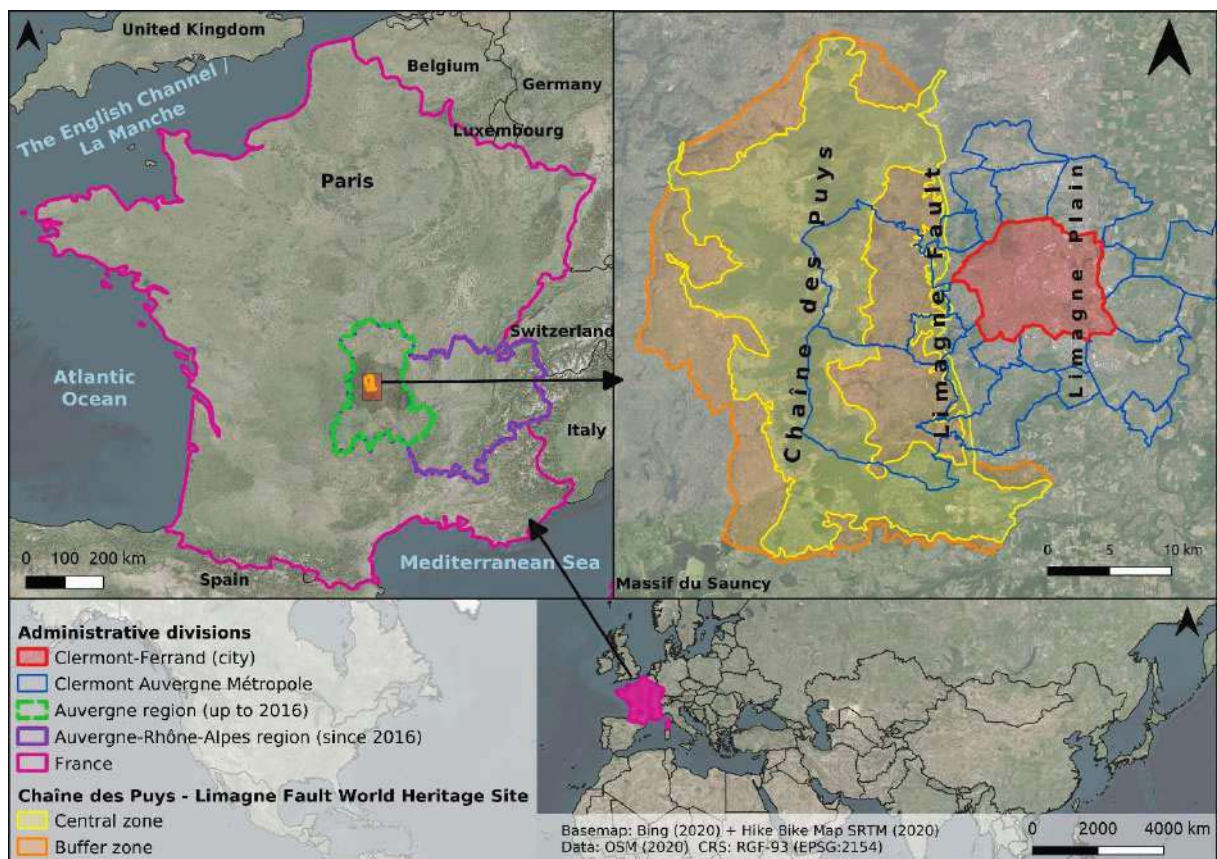


Fig. 2.1 The location of the Chaîne des Puy – Limagne Fault World Heritage site

The inscription process of natural properties to the World Heritage list and namely geological-geomorphological sites within it currently does not require a systematic inventory of the geosites of the area (but it can be included optionally). The key element of the applications is a comparative analysis with other potential properties of the same phenomena, justifying the ‘Outstanding

Universal Value' (OUV) and the role as the best available example globally (UNESCO 1972). The UNESCO 'International Geosciences and Geoparks Programme' - the dedicated international geoheritage management framework of UNESCO – already requires a comprehensive geosite inventory for aspiring geoparks (UNESCO-IGGP 2015). There are thoughts to add a similar requirement for new geoscience-focused World Heritage properties as well, and calling for inventories for already inscribed sites retrospectively as well (VAN WYK DE VRIES: pers. comm.).

France has a strong protection framework for natural and cultural heritage on a national and lower levels (departmental, municipal). A high number of sites are also part of international protection frameworks, with 45 World Heritage sites, 14 Biosphere Reserves and 7 UNESCO Global Geoparks. An important tool for effective conservation is the recording of valuable properties in inventories. The National Geosite Inventory of France (*Inventaire National de Patrimoine Géologique* - DE WEVER ET AL 2006, 2014, 2015) partly covers the area of the Chaîne des Puys – Limagne Fault World Heritage site with 15 geosites (ARA DREAL 2020). This list gives a good overview on the outstanding geodiversity of the area on a national level. However, many locally important sites and key elements of the World Heritage property are not included, not reaching the level of importance and rarity on the national scale. Moreover, the inventory seems to be not or only moderately adapted to site management practices so far, marked for example by recent stabilization works on the iconic *Puy de Dôme*, which negatively affected some important outcrops (PETRONIS ET AL. 2019).

This chapter presents the compilation of a dedicated geosite inventory for the *Chaîne des Puys – Limagne Fault* World Heritage property (often referenced later simply as 'the property' or the 'World Heritage site' or 'area'). The aim was to compose a more detailed list, where not only the sites of national relevance are included, but those regionally – locally important sites are also recorded, that function as important components of the integrity of the World Heritage area. Besides adding new, so far unrecorded geosites, large national geosites were often subdivided into smaller sites, that are still integral elements of a larger geological phenomena, but are more manageable units, considering effective geoconservation needs.

Chapter III about the urban geoheritage of *Clermont-Ferrand*, the centre of *Auvergne* is connected to this chapter, as the city is situated less than 10 kilometres from the eastern perimeter of the World Heritage property. The challenges are different there with its fast urbanization and a special context of geosites, but the geological and theoretical background of the geoheritage is mostly shared with the World Heritage property. For this reason, a compact, but comprehensive overview is given about the geological and geographical context of the area, and the key elements of protection and territorial management frameworks in France and *Auvergne* are also presented.

The contextual introduction is followed by the presentation of the inventorying and assessment process from site-selection to the comparative assessment of geosites with two methods: the national workflow of the INPG (DE WEVER ET AL. 2015), and an internationally used, predominantly geotourism-focused method, the ‘GAM’ published by VUJIČIĆ ET AL. (2011). The discussion of the results does not cover all elements of the inventory due to the high number of sites, but selected examples that cover relevant issues of geoconservation and geotourism in the World Heritage site. Besides the site-specific and geological context insights, the assessment methods themselves are also critically evaluated, presenting strengths and deficiencies and some aspects for future methodological updates.

Finally, the chapter is closed by a small-scale experimental study on the integration of visitors’ feedback in the evaluation of geosites. 20 selected geosites from the inventory were used for the so-called ‘M-GAM’ survey (TOMIĆ & BOŽIĆ 2014), where visitors of the area evaluated the importance of indicators of the GAM geosite assessment method (VUJIČIĆ ET AL. 2011), giving a feedback not only on the method itself, but also the geotouristic potential of the geosites. This research is a counterpart of ongoing projects in Central Europe, and here only some relevant elements are presented, results can be placed in a greater context later.

II/B Geographical and geological description

II/B/1 The greater context, the Massif Central

The geological basement of the *Massif Central* is a testimony of the Hercynian / Variscian orogeny, where this area was at the northern margin of *Gondwana*, during its collision with the *Armorican microplate* (FAURE ET AL. 2009). The mountain chains of the Hercynian orogeny were subsequently eroded into a peneplain. The *Plateau des Dômes* in our research area is a representative of this deeply eroded continental basement. The Alpine orogeny started during the late Mesozoic - where the collision of the *Eurasian Plate* with the *African Plate* and lithospheric subduction were accompanied by the extensional thinning of the continental plate - resulted a series of grabens, such as the *Rhône-valley*, the *Rhine-valley*, the *Eger Graben*, jointly known as the *Western European Rift* (MICHON & MERLE & 2001).

Of the generally N-S trending, extensional grabens of the *Massif Central*, the *Limagne* graben is the most significant. Asymmetrical sedimentation resulted a nearly 3000 meter infilling in the deepest parts of the *Riom Trough*, and thinner fill (several hundred meters) in the western and southern parts (MICHON & MERLE 2001, ROCHE ET AL. 2018). From the late Eocene, throughout the Oligocene up to the middle Miocene, a sedimentary sequence was formed in a fluvio-lacustrine

environment, of siliciclastic rocks and lacustrine marls and limestones, halites (ROCHE ET AL. 2018).

Scattered representatives of pre- and syn-rifting (the principal period of the extensional regime and the sedimentation) volcanism are observable in the northern *Massif Central* and the grabens of *Limagne*, *Bresse* and *Roanne-Montbrison*, with around 200 monogenetic volcanoes in the *Limagne* (MICHON & MERLE 2001). The major magmatic event creating the largest volcanic province of the *Western European Rift* system started in the southern *Massif Central*, in the Middle to Upper Miocene around 15 Ma, created by upwelling asthenosphere, displaced by the Alpine subduction (MICHON & MERLE 2001, BOIVIN ET AL. 2017). According to MICHON & MERLE (2001), two peaks of activity created the significant Cenozoic volcanic massifs of the *Massif Central*:

- the climax period between 9 – 6 Ma resulted the trachy-andesitic stratovolcano complex of *Cantal*, and the predominantly basaltic volcanic centres of *Aubrac*, *Velay*, *Cézallier*, *Causses* and *Coirons*.
- the second intense period of 3 – 0.5 Ma occurred both in the northern and southern domains of the *Massif Central*. Besides the principal units, the *Mont Dore – Sancy* stratovolcanic complex and the basaltic field of *Devès*, north-south trending monogenetic volcanic field appeared as well in *Escandorgue* and *Velay*.

The monogenetic volcanic fields of *Agde*, *Bas Vivarais* and the *Chaîne des Puys* are the most recent activity during the Pleistocene – Holocene, with the last dated eruption of 6.4 Ka at *Lac Pavin*. The ongoing processes of the Alpine orogeny, seismic activity and the geophysical modelling suggest the continuing existence of magma under the *Chaîne des Puys* and the potential continuation of volcanic events in the *Massif Central*.

II/B/2 Physiography of the Chaîne des Puys

The *Chaîne des Puys* is the youngest volcanic domain of the *Massif Central*, a series of monogenetic volcanic edifices, situated on the eroded Hercynian continental basement, the *Plateau des Dômes*. Their alignment is predominantly N-S trending, parallel to the Limagne Fault, situated 6-7 km from the main axis of the volcanoes, but several smaller, oblique lineaments also define disposition patterns (LE CORVEC ET AL. 2015, BOIVIN ET AL. 2017). Sensum stricto, the *Chaîne des Puys* is confined to the 30 km long spanning alignment between *Maar de Beaunit* and *Narse d'Espinasse*, and their associated lava flows. The lavas are dominated by the pre-eruption topography: channelled to existing valleys on the eastern flanks, but forming widely spreading lava fields on the western side – named ‘*cheire*’ locally - on the peneplain surface of the *Plateau des Dômes*.

In the broader sense, associated Quaternary volcanoes are also incorporated in the definition of the term of *Chaîne des Puys*. North of *Beaunit*, the scoria cones of *Puys de Rochenoir*, *Montiroir* and

Chalard and the maar of *Gour de Tazenat* are a continuation of the volcanic alignment. On the *Limagne plain*, the maars of *Ladoux*, *Clermont-Chamalières*, *Saint-Hippolyte* and *La Gantière* are direct predecessors of the main activity period of the *Chaîne des Puys*, with ages ranging between 200 and 85 Ka (BOIVIN ET AL. 2017). In contrast, located in the south, 20 km apart from the main range of the ‘*puys*’, sometimes referred under the *Mont Dore – Massif du Sancy*, the group of the scoria cones of *Puys de Montcineyre* and *Montchal* and the maars of *Estivadoux* and *Pavin* represent the most recent volcanic activity of the *Massif Central*, dating only 6.7 Ka. Finally, on the western side over the Valley of the *Sioule*, the *Petit Chaîne des Puys*, a less well-studied and dated, and more ancient cluster of eroded scoria cones (*Puys de Banson*, *la Vialle*, *Neuffont* and *Pranal*) and the *Maar of Anchald* is also included in the broader territorial extent.

Volcanic activity was already present during the Miocene and the Pliocene in the area of *Limagne* and the *Plateau des Dômes*. Originally valley infilling lava flows or volcanic necks are positive landforms now as inverted reliefs, being more resistant during the selective erosion of the intensive uplift of the Mio-Pliocene period. Preserved lava flows of *Plateau de Gergovie*, *Côte du Clermont*, *Montagne de la Serre*, or the peperitic volcanic neck of *Puy de Crouël* are testimonies of this volcanic activity and to the geomorphological inversion.

The chronology of volcanic events and the magmatic cycles of the *Chaîne des Puys* is summarized according to BOIVIN ET AL. (2017). After the activity of the maars of the *Limagne plain* (see above), sporadic activity of basaltic and more evolved trachybasaltic volcanic centres appeared in the present area of the range, such as *Puy de Grave Noire* (DE GOËR ET AL. 1993) or *Puy de Jumes* (GUÉRIN 1983). The period between 45 – 30 Ka is characterized by a significantly stronger and more widespread activity and silica enrichment, with mostly trachybasaltic lavas, but early examples of trachyandesites as well, such as the *Puy de Laschamp* (LAJ ET AL. 2014). Besides the numerous associated edifices (e.g. *Puy de Louchadière*, *Combegrasse*, *Paugnat*), the *Laschamp* paleomagnetic excursion should be noted as well, an anomaly recorded in numerous lava flows (e.g. at *Olby*, *Montmeyre*, *Laschamp*) of this period (LAJ ET AL. 2014). After a less intensive period, more differentiated magmas dominated the next and most recent magmatic cycle between 15 – 9.2 Ka. Trachyandesitic lavas of *Puy de Côme* or *Parion* (MIALLIER ET AL. 2012) and trachytes, like the *Le Clergeon* or *Puy de Chopine* are the most abundant in this period. However, the last, documented eruption of the *Chaîne des Puys*, the *Puy de Lassolas* and *la Vache* are connected to a less differentiated, trachybasaltic activity (BOIVIN ET AL. 2017).

The petrographic series of basalts to trachytes and rhyolites is associated with a variety of monogenetic volcanic edifices. Nearly 80% of them are scoria cones, associated with strombolian activity (BOIVIN ET AL 2017): I) enclosed single craters like *Puy des Goules* or *Parion*, II) breached,

open craters like *Puy de Lassolas* and *Louchadière*, or III) multiplied, nested or twin craters like *Puy de Côme* or *Puy de Jumes* and *de la Coquille*.

Lava flows of varying length (up to 10-20 km) and width (2-3 km) and thickness (1-150 meters) are associated with numerous scoria cones. Important surface features and microforms are associated with them, such as the variety of aa and pahoehoe surfaces, pressure ridges and bulges (e.g. *Puy de Combegrasse* lava flow), rootless cones (like at the *Puy de Montgy* and *Pourcharet* lava flows), spatter cones (*Cheire de Côme*) or even small lava tubes (in *Royat*) (BOIVIN ET AL. 2017).

Maars, associated with phreatomagmatic activity are seen as negative landforms that could be filled in with water or debris and sediments, and associated tuff rings, formed from the ejecta of the eruption. Their evolution and landscape representations are often paired with scoria cones in the *Chaîne des Puys*, such as *Maar de Beaunit – Puy Gonnard* or *Narse d’Espinasse – Puy de l’Enfer*, but they appear as independent features as well, such as *Maar d’Enval* or *Narse d’Ambois*.

Lava domes build up from more differentiated, viscous lavas, like trachyte or rarely rhyolite in case of the *Chaîne des Puys*. With their forms affected by the existing topography and changes of the magma plumbing system, they could be I) simple, low domes as *Le Clierson* or *Petit Suchet*, II) upheaved plugs of highly viscous lavas as *Puy de Chopine*, or III) complex dome structures, such as the iconic *Puy de Dôme* (BOIVIN ET AL. 2017).

II/C Protection and territorial management framework

The following section gives a brief overview of the legislative and effective protection and management frameworks that affect the considered area, which covers the extent of the World Heritage area, including both the core and the buffer zones. A detailed legislative background and rules of operation for each framework and agreement in the *Chaîne des Puys – Limagne Fault* area can be found in the World Heritage application document (PDD-CG 2012).

II/C/1 International agreements

The ‘flagship’ designation of the area is the nomination as a natural site on the World Heritage list in 2018. A short description of the ‘World Heritage Convention’, especially from the viewpoint of geoheritage was already given in *section I/B*, while the site-specific characteristics can be consulted in the application document (PDD-CG 2012). It must be underlined that although the World Heritage title gives the strongest international recognition, the legislative protection itself relies on national frameworks, the ratification of the World Heritage convention lays down only the principles for the effective measurements and the required legal environment to be carried out on the national level.

The *Chaîne des Puys – Limagne Fault* Tectonic Arena was inscribed under criterion (viii), as,

‘The property is an exceptional illustration of the phenomenon of continental break-up, or rifting, which is one of the five major stages of plate tectonics. The Chaîne des Puys - Limagne Fault tectonic arena presents a coincident view of all the representative processes of continental break-up and reveals their intrinsic links. The geological formations of the property, and their specific layout, illustrate with clarity this planet-wide process and its effects on a large and small scale on the landscape. This concentration has a demonstrated global significance in terms of its completeness, density and expression and has contributed to the site’s prominence since the 18th century for the study of classical geological processes.’
(UNESCO-WHC 2020).

‘Natura 2000’ is the other principal international (European) agreement, affecting certain parts of the World Heritage site. Considered as habitat/species management areas (category IV) or protected landscapes (cat. V) by the IUCN classification system (DUDLEY 2008), they cover fragile or rare ecosystems of certain species, with the aim of protecting their habitats, taking into account sustainable development as well. Many iconic elements of volcano-tectonic domain are enlisted here under the ‘Special Areas of Conservation of the *Chaîne des Puys*’, such as the clusters of *Puy des Goules* and *Grand Sarcouy*, a wide area between the *Puy de Dôme* and *Côme* or a southern cluster between *Puy de Pourcharet* and *Vichatel* comprising a total area of 2045 ha. (PDD-CG 2012).

II/C/2 National – local agreements

II/C/2/a Natural protection and management documents and agreements

The most powerful national legislative act applied in the area is the system of ‘*site classé*’ and ‘*site inscrit*’. These categories are based on ‘Environmental Code’, articles L341 1-15 that is the descendant of the 02/05/1930 ‘Law on the Environment’ (PDD-CG 2012). As the utmost regulator of natural and cultural protection in the French legal system, it strictly prohibits the destruction or the modification of the state or the appearance of the sites, without special authorisation (LEGIFRANCE 2020 - L341). In case of classified sites (‘*sites classes*’), it gives a strong restriction on potential urbanisation, and touristic developments could be carried out only within the strict authorization process of the authorities concerned. For inscribed sites (‘*sites inscrits*’), the regulation process is more compliant, but still giving strong licences. The central volcanic alignment of the *Chaîne des Puy* has been protected since 2000, the 13.640 ha. area is consisted of the central ‘classified site’ area and adjacent domains of ‘inscribed sites’ (Fig. 2.2).

Closely connected to the framework of ‘classified’ and ‘inscribed sites’, the lava dome of the *Puy de Dôme* was awarded the label ‘*Grand Site du France*’ in 2008. This designation helps and directs concrete management and development plans at the most frequented touristic sites (‘classified’ and

‘inscribed’), respecting the ‘genious loci’, the essential characteristics of the site. In case of the *Puy de Dôme*, the construction of the *Panoramique des Dômes*, the funicular to the summit, parking places, natural rehabilitation or the interpretation centre on the summit was carried out under the auspices of the *Opération Grand Site du France* (PDD-CG 2012).

An almost completely overlapping area to the World Heritage site - only small sections of the *Limagne Fault* and *Montagne de la Serre* are missing - is the *Parc Naturel Régional des Volcans D’Auvergne* (PNRVA, Fig. 2.2) that covers the Tertiary to Quarternary volcanic domains of *Auvergne*, namely *Monts du Cantal*, *Mont Dore*, *Cézallier*, *Artense* and the *Chaîne des Puys*. Natural regional parks do not have legislative licences, like national parks, but through their chart accepted by the governing syndicate of the parks - formed of delegates from the municipalities, the departments, the state and associations – they lay out the objectives of protection and sustainable development, local territorial and development plans are synchronized with the chart (PDD-CG 2012, LEGIFRANCE 2020, - L331). Since its creation in 1977, the PNRVA has carried out implementation projects, like the rehabilitation of quarries such as *Puy de Paugnat*, *Puy de l’Enfer*, slope rehabilitations like the case of *Puy de Pariou* and *Puy de Combergrasse* and numerous legislative harmonization with urban development plans (PDD-CG 2012).

Further national and local protection and management frameworks on natural heritage that are in effect in the World Heritage area (PDD-CG 2012, Fig. 2.2):

- *Espaces Naturel Sensibles* (ENS): departmental-level environmental policy for preserving natural habitats. *Marais du Paloux* at *St.-Pierre-le-Chastel* and *Côte de Verse* at *Volvic* are protected under this category.
- *Arrêté Préfectoral de Protection de Biotope* (APPB): conservation areas for ensuring essential nourishment reproduction needs and the survival of certain flora and fauna elements. The maar of *Narse d’Espinasse* is included here, as the most important habitat of *Ligularia sibirica* in the *Massif Central*.
- *Chartes Forestières de Territoire* (CFT): series of contracts between administrative units (department, municipalities), forestry association and landowners for the sustainable usage of forests, respecting biotopes, local development, or questions like the landscape integrity of volcanoes in light of their forest coverage. All public and private forests in the World Heritage area are under the following CFTs: *Faïlle de Limagne*, *Pays des Combrailles*, *Pays du Grand Sancy*, *Volvic Sources et Volcans*.
- *Schémas d’Aménagement et de Gestion des Eaux* (SAGE): territorial planning document for the quantitative and qualitative protection and usage of hydrographic resources in coherent,

defined hydrographical units. Due to its watershed role, the *Chaîne des Puys* is managed under two units: the western part by *SAGE Sioule* and the eastern by *SAGE Allier Aval*.

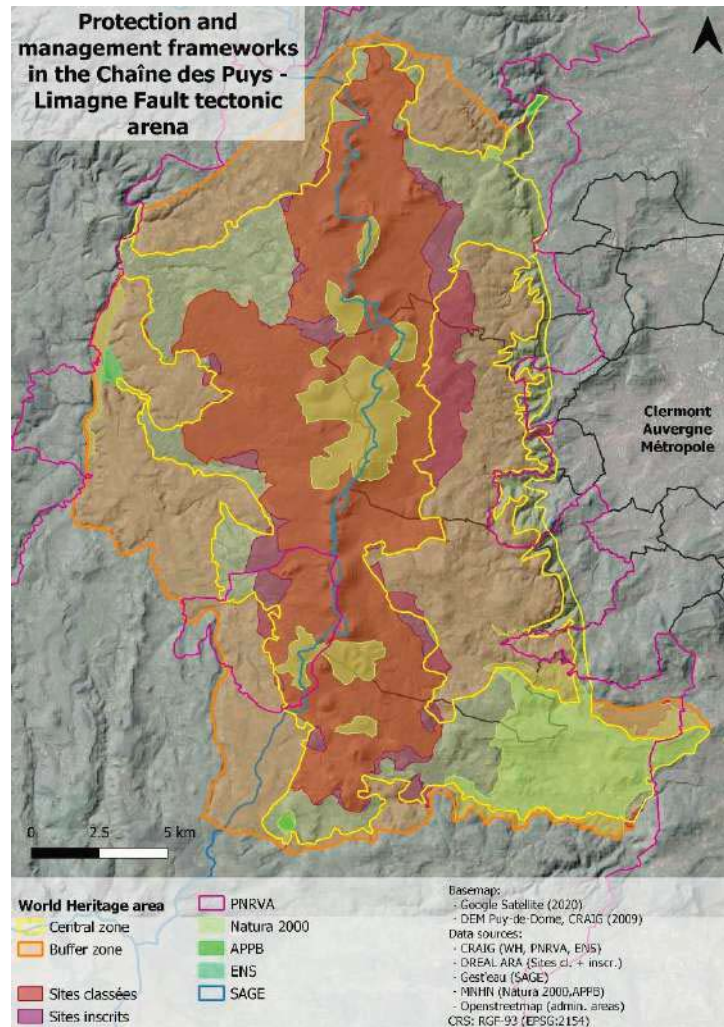


Fig. 2.2 International and national protection and territorial management frameworks at the World Heritage property

II/C/2/b Documents and agreements on urbanization

Although the World Heritage area is generally sparsely populated, smaller communities on the *Plateau des Dômes* (like *Orcines*), but especially municipalities on the western flanks (e.g. *Pontgibaud*) and the eastern flank, in the *Limagne Fault* area (such as *Durtol*, *Ceyrat*) are subject to urbanization, being popular destinations for the suburbanization of *Clermont Auvergne Métropole*. Propagated by the ‘Law on Solidarity and Urban Renewal’ of 2000, *Schéma de Cohérence territoriale* (SCOT) is the integrative urbanization and terrestrial planning document, regulating the needs, prospects and constraints between urbanization and natural areas. The SCOT of *Grand Clermont* came into effect in 2011, covering the almost entire area of the World Heritage site. Only the municipalities of *Pontgibaud* and *St. Pierre-le-Chastel* are part of the *SCOT de Combrailles*. The regulations of SCOT are harmonizing the natural protection framework described before and those urbanization and

planning documents of local level that are not described in detail in the thesis. These inferior-level urbanization documents are the following:

- *Cartes communales*: simplified planning document for small communities, delimiting areas to be built-in, but lacking detailed specifications development plans. Used in the smaller, western municipalities of the World Heritage property, such as *Nébouzat* or *Vernines*
- *Plan Locaux d'Urbanisme* (PLU): besides fixing the land use types of the municipality, it also regulates necessary documentation for development projects in cadastres, such as mid-term sustainable development plan, graphic documentation, etc. From the 28 communities of the *Chaîne des Puys – Limagne Fault*, 23 has a PLU in 2020 (PPD 2020)

II/C/3 Inventories

The following inventories are not legislative documents, but they give the list of those sites of scientific or other values, that make them eligible for further protection and management initiatives in the agreements described above.

II/C/3/a Inventaire National de Patrimoine Géologique (INPG)

The historical background and the methodology of the national geosite inventory of was described in *I/C/6*. In the World Heritage area, 15 sites are included in the national inventory (*Table 2.1, Fig. 2.3*).

Table 2.1 Geosites of INPG in the Chaîne des Puys – Limagne Fault Tectonic Arena

INPG ID	Site name	Geoheritage stars	Primary geological interest
AUV0001	Maar of Narse d'Espinasse and Puy de l'Enfer	2	Volcanism
AUV0003	Maar de Beaunit and Puy Gonnard	2	Volcanism
AUV0005	The lava dome of Grand Sarcouy	3	Volcanism
AUV0006	Puy Pariou	3	Volcanism
AUV0008	Puys de la Vache and Lassolas and their lava flow	3	Volcanism
AUV0010	Puy de Lemptégy	3	Volcanism
AUV0019	Narse d'Ampoix: reference site for the dating of the Chaîne des Puys	2	Geochronology
AUV0021	The lava flow of Laschamp: testimony of a magnetic excursion	3	Geochronology
AUV0025	Puy de Dôme	3	Volcanism
AUV0027	Puy de Côme and its lava flows	3	Volcanism
AUV0088	Puy de Gravenoire and its lava flows	2	Volcanism
AUV0098	Mining district of Pontgibaud and the mining museum	2	Mineralogy
AUV0100	Catchement area of Puy de Louchadière	3	Hydrogeology
AUV0120	Puy de la Nugère, the water and stone of Volvic	3	Volcanism
AUV0122	Chaîne des Puys	3	Volcanism

It is interesting to note that the whole *Chaîne des Puys* is considered as one geosite (AUV0122), but in parallel, its distinctive landforms are divided into further, smaller geosites as well. The majority of the national geosites were recorded with volcanology as *Primary Geological Interest*, and the two sites of geochronology (lava flow of *Puy de Laschamp*, *Narse d'Ampoix*) and the one with

hydrogeological importance (catchment area of *Puy de Louchadière*) are also associated with the Quaternary volcanism. The only exception is the mining district of *Pontgibaud* at the western edge of the World Heritage property, which is included in the inventory for the extraction of silver deposits and various minerals. It must be noted that although the area was inscribed on the World Heritage list with specially underlining the importance of the *Limagne Fault* and the testimony of inverted relief as well, namely the *Montagne de la Serre*, none of them are inscribed examples in the national inventory. The closest such phenomena of inverted reliefs on the list are the *Plateau de Gergovie* and the lava flow of *Puy de Grave Noire*.

II/C/3/b Inventories of biodiversity

There are at least two reasons why biodiversity inventories should be discussed as well in a geoheritage focused work. Natural heritage is composed of the elements of geodiversity and biodiversity, the two have complex interactions and function as a system together (see I/D). On the other hand, there might be a conflict of interest between elements included in biodiversity and geoheritage inventories, due to their long-term protection and management needs. This is the case of the *Chaîne des Puys*, where the clean-up of volcanic landforms from recent industrial forestation and reintroduction of pastoral activities in order to highlight the visibility of the landforms might affect some habitats as well as geological features, therefore a well-established compromise is required (PDD-CG 2012).

The principal national inventorying project of biodiversity in France is the ZNIEFF (*Zones Naturelles d'Intérêt Écologique, Faunistique et Floristique*), launched in 1982, and modernized between 1995 and 2016, coordinated by the Natural History Museum in Paris, the MNHN (INPN 2020). The two types of inventory zonation used, with examples from the *Chaîne des Puys* are the following (Fig. 2.3):

- ZNIEFF zones I: small, ecologically consistent areas, defined by one species or a fragile habitat of regional or national interest. For example, the *Puy de Dôme* is the only example in the wider area with species of subalpine – suboceanic characteristics (PDD-CG 2012)
- The ZNIEFF type II zones: larger, natural or slightly modified areas with important biological potential, with an emerging ecological importance from its surroundings. The slopes of the volcanic edifices are important habitats for the mountainous succession of tree species, from hazelnut to beech and conifers (PDD-CG 2012).

Further, national level inventorying programmes are coordinated by the MNHN, such as biodiversity corridors (*Trame verte et bleue*), or detailed inventory of different species (molluscs, amphibians, birds, etc.), where the inventorying sheets affecting the World Heritage area can be consulted at INPN (2020).

On the community level, the *Atlas de la Biodiversité Communale* (ABC) sets the goal for a detailed inventory of all important species and habitats, to be taken into consideration in planning documents and decision making in the future. As of 2018, only the municipality of *Volvic* has compiled an ABC in the *Chaîne des Puy – Limagne Fault* area, but certain inventories are in progress (CEREMA 2018).

II/C/3/c Inventories of cultural heritage

The importance of cultural heritage inventories, besides their intrinsic values of recording the most important testimonies of cultural achievements, could be interpreted from the viewpoint of geoheritage too. Properties included in these lists, especially buildings, but also some artefacts preserve geological elements as well, through their construction materials (heritage stones), minerals used in objects, or even by the documentary heritage of photos, drawings or historical maps that gives a snapshot on the human influence on natural heritage.

The early roots of cultural heritage inventorying in France leads back to the French Revolution, while the first official inventory of historical monuments (*Monuments historiques*) was issued in 1840 (CHOAY 1992). According to the ‘*Code du Patrimoine*’, sites listed under *Monuments historiques* are legally protected, of which certain ones could be ‘classified’ or ‘inscribed’ sites as well, giving an even stronger form of protection (see II/C/2/a).

A designated national inventory program for the cultural heritage, the ‘*L’Inventaire*’ started in 1964, recording cultural properties that are not considered as historical monuments, but bear certain scientific, historical or cultural values on a regional or local level. Containment in ‘*L’Inventaire*’ does not meet with legislative protection. The inventorying is realized by specialized databases from the 1970s: I) *Joconde* for artifacts in museums in 1975, II) *Mérimée* for architectural heritage in 1978, III) *Palissy* for furniture in 1989 and IV) *Mémoire* for iconography such as photos, drawings in 1996. Since 2018, all these databases, supplemented with the *Monuments historiques* properties could be queried from an integrated database, *Plateforme Ouverte du Patrimoine* (POP 2020).

The *Mérimée* database contains 120 architectural properties in the World Heritage area, of which 57 are ‘historical monuments’, of which 22 are ‘classified’ or ‘inscribed sites’ bearing the strongest legal protection (Fig. 2.3). The *Palissy* database of interior elements (furniture, decoration, etc.) has 270 items here with 100 pieces also recorded as historical monuments.

A local inventory of small buildings and constructions (*l’inventaire du petit patrimoine bâti*), such as mountain huts, crosses, fountains or historical dolmens was started by the regional natural park in 1990 (PNRVA 2018). Just in the World Heritage area, 848 items have been recorded so far (Fig. 2.3). The geoheritage potential of this list, together with the properties of the national cultural inventories should be evaluated in the future.

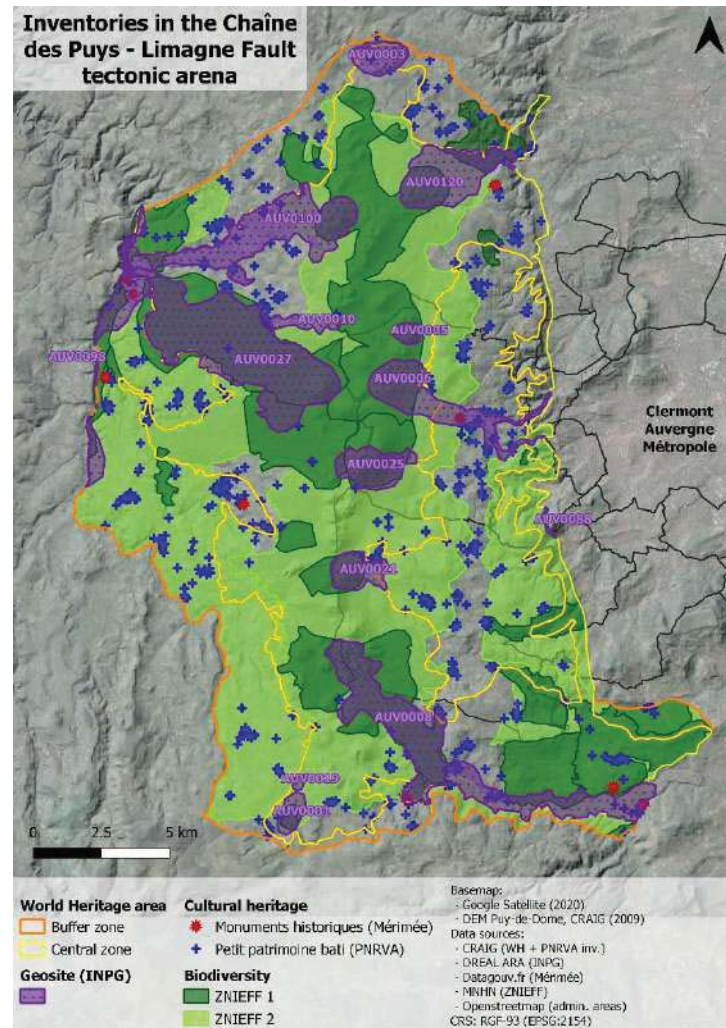


Fig. 2.3 Inventories of natural and cultural heritage in the World Heritage property

II/D The dedicated geosite inventory of the World Heritage property

It has already been noted in the introduction of II/A that geoheritage inventories are not required yet for World Heritage properties of geological significance, but might be relevant in the nearby future. Although the national geoheritage inventory of France, the INPG (DE WEVER ET AL. 2015) covers the area of the *Chaîne des Puys – Limagne Fault* as well, it has been conducted with a different scale and purpose, recording the best examples of certain geological phenomena and landforms on a national level, selected on a regional basis. However, the integration of this inventory into territorial management is limited. A practical note was already cited about the *Puy de Dôme* (PETRONIS ET AL. 2019), but even the World Heritage application document shows the signs of this lack of inventory (PDD-CG 2012). Geologists working with the World Heritage project have consistently recommended an inventory, since at least 2016, as a measure of protection and management (VAN WYK DE VRIES: pers. comm.). In the 5th chapter (*‘Protection et gestion du bien’* – PDD-CG 2012), all relevant frameworks, such as ZNIEFF areas, classified sites were presented in

details, but such a description of the INPG is missing, it is only listed among relevant documents in section 7.c (PDD-CG 2012).

It is interesting to note that the coverage of biodiversity and tangible cultural heritage in inventories is more advanced in a site which is inscribed on the World Heritage list primarily with a justification on the importance for geosciences under criterion (viii). The nationally conducted ‘ZNIEFF’ areas cover the overwhelming majority of the property, and the specific, local ‘ABC’ inventory was already created for the municipality of *Volvic* (Fig. 2.3). While the national cultural heritage inventory of ‘*Base Mérimée*’ are mostly restricted to some settlements, the local-level inventory of ‘*petit patrimoine bâti*’ by PNRVA gives a significant geographical coverage as well, often coinciding with the buffer zones of the World Heritage property (Fig. 2.2).

The commitment of this chapter is the compilation of a dedicated, detailed geosite inventory for the territory of the *Chaîne des Puy – Limagne Fault* Tectonic Arena. The scale is clearly defined by the boundaries of the core and buffer zones of the property, covering a total of 405.3 km². This limited area allows and calls for a finer scale inventory compared to the INPG database of national scale and regional data-collection data bases. Thus, sites that were not included in the national database - not reaching the rarity and relevance on a national – regional level viewpoint, or left out, as the national Inventory had a limited number of sites per region - can be incorporated into this specific inventory. These are also integral elements of the World Heritage area, and their recorded recognition in an inventory is a first-step for effective and legal geoconservation.

The purpose of this specific inventory is to give a dedicated tool for local stakeholders, especially the *Conseil Départemental de Puy de Dôme*, the DREAL (*Direction régionale de l'Environnement, de l'Aménagement et du Logement*) for I) the integration of geoheritage into daily territorial management practice, and II) an input for effective geoconservation works (e.g. slope stabilization, forestry or road works respecting geoheritage values, installation of interpretative facilities, control of urbanisation, basis for further legislative protection).

II/D/1 Methodology

The roadmap of the inventorying process followed the proposals of REYNARD ET AL. (2016) and considering several elements of the similar approach of BRILHA (2016). It also took into account the context-specific recommendations of the French national workflow, the INPG (DE WEVER ET AL. 2006, 2014, 2015).

Bibliographical study of the World Heritage property was based on some key inputs. The most important was the latest edition of the compact monograph on the volcanology of the *Chaîne des Puy* and the accompanying volcanological map (BOIVIN ET AL. 2017). The monograph itself was a primary input to identify potential geosites and to examine their scientific importance, but the

extensive bibliography of the book serves as secondary input, leading further to dedicated studies (e.g. LAJ ET AL. 2014, GUÉRIN 1983). Relevant chapters of the World Heritage nomination documentation (PDD-CG 2012), especially the 2nd chapter (*‘Description’*) also provided a number of sites that were potential geosites.

In terms of cartographical inputs, the previously mentioned volcanological map of the *Chaîne des Puys* (BOIVIN ET AL. 2017) was a key source for identification of landforms, outcrops and geological phenomena as potential geosites. This was further supplemented by the 1:50000 vectorized geological map of France (BRGM 2020), the different cartographical series *Institut National de l'Information Géographique et Forestière*, especially the *Carte d'état-major* (IGN 2020) and the 1:25000 hiking map of the *Chaîne des Puys* (IGN 2017). DEMs of 10 m resolution (CRAIG 2009) for the entire area of the property, and 0.5 m resolution for the central section of the *puys* (CRAIG 2011) were also consulted for the identification of potential outcrops according to slope values.

The initially selected potential sites were validated in all cases in the field, in two consecutive field campaigns in 2019 and 2020. Geosites finally selected to the inventory of the World Heritage property were photo-documented and they were recorded as point features in a database, but a delineation of the proposed extent of the geosites was also created.

The selection process not only affected the spatial distribution and the density of geosites in the final inventory, but also the territorial extent of each site: the smaller scale of the inventory of the World Heritage property compared to the national programme, as well as the aim of fostering geoconservation and integration into territorial management were already discussed before (*section II/A and II/C/1*). The selected geosites are an integral representation of a geological phenomenon or landform, but the subdivision reflects practical considerations as well. Therefore, larger units, represented as one geosite in the national inventory are subdivided into smaller elements, multiple separate geosites in the World Heritage property inventory, better reflecting different management considerations (e.g. ownership, land coverage type, challenges and purposes for conservation and interpretation).

Geosites recorded in the inventory are assessed in parallel with two methods. Due to the local context, and the potential integration of some sites to the national inventory as well, the methodology of the INPG, a semi-quantitative technique was used (DE WEVER ET AL. 2015). On the other hand, the method of VUJIČIĆ ET AL. (2011), the GAM (Geosite Assessment Model) was chosen. This entirely quantitative method has been already used globally in various geographical environments and protection framework scenarios (see the citation analysis of MUCIVUNA ET AL. 2019). Several indicators are specially focused on geotouristic aspects that could give an important feedback on the current state and geotouristic potential of the geosites of World Heritage property,

building on the growing importance of geoheritage in local tourism (PDD-CG 2012). The detailed description of each relevant assessment method can be found in *chapter I/C*.

II/D/2 Results and discussion

II/D/2/a Composition of the geosite inventory of the World Heritage property

A total of 122 geosites were recorded in the dedicated inventory of the *Chaîne des Puys – Limagne Fault* World Heritage property (Fig. 2.4, Table 2.2). 34 of these sites were already included before in the INPG, as elements of one of the 15 national geosites. In the more detailed inventory, the subdivision created a varying number of more compact geosites. For example, the *Grand Sarcony* national geosite (AUV0005) was not divided into further elements (D-GSY in the property's inventory), as it is a highly compact and well-interpretable, integral element of the *Chaîne des Puys*. On the other end, the 'Puits de la Vache and Lassolas and their lava flow' national geosite (AUV0008), incorporating all elements in its integrity from source (the scoria cones) to products (the lava flows) was dissected into 8 smaller geosites: the two scoria cones (S-LAS, S-VAC), the lakes of *Cassière* and *Aydat* created by the blocking of lava flows (H-LCA, H-LAY) and four important outcrops and landforms of the lava flows, such as the small lava tube of *La Fontaine Gelée* (L-GRH, L-GFG, L-LCP, L-LBS). The majority of geosites (88 sites) were previously not recorded. 5 sites are out of the World Heritage domain sensum stricto (*Gorges d'Enval* F-GEV, Sandstone outcrop of *Crouzol* O-SCR, *Maar d'Anchald* M-ACH, *Puy de Grave Noire* S-GRN, Ending of the *Montagne de la Serre* at *Le Crest* I-LCR, *Puy de Monténard* S-MOD).

Sites are grouped by the principal geological-geomorphological frameworks of the area: I) sites related to the *Limagne Fault* (10 sites, codes with 'F-'), II) inverted relief landforms of pre-Quaternary lava flows (9 sites, codes with 'I-'), III) lakes and springs under hydrological sites (9 sites, codes with 'H-'), IV) and some other elements, mostly related to the outcrops of the Hercynian basement rock on the *Plateau des Dômes* (5 sites, codes with 'O-'). The geosites of Quaternary volcanism of the *Chaîne des Puys* are subdivided by the three, locally dominant landform types, namely I) scoria cones (46 sites, codes with 'S-'), II) lava domes (10 sites, codes with 'D-'), III) and maars (11 sites, codes with 'M-'), and finally their products, IV) lava flows with their microforms and principal outcrops (22 sites, codes with 'L-'). This subdivision does not mean, that a geosite should not be associated with other aspects, only the most relevant one were indicated in the naming standard and their grouping.

On the other hand, a territorial clustering was also used, in order to facilitate the easier overview of the high number of sites, especially in categories with several examples (e.g. scoria cones, fault line outcrops). This rough zoning is defined by practical considerations. Different geological and

geomorphological conditions, also affecting the geoheritage values are not observable as a trend between the northern, central, and southern zone of geosites. Their borders are defined by the two main trunk routes crossing the World Heritage property at *Col de la Moreno* and *Col des Goules* (D942 and D941), and their elongation through lower level routes to *Clermont Auvergne Métropole*.

Table 2.2 The dedicated geosite inventory of the *Chaîne des Puys – Limagne Fault* World Heritage site – list of sites

Code	Name of the geosite	Cluster	Category	X coord.	Y. coord
F-BCO	Berzet - Ceysat route - fault line outcrop series	South	Fault line	6514662,4	704424,5
F-CCR	Chemin de Crête - fault line outcrop series	Central	Fault line	6518823	703238
F-GAR	Gorges de l'Artière - Fault facet, Dolmen de Samson and the tectonically influenced valley	South	Fault line	6513973	704856,97
F-GEV	Gorges d'Enval - Fault facet and the tectonically influenced valley	North	Fault line	6533227,6	703366,14
F-MPE	La Montagne Percée - fault line outcrop and viewpoint	Central	Fault line	6520364,2	703382,58
F-PCH	Puy Charmont - Fault line outcrops	North	Fault line	6522740,3	703432,61
F-PCX	Puy de Chateix - Fault line outcrops	Central	Fault line	6518617,8	704119,91
F-RSA	Rocher de Salut - fault line outcrop and viewpoint	Central	Fault line	6517587,7	702799,9
F-VRN	Route de la Nugère at Volvic - Fault line outcrops	North	Fault line	6530065,8	702094,54
F-VSR	Varennes - Saulzet route- fault line outcrop series	South	Fault line	6512016,9	705018,42
F-VVO	Vierge de Volvic - fault line outcrop and viewpoint	North	Fault line	6530480,2	702706,26
H-CSA	Cascade des Saliens	South	Hydrology	6513947	691755,68
H-FBC	Fontaine du Bois, Chambois	Central	Hydrology	6521067,1	691143,24
H-FOK	'Foker' mineral spring at Ceysat	Central	Hydrology	6518233,2	691836,31
H-LAY	The lava flow blocked Lac d'Aydat	South	Hydrology	6507813,9	699067,4
H-LCA	The lava flow blocked Lac de la Cassière	South	Hydrology	6509678,3	699763,26
H-MSI	Meanders of the Sioule	Central	Hydrology	6524273,2	687658,63
H-SCP	Spring of a paleovalley at 'Chez Pierre'	Central	Hydrology	6516802,8	692658,51
H-SSO	Source de Louchadière - Saint Ours	North	Hydrology	6527180,1	691698,53
H-VOS	The spring of Volvic	North	Hydrology	6530136,3	702209,52
I-BER	Puy de Berzet - inverted relief	South	Inverted relief	6514061,6	702244,48
I-BON	Bonnabaud - inverted relief	Central	Inverted relief	6521133,7	687813,09
I-CCG	Croix Chemagrand - Inverted relief and granite-lava contact	South	Inverted relief	6508120,2	701631,68
I-LCR	Front ending of the Montagne de la Serre at Le Crest	South	Inverted relief	6509566,8	710109,76
I-PCO	Puy de Cros - inverted relief	Central	Inverted relief	6515968,8	690729,11
I-PFR	Puy de Frimont - inverted relief	Central	Inverted relief	6522925,9	687507,66
I-QRH	Quarry of the Montagne de la Serre close to Rouillas-Haut	South	Inverted relief	6509156	701542,11
I-RED	Mont Redon - inverted relief	South	Inverted relief	6507602,3	702665,95
I-SPC	St. Pierre-le-Chastel - inverted relief	Central	Inverted relief	6522429,3	687655,39
D-CHO	Puy Chopine	North	Lava dome	6518768	699343,12
D-CLI	Le Cliersou	Central	Lava dome	6524930,6	697603,81
D-DOM	Puy de Dôme	Central	Lava dome	6526908,1	697088,77
D-GRO	Puy des Grosmaux	Central	Lava dome	6517004	703879,87
D-GSA	Grand Sault	Central	Lava dome	6517568	696419,47
D-GSU	Grand Suchet	Central	Lava dome	6518555,3	695878,79
D-GSY	Grand Sarcouy	North	Lava dome	6521210,9	696517,87
D-KIL	Cratère Kilian	Central	Lava dome	6527493,8	697520,83
D-MCR	Puy Montchar	South	Lava dome	6514863,2	695663,23
D-PPD	Petit Puy de Dôme	Central	Lava dome	6519834,9	697584,15

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L-ARG	Argnat lava flow outcrop	North	Lava flow	6527195,6	701692,41
L-CCP	Gorges de la Sioule and Côme lava flow front at Peschadoire	North	Lava flow	6527521,2	688778,41
L-CTG	Trou de Glace - Côme lava flow outcrops	Central	Lava flow	6523321,7	689875,02
L-GFG	La Fontaine gelée - lava tube	South	Lava flow	6509984,3	698814,48
L-GRH	La Grotte de Ribbe Haute - lava levée	South	Lava flow	6510543,9	697762,12
L-GRP	La Grotte et Maison de la Pierre	North	Lava flow	6530271	702540,48
L-LBS	Outcrop of the lava flow basement of Puys de la Vache and Lassolas at Saint-Saturnin	South	Lava flow	6506467,1	707247,22
L-LCP	Outcrop of the lava channel of Puys de la Vache and Lassolas at Ponteix	South	Lava flow	6506978,1	702159,3
L-LLC	The lava lake of the Côme lava flow	Central	Lava flow	6522087,5	694636,87
L-LLN	Columnar basalts of the lava lake at Nébouzat	South	Lava flow	6513009,6	692293,25
L-OCH	Lava flow outcrop at Chanonat	South	Lava flow	6510256,8	707654,53
L-PBR	Les Bramauds- pressure ridges	Central	Lava flow	6514849,8	692850,34
L-PCY	Ceyssat- pressure ridges	Central	Lava flow	6518542,1	692742,45
L-PRC	Lava flow of Puy de Combegrasse- pressure ridges	South	Lava flow	6507504,1	695439,1
L-PRP	Lava flow of Puy de Poucharet- pressure ridges	South	Lava flow	6511700,9	694261,01
L-PVA	Vauriat , lava flow of Louchadière - pressure ridges	North	Lava flow	6528404	694327,76
L-PVI	Outcrop of the lava flow of Pariou at Villars	Central	Lava flow	6519972,8	702950,84
L-QCB	Quarry of Chambols	Central	Lava flow	6523151	690905,4
L-QCS	Quarry of Ceyssat	Central	Lava flow	6519672,4	691466,67
L-QGO	The quarries of Volvic stone at Les Goulots	North	Lava flow	6529968,3	699031,9
L-QMF	Quarry of the lava flow of Puy de la Mey at Fontfreyde	South	Lava flow	6511253,2	699998,82
L-RME	Roche Merle - tumulus	Central	Lava flow	6516896,9	698229,1
L-SAY	Lava flow outcrop - Sayat	North	Lava flow	6526709,7	703352,34
M-ACH	Maar d'Anchald	North	Maar	6526955,9	687640,32
M-AMP	Narse d'Ampoix	South	Maar	6507333,8	694584,74
M-BCL	Bois de Clerzat	North	Maar	6524250,7	700655,23
M-BEL	Maar de Beauloup	North	Maar	6525856,7	692710,48
M-BEU	Maar de Beaunit	North	Maar	6534173,5	697093,1
M-CRM	Creux Morel	North	Maar	6523604,7	697412,29
M-ENV	Maar d'Enval	Central	Maar	6518444,4	699528,83
M-ESP	Narse de l'Espinasse	South	Maar	6506010,6	694260,88
M-MCT	Maar de Monchatre	Central	Maar	6517833,2	696234,87
M-NIP	Nid de la Poule	Central	Maar	6521886,7	700599,94
M-VIL	Maar de Villars	Central	Maar	6519984,4	697286,24
O-BCP	Hercynian base outcrop at 'Chez Pierre'	Central	Other	6519084,5	702018,95
O-GBC	Outcrop of Manson granite at Beaune-le-Chaud	South	Other	6516894,5	692619,11
O-PGG	Granite outcrop of Pontgibaud	Central	Other	6514239,1	699391,98
O-PMQ	Puy de Manson quarry	Central	Other	6525686,1	688028,19
O-SCR	Sandstone outcrop at Crouzol	North	Other	6516344,6	700640,95
S-BAR	Puy de Barme and its scoria quarry	Central	Scoria cone	6531898,3	703641,2
S-BCH	Bois de Chanut	North	Scoria cone	6515408,5	694642,98
S-BES	Puy Besace	Central	Scoria cone	6525167,5	700873,62
S-BLE	Puy de Bleymas and its scoria quarry	North	Scoria cone	6517927,4	695880,22
S-BNE	Puy de la Bannière	North	Scoria cone	6528185,9	698586,92
S-BNS	Puy des Bannières	North	Scoria cone	6531032	702605,18
S-CGR	Puy de Combegrasse	South	Scoria cone	6530771,5	696604,85
S-CGX	Chuquet-Genestoux scoriaceous outcrop	Central	Scoria cone	6507616	695972,3
S-CHR	Puy de Charmont	South	Scoria cone	6525419,7	696525,02
S-CHU	Puy de Chaumont	North	Scoria cone	6508658,3	696950,13
S-COM	Puy de Côme	Central	Scoria cone	6521590	696822,5

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S-COQ	Puy de la Coquille	North	Scoria cone	6521880,9	695547,99
S-ENF	Puy de l'Enfer and its scoria quarry	South	Scoria cone	6519218	697243,7
S-ESP	Puy de l'Espinasse and its scoria quarry	North	Scoria cone	6506411	694220,54
S-FIL	Puy Fillou	Central	Scoria cone	6529903,2	696443,79
S-GLI	Puy de la Goulie	North	Scoria cone	6520409,8	695517,51
S-GNN	Puy Gonnard	North	Scoria cone	6530360,9	696893,97
S-GOL	Puy des Goules	North	Scoria cone	6533440,2	697468,67
S-GOT	Puy des Gouttes	North	Scoria cone	6523170,9	698430,58
S-GRN	Puy de Grave Noire and its scoria quarry	Central	Scoria cone	6525001,4	696423,81
S-JUM	Puy de Jumes	North	Scoria cone	6523647,5	698714,19
S-LAC	Puy de Laschamps	South	Scoria cone	6514940,5	696263,28
S-LAS	Puy de Lassolas	South	Scoria cone	6512380,2	696747,58
S-LEM	Puy de Lemptégy	North	Scoria cone	6524311,6	695869,49
S-LOU	Puy de Louchadiere	North	Scoria cone	6528136	696206
S-LOV	Puy la de Louve scoria quarry of Gare de Volvic	North	Scoria cone	6529341,2	699840,82
S-MCE	Puy Montchié	Central	Scoria cone	6516418,6	696053,83
S-MEC	Puy de Mercœur	South	Scoria cone	6512998,4	696604,14
S-MET	Puy de Monteillet	South	Scoria cone	6512623	695423,94
S-MEY	Puy de la Mey	South	Scoria cone	6512336,9	697165,02
S-MGY	Puy de Montgy	South	Scoria cone	6511359,8	694749,86
S-MOD	Puy Monténard	South	Scoria cone	6504011,7	694760,82
S-MOR	Puy de la Moreno	South	Scoria cone	6515324,8	695730,22
S-NAI	Puy Nain	South	Scoria cone	6507386,9	696460,67
S-NUG	Puy de la Nugère	North	Scoria cone	6528977,5	698877,46
S-PAR	Puy de Pariou	Central	Scoria cone	6521909,7	697800,54
S-PAU	Puy de Pagnat and its scoria quarry	North	Scoria cone	6531146,6	698234,3
S-POU	Puy de Poucharet	South	Scoria cone	6512168,2	694676,19
S-ROD	Puy de la Rodde	South	Scoria cone	6506970	696530,81
S-SAL	Puy de Salomon	Central	Scoria cone	6517205,4	696001,68
S-TEN	Puy de Ténuzet and its scoria quarry	North	Scoria cone	6528353,1	697228,21
S-TOU	Puy de la Toupe	South	Scoria cone	6509205,4	695628,8
S-TRE	Puy de Tressous	North	Scoria cone	6529631,7	696443,49
S-VAC	Puy de la Vache and its scoria quarry	South	Scoria cone	6511779,9	697119,28
S-VER	Puy de Verrières	North	Scoria cone	6532471,6	696542,25
S-VIC	Puy de Vichatel	South	Scoria cone	6509620,5	696983,54

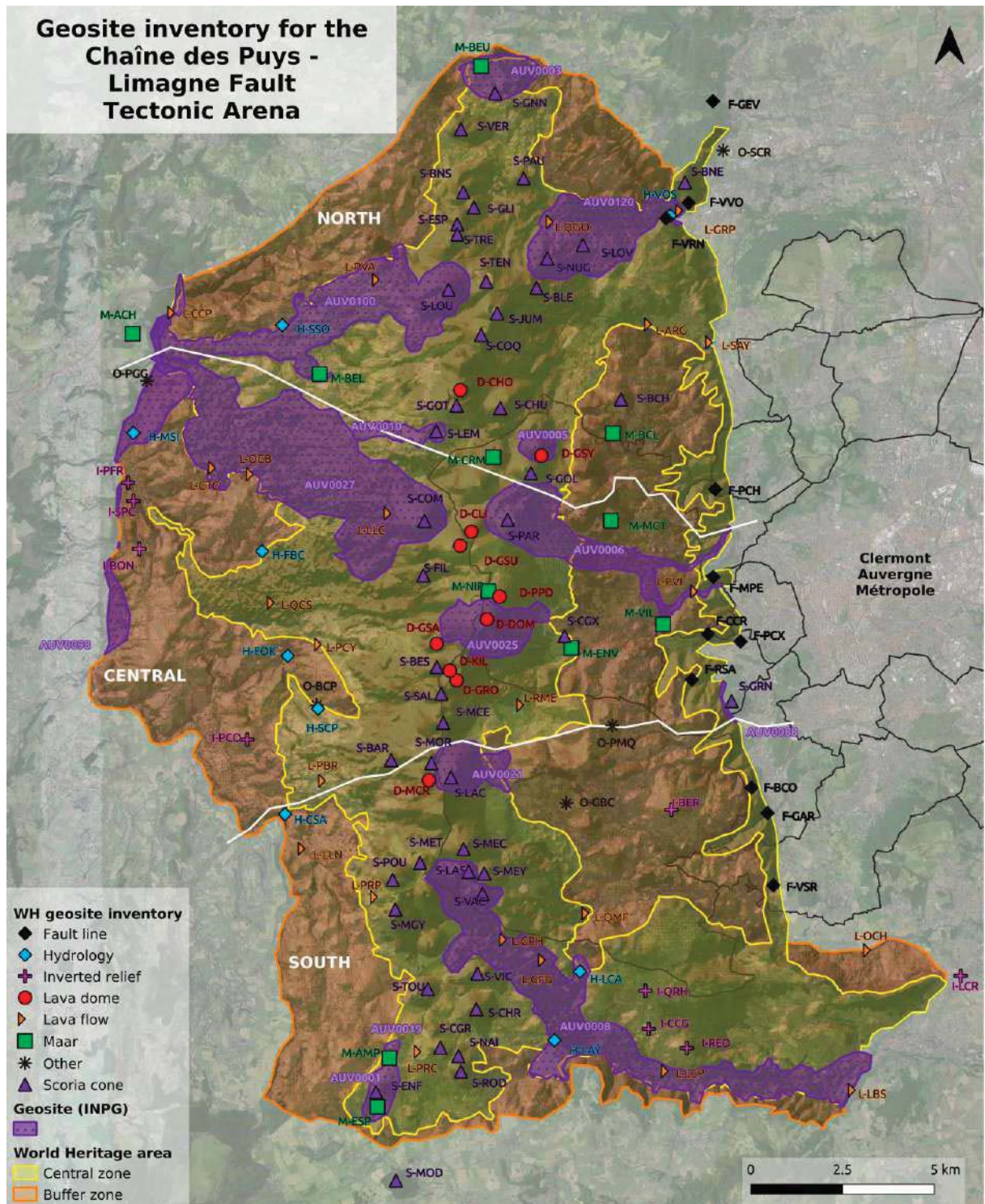


Fig. 2.4 The dedicated geosite inventory of the Chaîne des Puys – Limagne Fault World Heritage site – geographical distribution

II/D/2/b Geosite assessment with the DE WEVER ET AL. (2015) method

As it was noted in the description of the French national workflow for geosite inventorying (*chapter I/C*), the INPG is a semi-quantitative method, where the quantitatively (numerically) assessed indicators only make a part of the complex inventorying sheet per geosite. The thesis only presents the results of the quantitatively assessed indicators, but the complete dataset is planned to be shared with the relevant stakeholders.

Results are interpreted by each geological framework cluster and summarized in two forms: by the unweighted score of the individual indicators clustered by their geological frameworks (*Figs. 2.6 – 12, 14*), and by their weighted, summed form divided into scoria cones and all the other sites, due the high number of geosites (*Figs. 2.5 and 2.13*). For the latter, the scatter plot proposed by AUBERGER (2018) was used, where the *Geoheritage Interest* (axis X) is plotted against the *Protection & Vulnerability* (axis Y). From a methodological viewpoint, it must be noted that this depiction is moderately biased, as the Y-values are partially reliant on the X-values: the number of ‘*Geoheritage Interest stars*’ calculated from the X-axis values are used as an input for the *Protection & Vulnerability* status, therefore the Y-values. Although the ‘*heritage star values*’ comprises a wide range of *Geoheritage Interest* values (e.g. 30-48 points for 3 ‘*heritage stars*’), the biasing effect during the interpretation of correlation between the two dataset has to be taken into account.

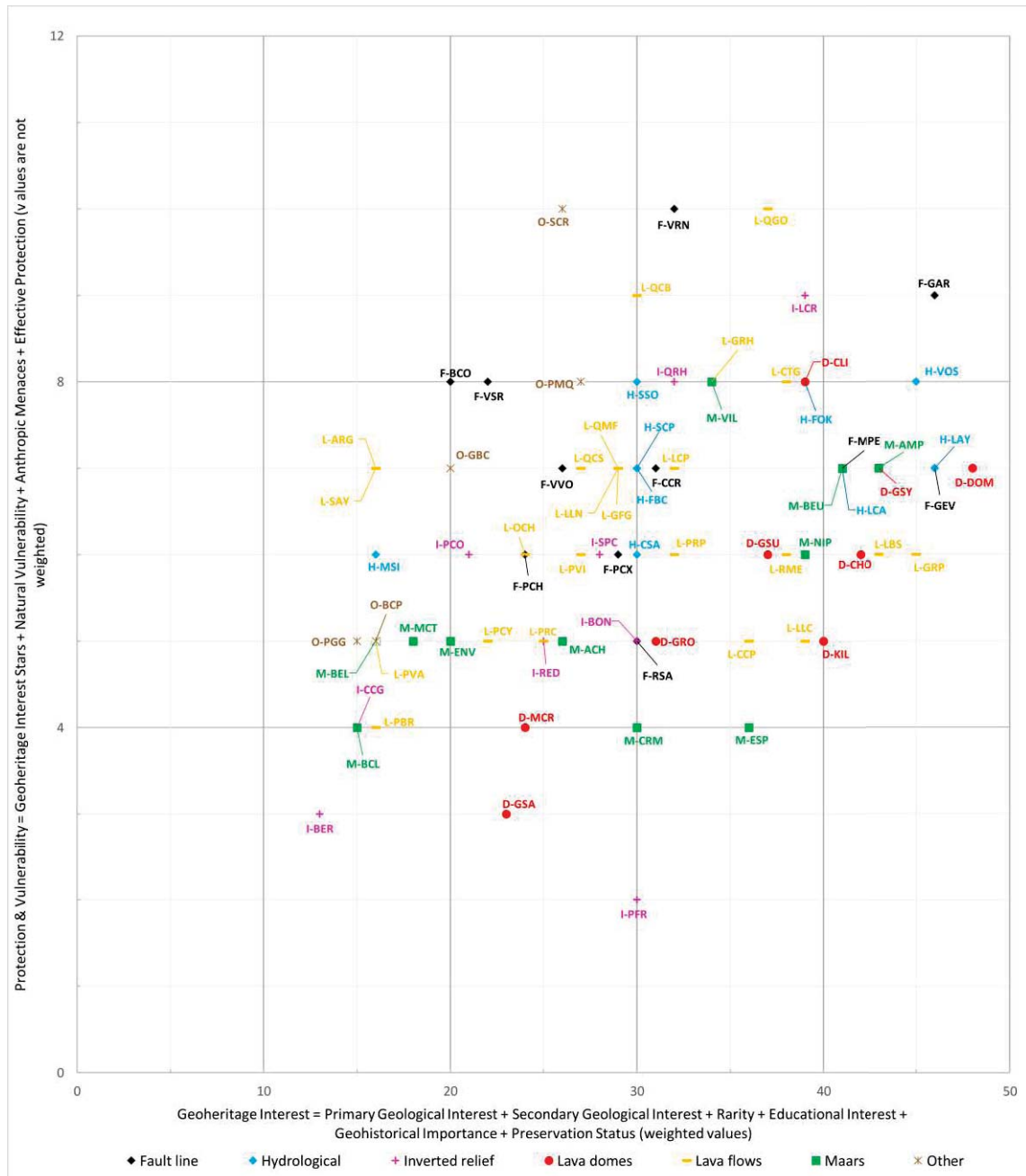


Fig. 2.5 The Geoheritage Interest – Protection & Vulnerability matrix of the non-scoria cone geosites

II/D/2/b/i Fault line geosites

Geosites of the *Limagne Fault* (Fig. 2.6) are inventoried and assessed for the first time, as this phenomenon was not included in any form in the national inventory. The fault zone was an important element of the justification of the outstanding universal value of the World Heritage property (PDD-CG 2012), which is well visible in the assessment results too. In the *Geoheritage Interest – Protection & Vulnerability* matrix (Fig. 2.5), all representatives of this cluster fell into the two (above 20 points) or three heritage stars (above 30 points) category, marking moderate to high scientific interest. The *Primary Geological Interest* (PGI) is significant in all cases (2-3 points), as each

geosite illustrates a slightly different section, therefore a slightly different geological story of the fault zone. *Secondary Geological Interests* (SGI), associated primarily to geomorphology (such as triangular facets of outcrops) and mineralogy are also observable in all cases on a varying level, related to limited scores of limited direct outcrops (e.g.– *Vierge de Volvic* F-VVO) or complex sites with a series of outcrops and landforms (such as *Chemin de Crête* outcrops F-CCR). Generally, the three sites with the highest scores of *Rarity* received the higher scores in other aspects as well, such as *Educational Interest* or *Preservation Status*. The *Gorges de l'Artière* (F-GAR) and *Gorges d'Enval* (F-GEV) are equally valuable representatives of outstanding triangular facets, exiting points of tectonically influenced river valleys and granitic tors scattered in the valleys, such as *Dolmen de Samson* and *la Roche Branlée*. Therefore, they both got the highest *Rarity* score, just as the *Montagne de la Percée* (F-MPE), which offers probably the most representative view to the fault zone between the *Plateau des Dômes* and the *Limagne Basin*, besides depicting good examples of granitic outcrops and some cavities too. These sites have the highest relevance from an educational viewpoint (3 points), because the concept of the *Limagne Fault* can be best introduced here to visitors, besides some other representative sections. From the *Protection & Vulnerability* aspect, roadcut fault line geosites (F-BCO, F-VSR, F-VRN) are interesting. As noted before, there is a certain level of (biased) correlation between the two sets of indicators, as the higher the *Geoheritage Interest* is, the more vulnerable it is, due to the further usage of heritage star value as an indicator. For these roadcut geosites, the *Geoheritage Interest* is often somewhat limited (not rare or not the most integral sites), but they are highly vulnerable, both by natural processes (erosion, over vegetation) and anthropic processes (not respective stabilization works).

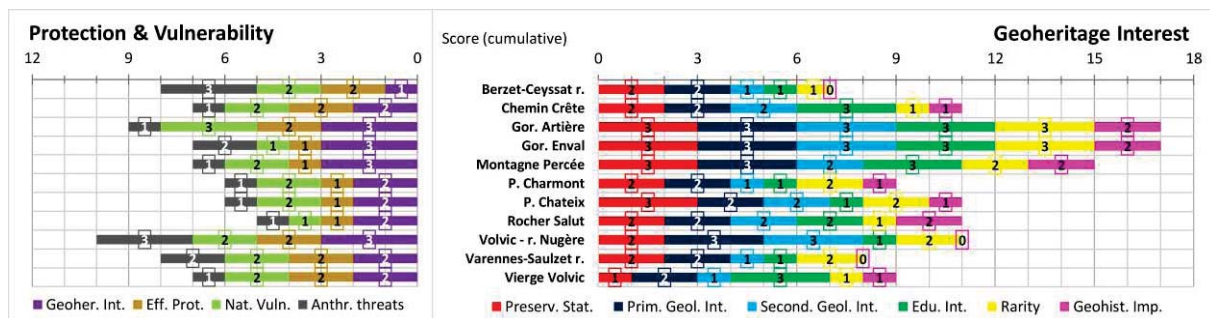


Fig. 2.6 Scores of individual indicators of DE WEVER ET AL. (2015) method for fault line geosites

II/D/2/b/ii Hydrological geosites

Hydrological geosites (Fig. 2.7) were all evaluated to give the 3 star *Geoheritage Interest* category, except the Meanders of the *Sionle* (H-MSI) geomorphosite. The latter is an interesting and important testimony of active fluvial processes at the western edge of the World Heritage property. But its importance does not reach the level of the similar national geosite (AUV0020 – Meanders of the *Sionle*) at *Quenille*, just outside the property, therefore its *Geoheritage Interest* scores are limited

(scoring the 1-star category, below 20 points). Three of the highest *Geoheritage Interest* value sites were already elements of holistic national geosites. *Lac d'Aydat* (H-LAY) and *Cassière* (H-LCA) formed by the river-valley blocking *Puy de la Vache* and *Lassolas* lava flow, being part of this national level geosite, while the semi-artificial Spring of *Volvic* (H-VOS) is also associated with a lava flow, namely the *Puy de la Nugère* and *Louve* flows. The 'Foker' mineral spring in *Ceyssat* (H-FOK) was not inventoried before on a national level, but it should be considered a key hydrological geosite too. Almost each element of this cluster is vulnerable and calls for an effective protection (7-8 points on this scale), as their water quality is fragile, both by natural (e.g. precipitation changes) and anthropogenic (e.g. contamination of watersheds) influences. These geosites in the present inventory are restricted to a limited, but integral area, namely the nuclear zone around the springs as exit points, or the vicinity of lakes. However, their protection highly relies on the holistic management of their entire watershed, which often coincides with national geosites, related to entire lava flows, like in the case of *Puy de Louchadière*.

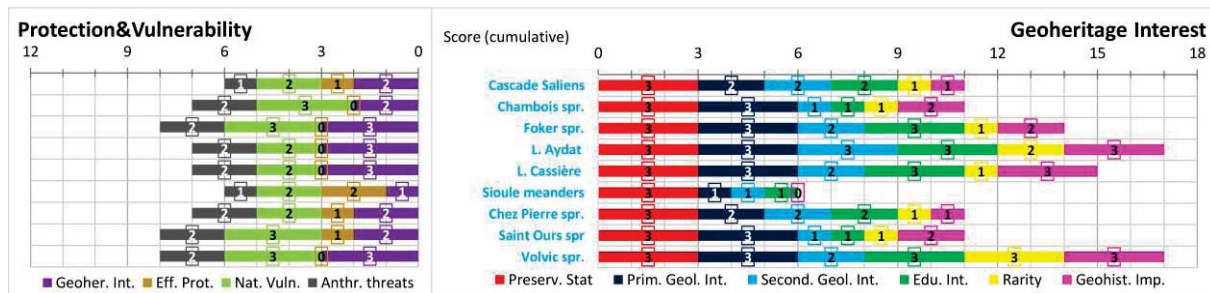


Fig. 2.7 Scores of individual indicators of DE WEVER ET AL. (2015) method for hydrological geosites

II/D/2/b/iii Geosites of relief inversion

Relief inversion (Fig. 2.8) is an important testimony to *Limagne* tectonic topography and it was also a key element of the World Heritage nomination (PDD-CG 2012). From the number of pre-Quaternary, originally valley-infilling lava flows which are now on a plateau position, only the *Plateau of Gergovie* was included in the INPG (AUV0026 geosite), however it is excluded from World Heritage area. *Montagne de la Serre* is the only integral representative of the eastern (*Limagne*) side inverted relief in the property this way. The ca. 30 km² area was subdivided into smaller elements instead of one significant, concluding geos(morpho)site. Two outcrops of the lava capping (Ancient quarry close to *Ronillas-Haut* I-QRH and the ending of the lava flow at *Le Crest* I-LCR) got the highest scores, as they are rare examples (3 points in this aspect) of visible outcrops of the Pre-Quaternary basalts on the plateau, allowing petrographic descriptions as well in the future (*Secondary Geological Interests* – 2 points for each) besides the *Primary Geological Interest* of the relief inversion phenomena (2 points for each). The two other geosites of the *Montagne de la Serre*, the *Croix Chemagrand* granite-lava contact site (I-CCG) and the *Mont Redon* as an even more erosion-

resistant element of the lava capping (I-RED) are less prevailing testimonies of the complex relief inversion framework, therefore their scores are also more limited in almost each aspect, except *Rarity*, as outcrops or even larger geomorphosites are somewhat hard to delineate on the flat, agri-pastoral plateau.

Although *Montagne de la Serre* at the eastern side of the property was used as a primary example on relief inversion during the World Heritage nomination process (PDD-CG 2012), the western side also contains a series of textbook examples: the plateaus of *Bonnabaud* (I-BON), *St. Pierre-le-Chastel* (I-SPC) and *Puy de Frimont* (I-PFR). Although they are all connected to the same phenomena - Pliocene basaltic lava flows now in a plateau position - it was divided into 3 geosites, as the plateaus are clearly divided from each other by small, deep valleys. In terms of management, the two plateaus topped by small settlements (I-BON and I-SPC) and the isolated, highly vegetated *Puy de Frimont* all call for a slightly different geoconservation strategy, better addressed by different geosites. Their *Geoheritage Interest* pointing is concordant, showing similar characteristics, however their *Protection & Vulnerability* values diverge. The western two plateaus with municipalities are more threatened by anthropogenic processes (urbanization), just like the similar sites of *Montagne de la Serre* (I-QRH, I-LCR). Sites of limited or no anthropogenic disturbance (I-PFR, I-CCG) are generally moderately vulnerable, also concerning their limited natural vulnerability (larger geomorphosites instead of small outcrops) and the legal backing by the World Heritage title.

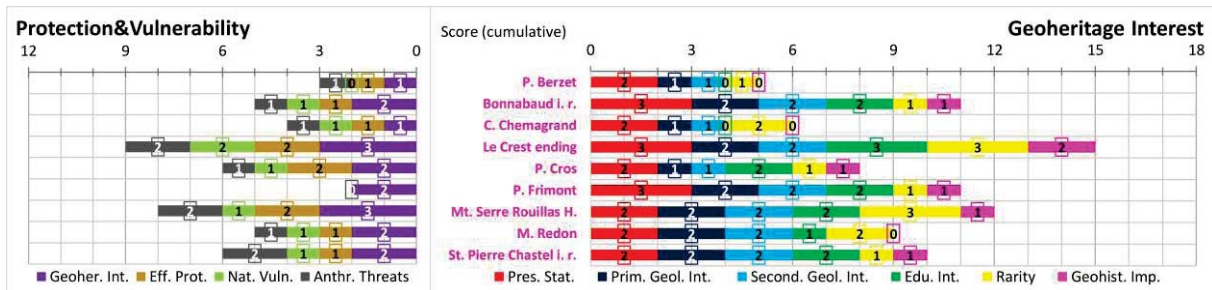


Fig. 2.8 Scores of individual indicators of DE WEVER ET AL. (2015) method for inverted relief geosites

II/D/2/b/iv Other geosites of value

The cluster of ‘other geosites’ (Fig. 2.9) as noted before, contain 4 examples of the Hercynian basement rocks of the *Plateau des Dômes* and a rare sandstone outcrop at Crouzol (O-SCR). Their *Geoheritage Interest* scores are moderate (summed as 1 or 2 ‘heritage star’), as the context of the Hercynian basement rocks are more superposed in the fault zone environment, than in the plateau position. Also the outcrops are less significant in extent and features, resulting lower *Primary* and *Secondary Geological Interest* values (1-2 points). In terms of *Protection & Vulnerability* indicators, 3 of 5 currently inventoried sites got relatively low scores – meaning moderate vulnerability – as the rock surfaces are erosion-resistant, threat by anthropic and natural influences are limited, also backed by

the strong protection background of the UNESCO title. The *Puy de Manson* quarry (O-PMQ) got high vulnerability scores because of the ongoing extraction activity, while the *Crouzol* sandstone outcrop (O-SCR) is one of the most vulnerable geosites in the whole inventory, due to its limited protection (just outside the property) and the easily erodible sediment nature.

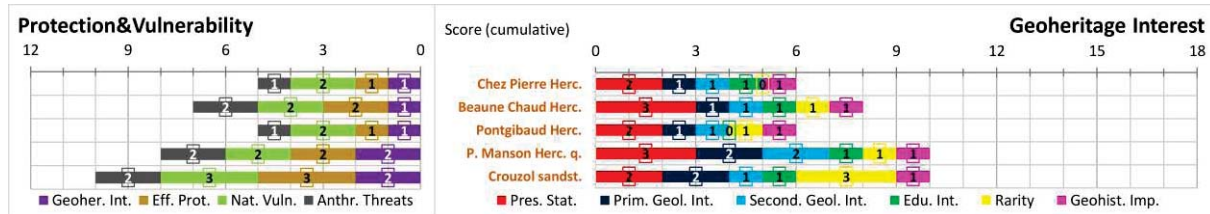


Fig. 2.9 Scores of individual indicators of DE WEVER ET AL. (2015) method for 'other' geosites

II/D/2/b/v Quaternary Volcanism – Lava flows

Turning to the geosites of the Quaternary volcanism of the *Chaîne des Puys*, sites related to lava flows (Fig. 2.10) makes one of the most extensive clusters, containing several individual, smaller elements that might be included in a larger, holistic national geosite before. It included individual sites, like a single tumulus (*La Roche Merle* L-RME), lava levées (*Grotte de Ribbe Haute* L-GRH), selected outcrops (*Parion* lava flow outcrop at *Villars* L-PVI) and larger, 'concluding' geo(morpho)sites as well, especially for pressure ridges cluster (*Ceyssat* L-PCY, *Pourcharet* L-PRP, *Les Bramauds* L-PBR). This high variety is also represented in the *Geoheritage Interest* and *Protection & Vulnerability* scores. Most of the sites are part of the 2 (above 20 points in total) or 3 'heritage stars' category, marking that their scientific importance is important or outstanding. This is especially true for the *Grotte de la Pierre* (L-GRP), a semi-artificial quarrying site, where the *Volvic* stone was extracted for centuries and now it is a museum and interpretation site (45 points in total for *Geoheritage Interest*). The outcrop of the *Puy de la Vache* and *Lassolas* lava flow base at *Saint-Saturnin* (L-LBS), also got significant points, especially in terms of *Primary* and *Secondary Geological Interests* and *Rarity* (the maximal 3 points), as it is a rare site, where the bottom of a lava flow is well visible in the property, also showing an insight to the pre-eruption paleosoil. Further sites of high *Geoheritage Interest*, were also justified primarily by elevated scores of *Rarity* (2 points mostly), maximal *Primary Geological Interest* and also significant *Educational Interest* (1-2 points). These are geosites like the *Trou de Glace* (L-CTG) containing not only significant roadcut outcrops of the *Puy de Côme* lava flow, but also rare annual ice remnants in the deeper parts of the lava flow holes; the well-preserved area of the lava lake of *Puy de Côme* (L-LLC); the *Roche Merle* (L-RME), the probably best preserved isolated tumuli in the World Heritage property.

On the 'other end', there are three geosites awarded with 1 heritage star only. The pressure ridges close to *Les Bramauds* (L-PBR) are important for their own intrinsic value, but somewhat less significant compared to other similar clusters (L-PCY, L-PRP, L-PRC), which also scored

somewhat lower in comparison with other lava flow geosites on the *Geoheritage Interest* scale, due to their common nature (0 points on *Rarity*). The lava flow outcrops at *Argnat* and *Sayat* also got limited scores in their present forms: their exact output source and their scientific importance is scarcely known, and the roadcut outcrops themselves are quite limited (1 point for almost all indicators, 0 for *Geohistorical Importance*, due to the lack of extensive scientific knowledge). However, considering their significant vulnerability, their inclusion in the inventory for raising attention about their effective protection was desirable, and their *Geoheritage Interest* can be reconsidered by future, detailed geological studies.

In terms of *Protection & Vulnerability*, besides the moderate to high (4-8 points) category, two geosites, the active quarries of the *Côme* lava flow at *Chambois* (L-QCB) and the *Nugère-Louve* lava flow at *les Goulots* (L-QGO) got significant final scores (9 and 10 points respectively). Here, the active, small-scale quarrying could bring alight new aspects of the inner structure of the lava flows, but they could be easily destroyed by the same quarrying, and the natural erosion is also accelerated by mass movements. For other sites, their vulnerability also depends on individual considerations. For example, the previously mentioned *Trou de Glace* (L-CTG) ice remnants are vulnerable on mid-term by land use changes connected to forestry works; and on a mid to long-term, climate change is a significant threat, and its roadcut outcrops could be also easily modified (2-2 points on natural and anthropogenic vulnerability, 8 on total). In contrast, the pressure ridge ‘fields’ are generally less vulnerable (4-6 final points, 1-1 points for the natural and anthropogenic vulnerability, 1-2 points for effective protection), as they are generally well protected by their unsuitability for agriculture, which is often manifested in their coverage by shrub or trees (e.g. at *Les Bramauds* L-PBR or *Vauriat* L-PVA). However, forestry and agriculture techniques should be controlled to make sure that the features are not destroyed. At present there is no culture of geoheritage in the forestry and agriculture works or knowledge of what is valuable.

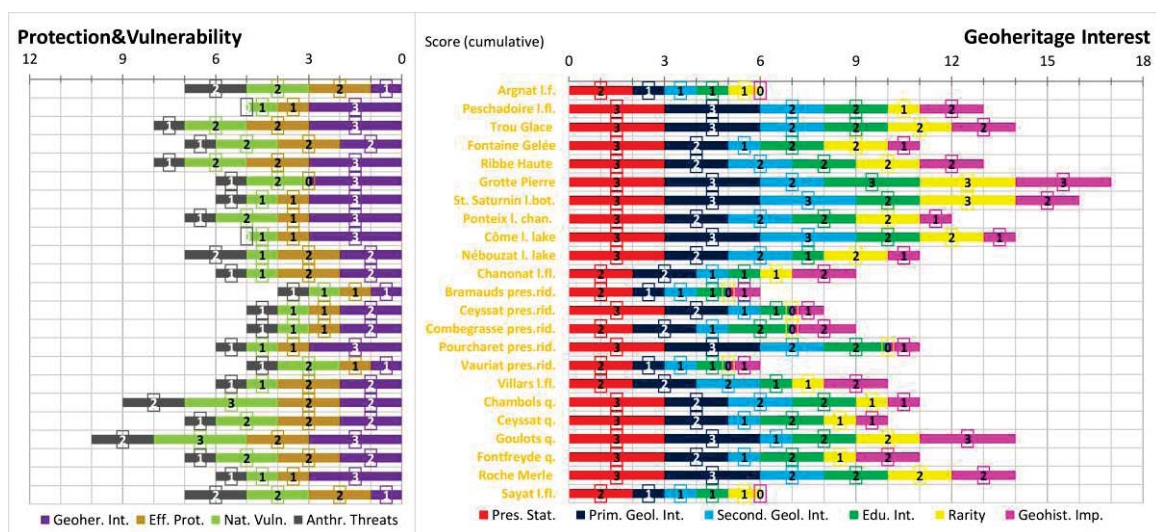


Fig. 2.10 Scores of individual indicators of DE WEVER ET AL. (2015) method for lava flow geosites

II/D/2/b/vi *Quaternary volcanism - maars*

Maars (Fig. 2.11) can be interpreted as ‘negative landforms’ connected to monogenetic volcanism. This often means at least in the *Chaîne des Puys* that their field representation is limited, their existence could be scarcely deduced from the topography, and visible outcrops might be constrained to limited sections of the surrounding tuff rings, if still traceable. Regarding these aspects, the highest scoring geosites showed clearly at least the topography (*Narse d’Ambois* M-AMP, *Narse d’Espinasse* M-ESP) or even an outcrop with its products as a tuff ring (*Nid de la Poule* M-NIP, *Maar de Beaunit* M-BEU). These sites, besides their high volcanological *Primary Geological Interest* (2-3 points) and *Secondary Geological Interests* of mineralogy, sedimentology or even geomorphology (2-3 points as well), got high scores of *Geohistorical Importance* too (3 points), as they are mostly-dated, and they were important cornerstones in the timing of the local Quaternary volcanism. All these five sites were already part of national geosite in the INPG, M-BEU and M-ESP with their adjacent scoria cones (*Puy Gonnard* S-GNN and *Puy de l’Enfer* S-ENF respectively) and M-NIP as part of the *Puy de Dôme* site (AUV0025), while M-AMP in the World Heritage property inventory is identical with its national counterpart site (AUV0019).

Those sites that were not inventoried before in the INPG got lower *Geoheritage Interest* rating in general (15 to 26 points between *Bois de Clerzat* M-BCL and *Maar d’Anchald* M-ACH). On one hand, it justifies the selection process of the national inventory, which has chosen the most representative phenomena of maars in the property. On the other hand, the 1-2 heritage interest stars for sites like *Creux Morel* (M-CRM) or *Maar d’Enval* (M-ENV) shows that on a local-regional level, these are valuable sites, that should be recognized ‘officially’ in an inventory, and their effective protection should be also considered, based on their scientific importance. Generally, the *Protection & Vulnerability* value of maar geosites is somewhat lower than for the other clusters (all sites are on the moderate scale, between 4-8 points). Due to their large size, the complete destruction of these features is a less-likely scenario, however for a small site like *Narse d’Ambois* (M-AMP), a serious natural deterioration is not impossible, marked therefore with 3 points in this aspect. Two sites are moderately threatened by the closeness of urban centers (*Maar de Beaunit* M-BEU and *Maar de Villars* M-VIL, 2 points for anthropic threats), while most of the other maars are used as pastoral fields, with limited disturbance in the ancient diatreme areas, but moderate possibility of deterioration in the tuff ring sections, where it still exists (1 points for natural vulnerability, 0-1 points for anthropic threats).

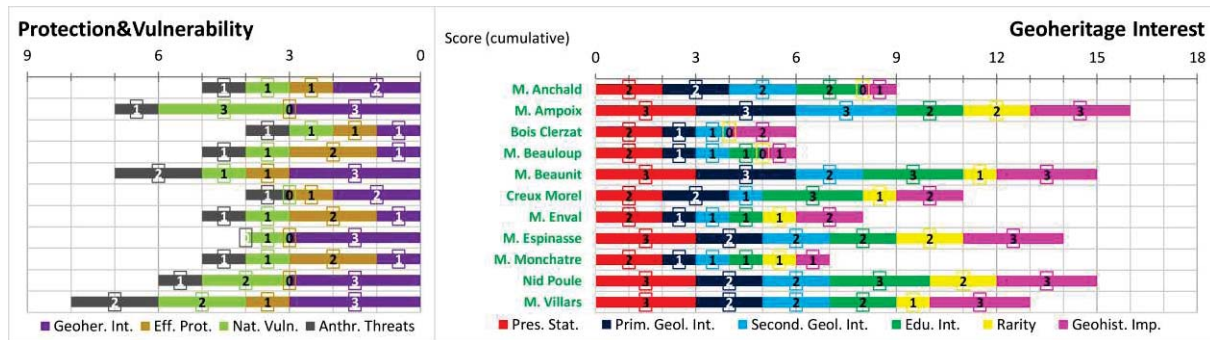


Fig. 2.11 Scores of individual indicators of DE WEVER ET AL. (2015) method for maar geosites

II/D/2/b/vii Quaternary volcanism - lava domes

The lava domes (Fig. 2.12) of the *Chaîne des Puys*, associated with the more differentiated, viscous trachytic lavas are mostly concentrated to the central section of the volcanic alignment, relatively close to each other. The *Puy de Dôme* (D-DOM) – *Petit Puy de Dôme* (D-PDD) and the *Grand Sarcony* (D-GSY) were included in the INPG (as AUV0025 and AUV0005 respectively). From the subdivided AUV0025 national geosite, the ‘independent’ *Puy de Dôme* (D-DOM) received the highest *Geoheritage Interest* rating not only for the lava dome cluster, but also for all geosites (48 points): outstanding *Primary Geological Interest* as a complex lava dome, *Secondary Geological Interests* for geomorphological, mineralogical and even heritage stone considerations due to Temple of Mercury, a key role in geoeducation and its historical importance during volcanological researches justified the highest scores for each indicator (3 points). Due to the biasing effect mentioned before, the highest heritage star rating (3) also affected its *Protection & Vulnerability* scale, but the elevated scores of natural and anthropogenic vulnerability (2-2 points) and the final 7 points are prompted by the extreme frequentation of the site, and some conversation issues too, noted by PETRONIS ET AL. (2019). For the cryptodome of *Petit Puy de Dôme* (D-PDD), the *Educational Interest* is less outstanding, than for its younger but more voluminous counterpart (PETRONIS ET AL. 2019), therefore the *Geoheritage Interest* is slightly lower (40 points), just as its vulnerability (1-1 points for the natural and anthropogenic aspects), as it is less frequented by visitors, lowering the rate of erosion processes. The *Grand Sarcony* (D-GSY) which is identical with the delineation of the national geosite (AUV0005) received outstanding scores in this independent evaluation too in terms of *Geoheritage Interest* (43 points), justified by clear, well-preserved trachytic outcrops and caves. The slopes are easily erodible at the frequented touristic trails, but relatively resistant at most other places due to the thick vegetation cover, resulting in moderate *Protection & Vulnerability* scoring (7 points in total, 2-2 for the natural and anthropogenic aspect).

Although they are really close to some national geosite delineations, other lava dome features were omitted from the national inventory, such as *Puy Chopine* (D-CHO) close to *Lemptégny* or as

they do not share the same geological framework and evolution. A part of these, namely *Puy Chopine* (D-CHO), the *Kilian Crater* (D-KIL), *Le Cliersou* (D-CLI) and the *Grand Suchet* (D-GSU) were also classified into the 3 heritage star category. The latter two are also good examples of simple lava domes (BOIVIN ET AL. 2017), but they were probably omitted from the national inventory, due to limiting the number of similar sites, already represented by *Grand Sarcouy* (D-GSY, AUV0005) mentioned before. *Puy Chopine* (D-CHO) is the best preserved extruded plug (BOIVIN ET AL. 2017) in the World Heritage property (3 points for *Primary Geological Interest* and *Rarity* as well), while the explosive crater of *Kilian* (D-KIL) is important to the evolution of the neighbouring *Puy de Dôme*, marking the last phase of its activity. Two sites, namely the *Puy de Monbchar* (D-MCR) and *Grand Sault* (D-GSA) fell into the 2 heritage star cluster (23-24 points). They are covered with a dense forest canopy, outcrops or microforms are harder to be recognized, which lowered especially their *Educational* and *Secondary Geological Interests* (0-1 points). On the other hand, this dense coverage and the lack of touristic trails serves well their protection, resulting moderate scores in this aspect (3-5 points on the *Protection & Vulnerability* scale).

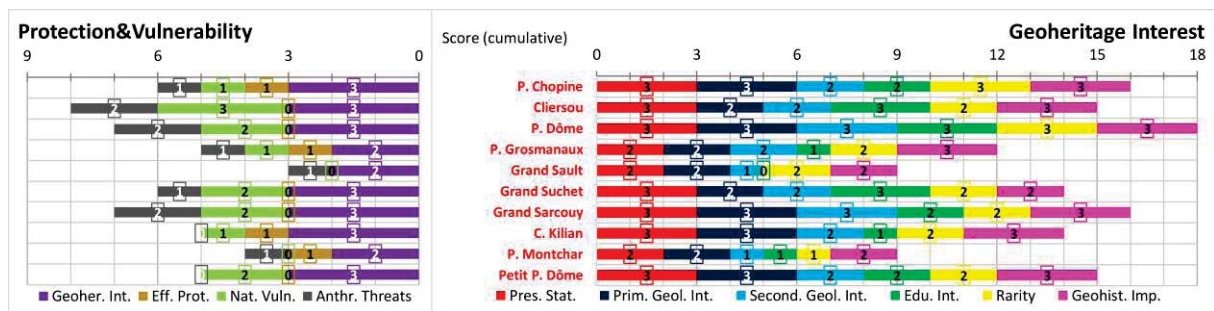


Fig. 2.12 Scores of individual indicators of DE WEVER ET AL. (2015) method for lava dome geosites

II/D/2/b/viii Quaternary volcanism - scoria cones

Finally, the most numerous cluster is associated with the scoria cones, as it is also the most prevailing landform in the *Chaîne des Puys*, associated with basaltic to trachybasaltic monogenetic activity. The *Geoheritage Interest – Protection & Vulnerability* matrix (Fig. 2.13) shows two typical scenarios and some geosites, where the X or Y axis values are rather different from these ‘clusters’.

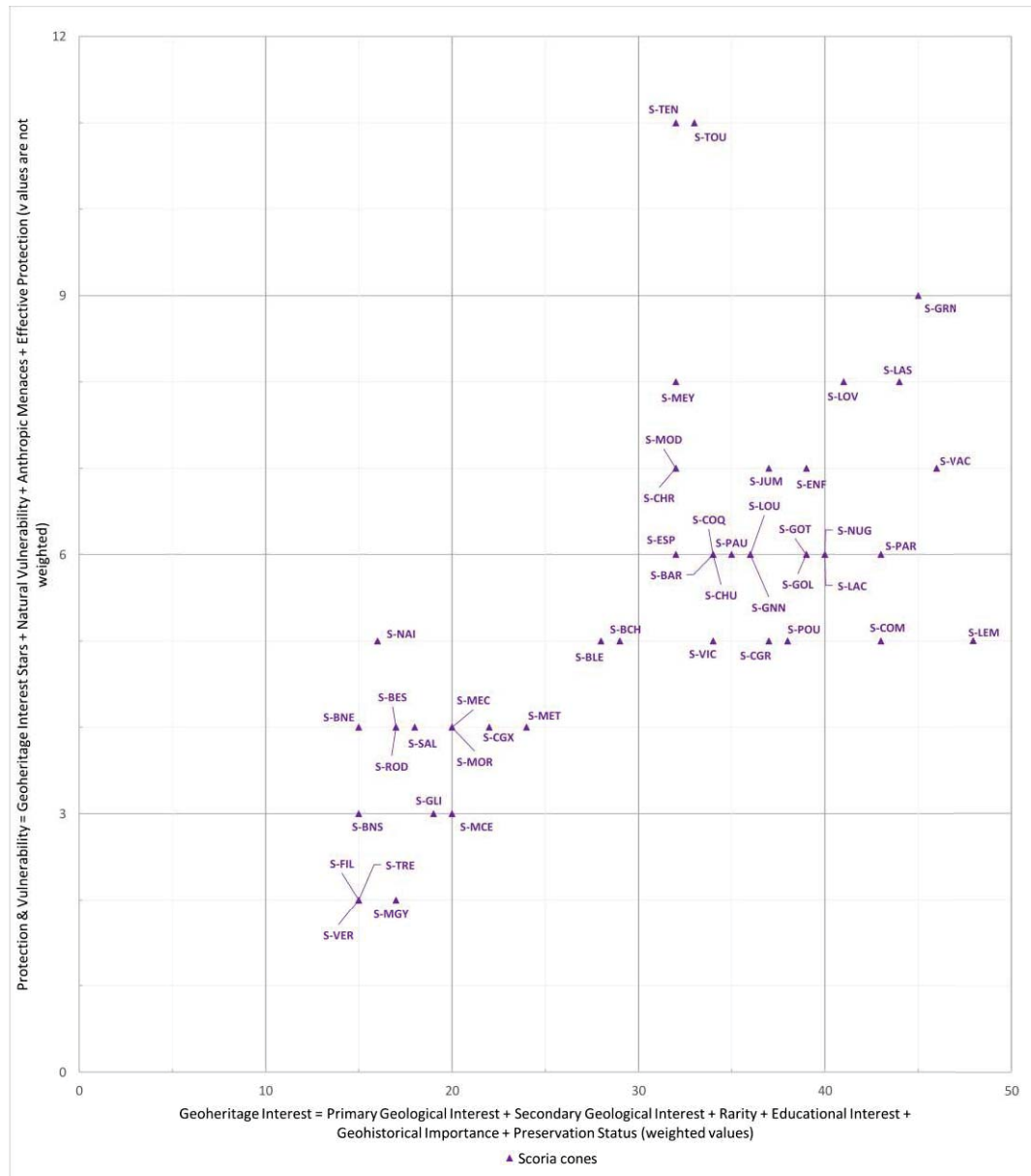


Fig. 2.13 The Geoheritage Interest – Protection & Vulnerability matrix of the scoria cone geosites

The first cluster is defined by a low to moderate *Geoheritage Interest*, between 15 points (such as *Puy de Tressons* S-TRE) to 25 points (*Puy de Monteillet* S-MET), and a *Protection & Vulnerability* value of 2-4 points. Most of the sites that were classified into this category are generally less-studied as they are not the most prevailing examples in the area, either for their morphometry or petrological characteristics, compared with sites like *Puy de Pariou* (S-PAR) or *Puy de Laschamps* (S-LAS). Outcrops are completely missing or limited to some heavily vegetated sections, microforms are hidden by gentle forest canopy or even denser vegetation, which is a limiting factor for scientific investigations. There are a limited number of dedicated studies for some of these geosites, such as CAMUS & VINCENT (1973) for *Chuquet-Genestoux* (S-CGX) or the tephrastatigraphy-related study of *Puy de la Rodde* (S-ROD) by VERNET ET AL. (1996), but several are constrained to general morphological or general petrographic studies, and rough geological mapping campaigns of the

Chaîne des Puys. *Primary* and *Secondary Geological Interest* values were generally limited to 1 this way, but a *Geohistorical Importance* of 1 point was awarded to each site too, as even the less-studied sites contributed indirectly to the scientific discussions about the local monogenetic volcanism (Fig. 2.14). Their *Educational Interest* is also limited due to lack of knowledge (1 point generally), but those which are currently unavailable on any kind of track or trail, got 0 points. These were sites that scored low also on the *Protection & Vulnerability* scale. Being virtually unavailable and with slopes protected by thick vegetation, their natural and anthropogenic vulnerability is 0, noting that inattentive forestry works might mean a threat in the future. The World Heritage title functions as a strong backbone for their Effective Protection (1 point).

The other ‘group’ of scoria cones is comprised of 3 ‘heritage star’ geosites and two geosites very close to this in terms of *Geoheritage Interest* scores (*Puy de Bleymas* S-BLE and *Bois de Chanat* S-BCH with 28-29 points). On the *Protection & Vulnerability* scale, these sites have a moderate to elevated scores (5-9 points). Higher scores for *Geoheritage Interest* are related to multiple factors. Many sites have been quarried (such as *Puy de la Vache* S-VAC, *Puy de Bleymas* S-BLE, *Puy de Pagnat* S-PAU), which gives a good insight to the inner structure (*Educational Interests* of 2-3 points) and facilitates also field work for scientific studies. Vegetation coverage is also often more favourable: the craters of the cones are not forested, for example at *Puy de Pourcharet* (S-POU), *Puy de Côme* (S-COM) or *Puy de Chaumont* (S-CHU) which gives a good didactic insight to the morphology of the scoria cones, without the need to use high resolution DEMs. In other cases, a similar background is provided by less-dense forests (e.g. *Puy de Monténard* S-MOD), or strategic viewpoints (e.g. *Puy de Jumes* S-JUM and *Puy de la Coquille* S-COQ).

Similar to the previous examples with other geological frameworks, those geosites that are part of a national geosite in the INPG, were among the highest scoring. The *Puy de Lemptégy* (S-LEM) received the highest (the maximum) *Geoheritage Interest* score, as an internationally outstanding rare example of showing the inner, deeper structure of the complex interactions of two scoria cones (*Lemptégy* I and II) and products of nearby volcanic centres too (*Puy Chopine*, *Gouttes*, *Côme*, *Parion*), with excellent interpretative potential. The standalone geosites of *Puy de la Vache* (S-VAC), *Lassolas* (S-LAS), *Nugère* (S-NUG), *Louve* (S-LOV), *Côme* (S-COM) or *Grave Noire* (S-GRN) are high scoring geosites (36-46 points) on ‘their own’ as well, considering just the scoria cones, without their output products, the lava flows that are included in their respective national geosites (AUV0008, 0120, 0027, 0088).

Five scoria cones were not inventoried before in the INPG, but they were classified into the same range in terms of *Geoheritage Interest* (above 35 points). *Puy de Pourcharet* (S-POU) and *Puy de Combegrasse* (S-CGR) are among the finest examples of horseshoe-shaped cones with high didactic

potential, while *Puy des Goules* (S-GOL) represents a single, enclosed crater of trachy-basaltic composition (BOIVIN ET AL. 2017). *Puy de Jumes* (S-JUM) is the best example of twin, aligned craters together with its counterpart, *Puy de la Coquille* (S-COQ). The slight difference in final points is related to the higher educational potential of S-JUM, as its crater is better visible and thus more interpretable. Finally, *Puy des Gouttes* (S-GOT), destroyed by the violent activity related to *Puy Chopine* (D-CHO) is an important aspect in the history of local monogenetic volcanism, and an internationally renowned site (e.g. VAN WYK DE VRIES ET AL 2014, SCROPE 1825).

In terms of *Protection & Vulnerability*, site-specific scenarios stand behind each values. The higher scores, compared to the previously discussed group of scoria cones is mostly related to the following factors. The high number of ancient quarries raises the *Natural Vulnerability* (1-2 points) as the slopes here are often steep and unstabilized (e.g. *Puy de l'Espinasse* S-ESP, *Puy de Pagnat* S-PAU). The slopes in general are also vulnerable at cones, where the vegetation cover could not stabilize some steeper sections or it is damaged (e.g. *Puy de Parion* S-PAR, *Puy de la Mey* S-MEY). This can be further propagated by erosion along trails, resulting higher scores (2 points) in terms of anthropogenic vulnerability (e.g. *Puy de Lassolas* S-LAS, *Puy de Jumes* S-JUM). The highest score in this aspect (3 points) was awarded to *Puy de Grave Noire* (S-GRN) which is also threatened by massive urbanization, besides the erosion of the ancient scoria quarry and degradation of the top viewpoint, blemished by rubbish from local party goers, wild barbecues.

Several sites received 6 points for *Protection & Vulnerability*, but for different considerations. For example, at *Puy de Parion* (S-PAR), the *Effective Protection* is the strongest (0 points) due to the comprehensive use of wooden steps to the summit, reducing relevant *Anthropogenic Vulnerability* to the crater area, where there are remedial works planned (1 point). For the *Parion*, the *Natural Vulnerability* (2 points) is still elevated, due to some landslides in slope areas of the cone. At *Puy de la Nugère* (S-NUG), the densely vegetated slopes reduce the *Natural Vulnerability* (1 point), and while the steeper sections of the trails are not stabilized directly (1 point for *Effective Protection*), they tend to be more erosion resistant, than at other frequented cones (e.g. *Puy de Lassolas* S-LAS).

Finally, the very high *Protection & Vulnerability* values (11 points) of *Puy de la Toupe* (S-TOU) and *Puy de Ténuzet* (S-TEN) are related to active quarrying. These sites are currently excluded from the World Heritage zone (PDD-CG 2012) marked with 3 points in terms of *Effective Protection* (serious threats). On the other hand, active quarrying is a chance for the discovery, not just destruction of geological phenomena, the latter propagated both by natural (erosion) and anthropogenic modification of slopes.

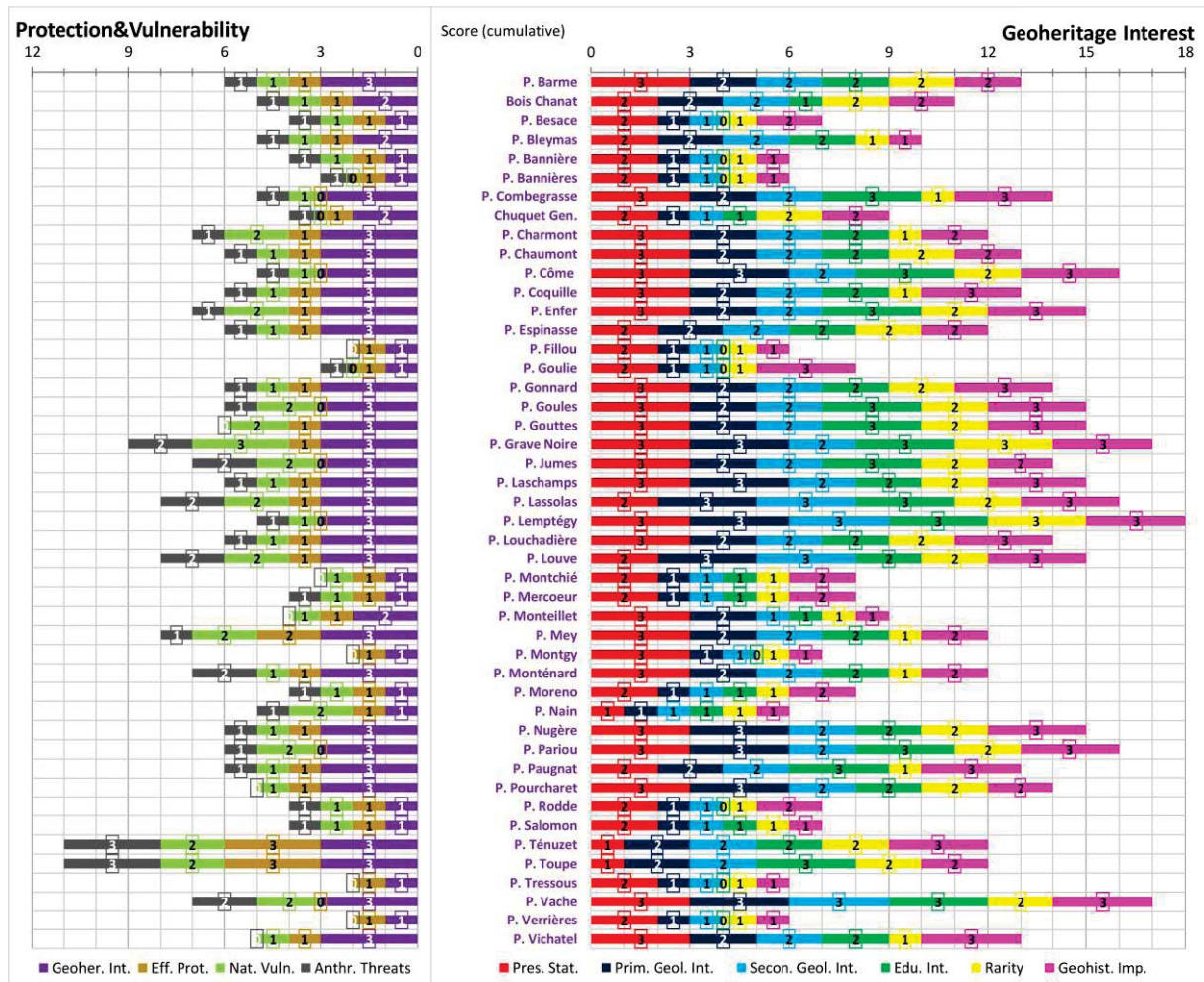


Fig. 2.14 Scores of individual indicators of DE WEVER ET AL. (2015) method for scoria cone

II/D/2/c Geosite assessment with the VUJIČIĆ ET AL. (2011) method

The method of VUJIČIĆ ET AL. (2011), the GAM is an entirely quantitative assessment based on two principal indicators, described in *chapter I/C*. Results are summarized in form of a matrix where the *Main Values* (MV) are plotted against the *Additional Values* (AV). Due to the high number of geosites, two separate GAM matrices have been produced, one for scoria cone sites and one for all other geological frameworks (Figs. 2.15 and 2.22). A more detailed insight is provided through the charts on the sets of indicators (Fig. 2.16 – 2.21 and 2.23), which contains the subgroups of *Main Values* as *Protection/Vulnerability Values* (VPr), and *Additional Values* as *Functional Values* (VF_n).

Some of the considerations such as *Scientific/Educational Values* (VSE) indicators are similar to the ones of the DE WEVER ET AL. (2015) method. However, the VUJIČIĆ ET AL (2011) has fixed considerations and values for scoring (e.g. level of publications about a geosite, number of viewpoints), while the French workflow generally proposes the two ends of the Likert-scale. Therefore, the values in this section between the two methods can be significantly different for a similar indicator, compared to *section II/D/2/b*.

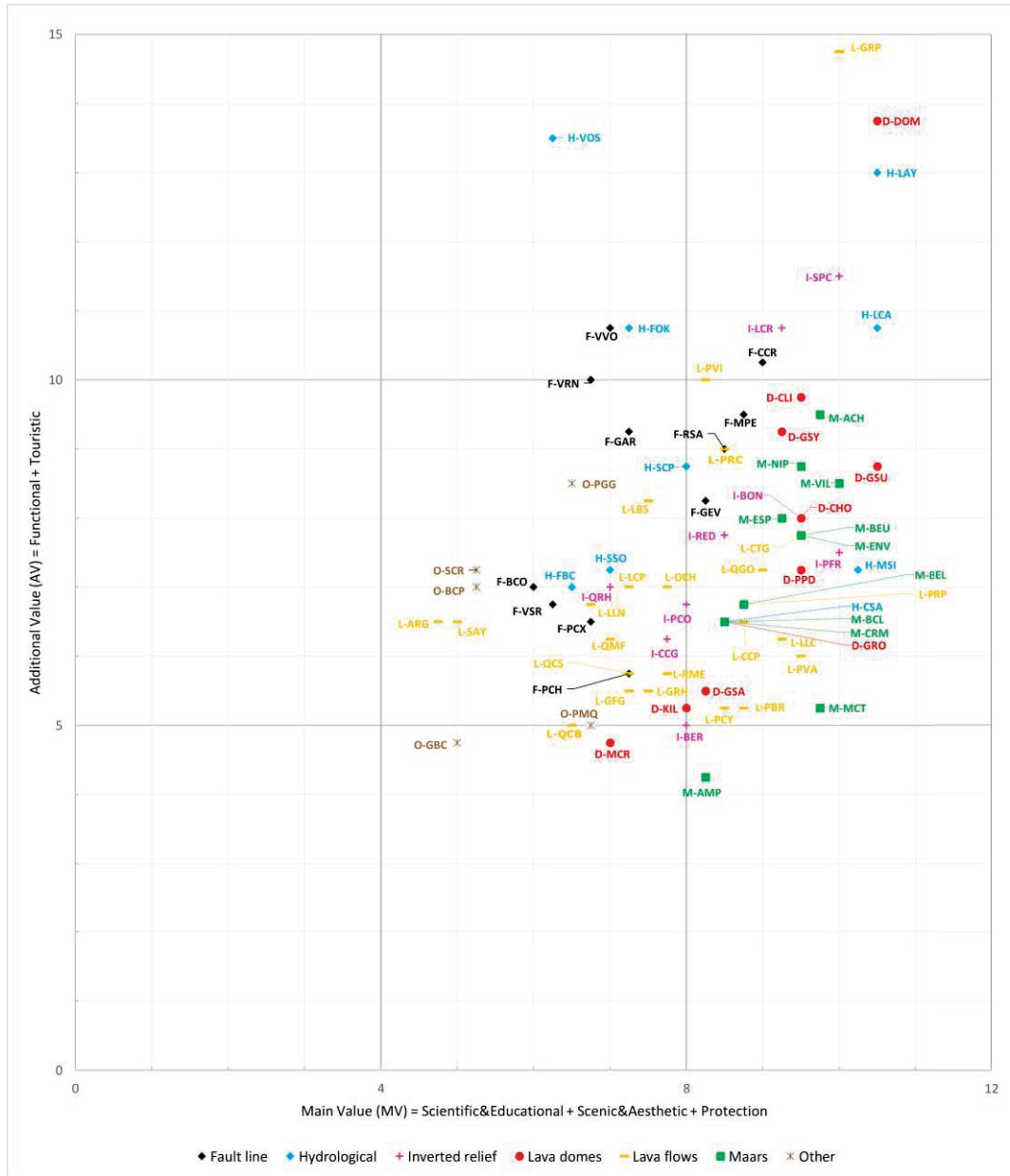


Fig. 2.15 The GAM matrix for non-scoria cone geosites

II/D/2/c/i Fault line geosites

In case of geosites of the *Limagne Fault*, the GAM-matrix suggests two typical scenarios (Fig. 2.15). Four sites reached moderate scores both in terms of *Main Values* (\sim geoheritage importance) and *Additional Values* (\sim geotouristic importance). Two of them are a series of small roadside outcrops (F-BCO between *Berzet* and *Ceyrat*, F-VSR between *Varennes* and *Saulzet-le-Chaud*); *Puy de Chateix* (F-PCX) is a fault facet in a small area next to the outskirts of *Royat*, while *Puy de Charmont* (F-PCH) is an isolated area with some minor outcrops. In each case, the *Scientific/Educational Values* are limited (1,25 – 2 points, Fig. 2.16), as dedicated studies of them are still limited, and although they are important mosaics of the fault zone, they are not the most representative and rare examples. *Protection Values* are low for the two roadside outcrops (F-BCO and F-VSR) as they are

vulnerable both by natural erosion of its slopes and potential roadworks. The two other sites (F-PCH, F-PCX) got higher scores in this aspect, due to their isolation, which reduces their vulnerability, especially from an anthropogenic aspect. In terms of the *Additional Values*, especially the *Touristic Values* (2,75-3 points) are limited, as these sites are currently unexploited from this aspect, lacking not only interpretative facilities (e.g. information panels), but direct (F-PCH, F-PCX) or safe (the roadcut outcrops of F-BCO and F-VSR) access as well for visitors. Therefore, the geotourism-related *Additional Values* are predominantly not relying on site-specific touristic facilities, but are the closeness of other facilities, such as restaurants, road infrastructure, associated heritage sites, evaluated both under *Touristic* and *Functional values*.

The other group of fault line geosites has higher scores both in terms of *Main* and *Additional Values*. In case of two sites, a roadside outcrop of the fault line next to *Volvic* (F-VRN) and the ‘*Vierge de Volvic* outcrops and viewpoint to the fault zone’ (F-VVO), the *Main Values* are similar to the previously discussed cluster. This is connected mainly to the vulnerability of the sites (low points of *Protection Values*), both by natural erosion and anthropogenic influence (path erosion at F-VVO, disrespectful roadworks at F-VRN). Although other sites are also threatened by anthropogenic influence, such as the frequently visited *Gorges de l’Artière* (F-GAR) and *Enval* (F-GEV) or the *Chemin de Crête* outcrops next to Royat (F-CCR), but path erosion mostly spare the outcrops themselves, as they are next to trails, while in case of the *Vierge de Volvic* (F-VVO), the trail ascends directly on the outcrops.

These sites of the second group are the most representative examples of the *Limagne Fault*, therefore they have relatively higher scores for the *Scientific/Educational Values* (2,25-2,75 points), although these are still somewhat limited, especially because of the lack of of systematic studies. *Montagne Percée* (F-MPE) offers one of the clearest views with the highest didactic potential to the fault zone, while the two ‘*gorge*’ geosites (*Artière*, F-GAR and *Enval*, F-GEV) are equally representative examples of the interaction of fault tectonics and river erosion in creating morphology, also having important fault facet outcrops. These sites are already frequented by tourists, there is a touristic infrastructure of trails, but dedicated interpretation of the faulting process is still very limited or non-existent (lack of organized tours or interpretative panels). Therefore, the *Touristic Values* are higher (3,75-6,75), but with a room for improving the geotouristic potential of the sites.

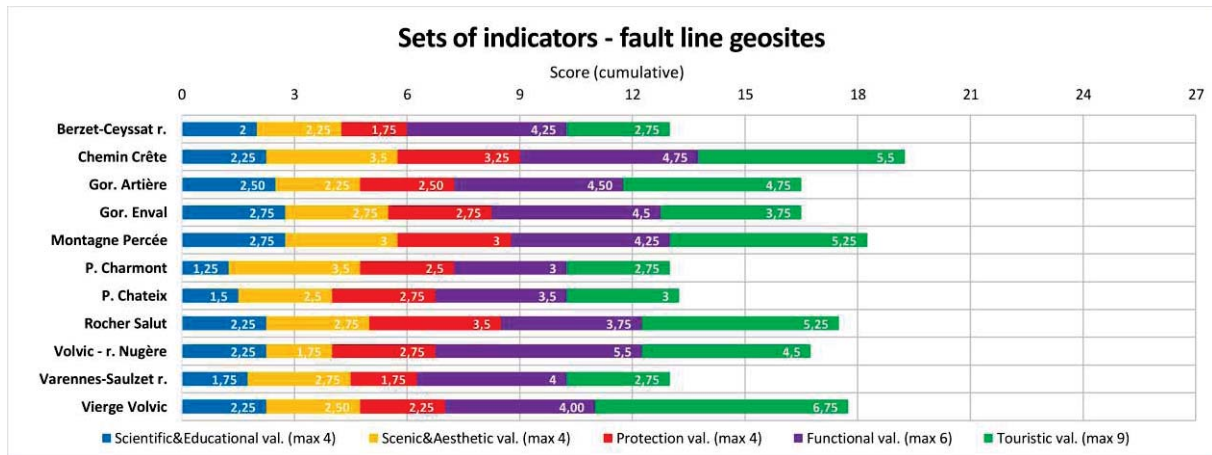


Fig. 2.16 Scores for sets of indicators for the method of VUJIĆ ET AL. (2011) for fault line geosites

II/D/2/c/ii Hydrological geosites

Hydrological geosites consist of two typical groups, suggested by the differences of their *Additional Values* (Fig. 2.15, 2.17). Five sites, namely three springs emitting from lava flows (H-FBC at *Chambois*, H-SCP at *Chez Pierre*, H-SSO at *Saint-Ours*), the ‘*Cascade des Saliens*’ waterfall (H-CSA) and the meanders of the *Sioule* between *St.Pierre-le-Chastel* and *Pontgibaud* (H-MSI) received moderate scores (6,5-8,75 points) in this aspect. The springs are protected watersources, fenced away from visitors, only the *Chez Pierre* source presents a slight (geo)touristic approach with an interpretative panel, giving in a slightly higher (4,25 points) *Touristic Value*, compared to the other four sites. Their *Main Values* are also among the lowest, especially because of their small size, which affected the *Surface* indicator in the *Scenic/Aesthetic Values* (1,25-2,5 points), and also because of their potential vulnerability by contamination from the catchment area of the lava flows (*Protection Values* 2,25-2,75 points). The ‘*Cascade*’ (H-CSA) and the *Sioule* meanders (H-MSI) are significantly larger and aesthetically important features (*Scenic/Aesthetic Values* 2,5-4 points), their natural vulnerability is associated to long-term processes rather, and the anthropogenic threats are limited (*Protection Values*: 3,25-3,5 points). This is true for the waterfall (H-CSA) that is frequented by visitors, but especially fits the meanders (H-MSI), which are hardly accessible, visited only by anglers. Somewhat controversially, their *Additional Values* contradict this current touristic pattern, which can be connected to the content of the evaluation indicators. The *Functional Values* are higher for the meanders (H-MSI) as they are stretching between *St.Pierre-le-Chastel* and *Pontgibaud*, surrounded by a higher number of additional natural and cultural attractions. While the waterfall is already touristically exploited with a small trail and protective poles (slightly higher *Touristic Values* with 3,75 points), its isolation at the western edge of the World Heritage property limited the number of additional heritage features in the vicinity, therefore the *Functional Values* and the whole category of *Additional Values*.

Two springs, one at *Volvic* (H-VOS) and the ‘*Foker*’ source at Ceyssat (H-FOK), and two lakes, namely *Lac d’Aydat* (H-LAY) and *Cassière* (H-LCA) received outstanding scores for the *Additional Values*, marking an already high level of geotouristic exploitation. The two springs received similar points for the *Main Values* as described before (small size, vulnerability), while the two lakes the highest scores for the whole hydrological geosite cluster. This is related to their scientific importance (3,25 – 3,5 points) as the two representative examples of lava-flow dammed lakes in the World Heritage property; maximal *Scenic/Aesthetic Values* by their size and landscape role (4 points) and advanced protection and managed vulnerability concerns (3-3,25 points), for example by the protecting walkpaths at *Aydat* for *Lac d’Aydat* (H-LAY).

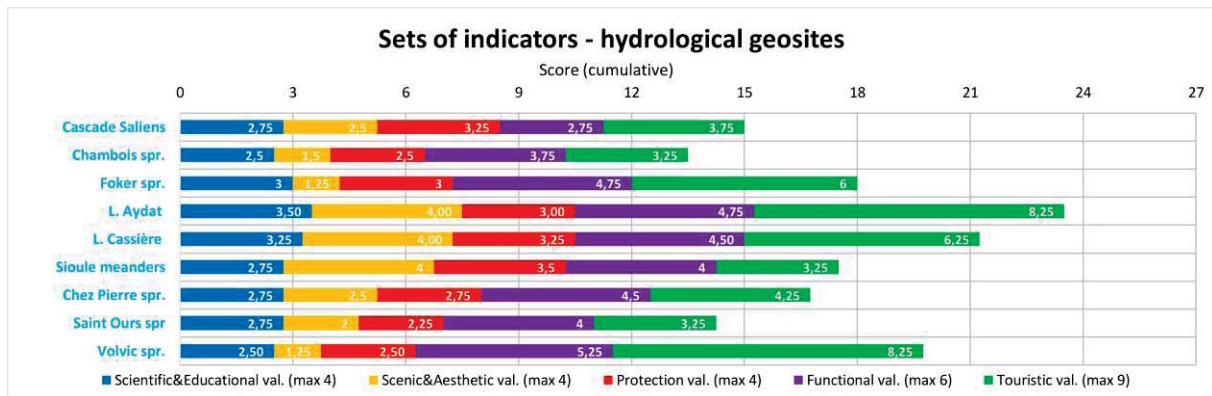


Fig. 2.17 Scores for sets of indicators for the method of VUJIČIĆ ET AL. (2011) for hydrological geosites

II/D/2/c/iii Geosites of relief inversion

Relief inversion of pre-Quaternary volcanism was one of the the key justifications for the World Heritage nomination, as noted before. This scientific and didactic importance is well reflected in the *Main Values* of these geosites as well (Fig. 2.15, 2.18) as they mostly reached high scores (above 7,75 points, with one exception). In terms of *Additional Values*, the scores are mostly moderate (between 5 and 8 points, with two exceptions), indicating that the geotouristic potential is as yet limited for these features. Most of the geosites in this category are part of a subdivision of two, long lava flows, to make more understandable and manageable units, namely the *Montagne de la Serre* in the southwest (with *Croix Chemagrand* I-CCG, I-QRH Quarry at *Rouillas-Haut* I-QRH, I-LCR lava flow ending at *Le Crest*, I-LCR, *Mont Redon* I-RED) and a Pliocene lava flow remnant from the *Massif du Sancy*, in the western area of the property (*Bonnabaud* section I-BON, *St. Pierre-le-Chastel* section I-SPC, *Puy de Frimont* I-PFR). The *Montagne de la Serre* is considered as a textbook example of relief inversion (SCARTH 1967), used since DESMAREST (1776) as type site. Therefore, the representativity and scientific knowledge justified elevated scores for the *Scientific/Educational Values* (2,25-3 points). *Scenic/Aesthetic Values* are generally significant (mostly above 3 points), as these geosites are large, dominant and well-fitting features of the landscape. Exceptions are the

abandoned and yet neglected small quarry at *Rouillas-Haut* (I-QRH) and the isolated, small granite-lava contact of *Croix Chemagrand* (I-CCG). Their extent can be partially connected to the high *Protection Values* too: in their integrity, they are generally less fragile, their current condition and legal protection is satisfactory, but can be still improved. Moderate threats (0,5-1 points) can be connected to natural or man-made erosion (especially at *Mont Redon* I-RED due to the touristic path leading to the top) and potential urbanization in some areas, such as *Bonnabaud* (I-BON).

From the two subgroup of *Additional Values*, the *Touristic Values* illustrates well how the structure of the evaluation method can affect the final results. The two sites that got the highest scores in this aspect (*St. Pierre-le-Chastel* I-SPC and *Le Crest*, the end of *Montagne de la Serre* I-LRC) are well justified by their ease of accessibility, existing touristic infrastructure of interpretative panels, nearby food and accommodation facilities. On the other hand, *Puy de Frimont* (I-PFR) where the slopes and the top is inaccessible on any kind of trail, got higher scores than *Puy de Cros* (I-PCR) which is covered by a dedicated touristic trail. What the *Frimont* lacks in trails, it gains in interpretative panels and promotion scores (0,75 points) due to the ‘*marais*’ (wetland) on the other side of the road, addressing partially the geology of the *Puy de Frimont*. The moderate touristic trail or guide service scores (0,25-0,5 points) cannot counterweight the lack of any interpretative panels and promotion at *Puy de Cros* (I-PCO), although sensum stricto, this site should be considered more exploited for its geoheritage-geotouristic values.

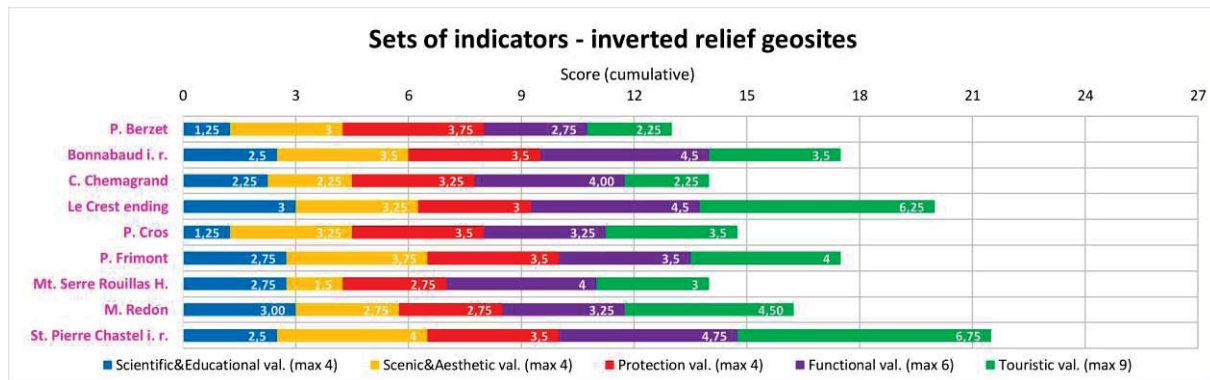


Fig. 2.18 Scores for sets of indicators for the method of VUJIĆ ET AL. (2011) for inverted relief geosites

II/D/2/c/iv Other geosites of value

Regarding the cluster of ‘other geosites’ – mostly comprised of some limited outcrops of the Hercynian basement rocks – it is well visible both in the GAM matrix (Fig. 2.15) and the overview of the sets of indicators (Fig. 2.19) that their current scores are moderate to low. These are small, less evident and less spectacular outcrops (low *Scenic/Aesthetic Values*) and currently, they are scarcely described scientifically (*Scientific/Educational Values*), nor integrated into geotourism (*Touristic Values*). With better scientific reconnaissance and improvement of touristic facilities at and around the sites, these values can change in the future. Such site-specific development projects can build

on the ‘backbone infrastructure’, suggested by the *Functional Values* with moderate to even elevated scores (2,5-5,75 points), which are similar to geosites of the rest of the clusters.

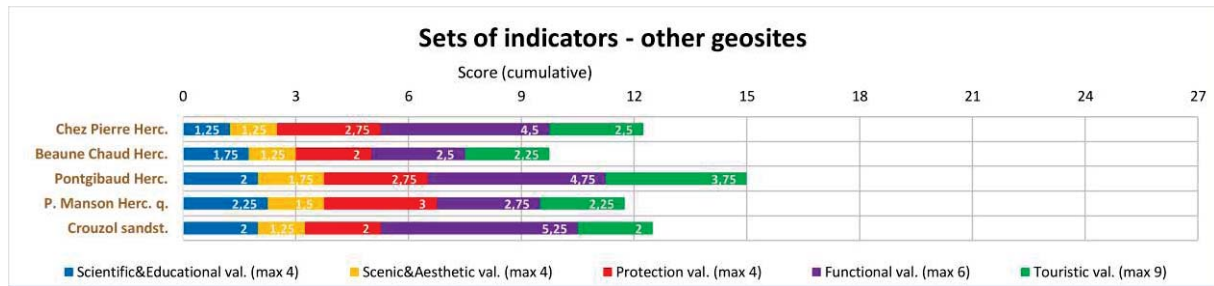


Fig. 2.19 Scores for sets of indicators for the method of VUJIĆ ET AL. (2011) for other geosites

II/D/2/c/v Quaternary Volcanism – Lava flows

The lava flows are made of distinct, smaller units of large lava flow areas, descended from the monogenetic volcanic alignment. Regarding their scores both on the GAM matrix (Fig. 2.15) and the chart of the sets of indicators (Fig. 2.20), there are generally slight differences between most of these geosites, with the exception of some distinctive sites. These are: the roadcut lava flow outcrops at *Argnat* and *Sayat* (L-ARG, L-SAY), which received low scores on the *Main Value* axis for each indicator group. Their scientific importance is not yet fully examined and they are not strong examples in (general) education (*Scientific/Education Values* 1,25-15 points), they are small and less aesthetic features (*Scenic/Aesthetic Values* 1,25 points) and their *Protection* scores (2,25 points) are moderate. But they are still among the lower scoring examples in the lava flow clusters, as they are more vulnerable due to their roadcut nature. On the other hand, their *Additional Values* (*Functional* + *Touristic*) are comparable to the large number of lava flow geosites, which will be discussed below.

A second small, loose group of geosites is comprised of those elements where the range of *Main Values* with elevated to high scores is similar to the geosites in the final, most voluminous group to be discussed, but the *Additional Values* related to geotourism are higher, but still moderate, except the highly outstanding (*Functional Values* 5,75 points, *Touristic Values* 9 points) *Grotte de la Pierre* (L-GRP), the interactive exhibition about the famous ‘*Vohic* stone’ inside the subterranean quarry of the *Puy de la Nugère* lava flow. The other four sites are: the visible lava flow base at *Saint-Saturnin* (L-LBS), a group of pressure ridges at the lava flow of *Puy de Combegrasse* (L-PRC), the ‘*Trou de Glace*’ roadside outcrops and ice remnants in the hollows of the *Puy de Côme* lava flow (L-CTG), and the outcrops of the *Puy de Parion* lava flow next to *Villars* (L-PVI).

These sites are either situated close to some easily accessible tourist destinations or villages (L-LBS, L-PRC, L-PVI), or they already bear some form of touristic development, such as a dedicated trail (L-CTG, L-PRC, L-PVI) or even a reference on a nearby interpretative panel (L-PRC). In terms of their *Main Values*, different considerations can be found behind the scores. For example,

the *Saint-Saturnin* lava flow bottom L-LBS is a scientifically and didactically important site (3,25 points for this aspect), but as its outcrop is currently unstable and highly vulnerable, the *Protection Values* (2 points) decreases the final *Main Value*. In contrast, for the *Combegrasse* pressure ridges (L-PCR), the *Scientific/Educational Values* are a bit lower (2,75 points) as they are important, but less rare examples of a phenomena, but this is compensated by a larger area that fits well to the surrounding landscape (*Scenic/Aesthetic Values* 2,5 points) and limited vulnerability due to their fencing as a grazing land and less steep outcrops (*Protection Values* 3,25 points).

Finally, 16 geosites range between the moderate to elevated *Main Values*, but lower *Additional Values*, than the 5 sites described before. Geomorphological features, such as the tumulus of *Roche Merle* (L-RME) were not described in detail individually, but they are certainly mapped in geological and volcanological maps (BRGM 2020, BOIVIN ET AL. 2017), known by field reports and mentioned in monographs (e.g. BOIVIN ET AL. 2017) or dedicated papers on the eruptive histories of distinctive scoria cones. Phenomena, such as pressure ridges or tumuli are common features of the lava flows and represented with several examples on this list (e.g. *Vauriat* L-PVA, *Pourcharet* L-PRP, *Ceyssat* L-PCY pressure ridges), therefore the *Rarity* scores are lower (0,25-0,5 points), but often with good interpretation potential, resulting in moderate to slightly elevated *Scientific/Educational Values* (2-3,25 points).

The larger a geosite, like the mentioned pressure ridges cluster, the higher the *Scenic/Aesthetic Values* are (3-3,75 points), as the size is an indicator here. It also affects the *Protection Values*, as these sites are generally less vulnerable and could tolerate a higher number of visitors (3,25-3,5 points). On the contrary, smaller, individual features of this category, such as the outcrop of *Nébonzat* lava lake (L-LLN) or the ‘*Fontaine Gelée*’ lava tube (L-GFG) bear somewhat lower scores here (2-3 points).

Additional Values are even more similar for this cluster (5-7 points). *Functional Values* are moderate to elevated (2,75-4,25), especially depending on the number of additional natural and cultural sites in the vicinity. The *Touristic Values* (2,25-3 points) are universally low, as these sites are not exploited yet directly for (geo)tourism with interpretative panels or guided tours. Many of them are also isolated from dedicated touristic trails, only accessible on small tracks (e.g. L-GFG ‘*Fontaine Gelée*’ lava tube), or currently inaccessible on a trail, located in agricultural fields (e.g. L-RME *La Roche Merle* tumuli, L-PCY *Ceyssat* pressure ridges).

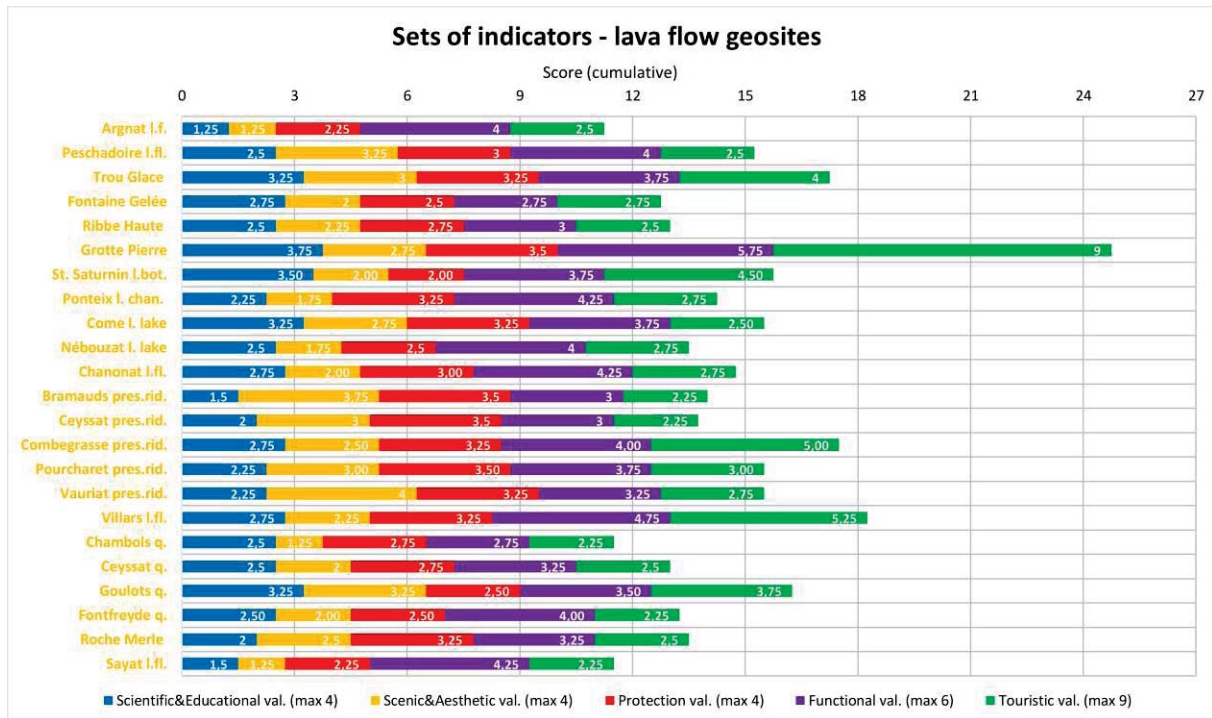


Fig. 2.20 Scores for sets of indicators for the method of VUJIĆ ET AL. (2011) for lava flow geosites

II/D/2/c/vi Quaternary volcanism - maars

The maars of the World Heritage property as noted previously, are large geosites, but often not so evident landforms of the landscape. With the VUJIĆ ET AL. (2011) evaluation, this highly affected the *Scenic/Aesthetic Values* with generally high scores for the large, mostly not or lightly forested features (almost universally 3-4 points, Figs. 2.15 and 2.21). Maars are generally among the better studied elements of the local monogenetic volcanism (see for example the bibliography of BOIVIN ET AL. 2017) and there are even more potential maar sites that are suspected by typical phreatomagmatic deposits (*Maar de la Rodde*, *Maar de Tressous*), but these were not included so far in this inventory, waiting for a more prescriptive identification of their landforms in the field.

The differences of the *Scientific/Educational Values* are mostly connected to the didactic potential: those sites, where the negative landform and the ejecta, the tuff ring are both well identifiable, or the landform is evident in the landscape, received higher scores in this aspect (0,75-1 points), raising the total score for this set of indicators for sites. Examples are *Narse d'Ampoix* (M-AMP), *Maar de Beaunit* (M-BEU) or *Maar d'Anchald* (M-ACH).

Protection Values are generally significant (3-3,75 points) as although a high number of sites are used as agricultural fields or grazing ground (e.g. *Maar de Beauloup* M-BEL, *Bois de Clerzat* M-BCL), these activities at their current level do not affect the sites in their integrity, just as the water reservoir usage of *Maar d'Anchald* (M-ACH). The slightly lower scores (2,5-2,75 points) of *Narse d'Ampoix* (M-AMP) and *Narse d'Espinasse* (M-ESP) are related to two different considerations. The

former is the smallest identified, complete maar feature in the property, in the middle of an agricultural field, meaning an elevated vulnerability to damage from poorly considered agricultural works, especially on the slopes of the ejecta. The *Narse d'Espinasse* is an '*Espace Naturel Sensible*' (ENS) due to its wetland flora and fauna, a fragile ecosystem. This counts for the integrity of the geosite as well, which was indicated with a higher chance of deterioration of the site (0,25 points).

The current geotouristic development of the sites, evaluated through the *Touristic Values* of the *Additional Values* is moderate to low. Those sites that are situated along a tourist trail and other elements of tourist infrastructure (food and accommodation services, interpretative panels) are available at the site or in the vicinity, have received the higher scores, such as *Maar de Beaunit* (M-BEU) or *Nid de la Poule* (M-NIP) with 3,25-5,5 points. Sites with very low values (2-2,5 points) currently lacks the interpretative facilities or touristic promotion: they are harder to interpret, such as *Maar de Beauloup* (M-BEL) or *Maar de Montchatre* (M-MCT) or they are inaccessible on private property, namely the *Narse d'Ampoix* (M-AMP).

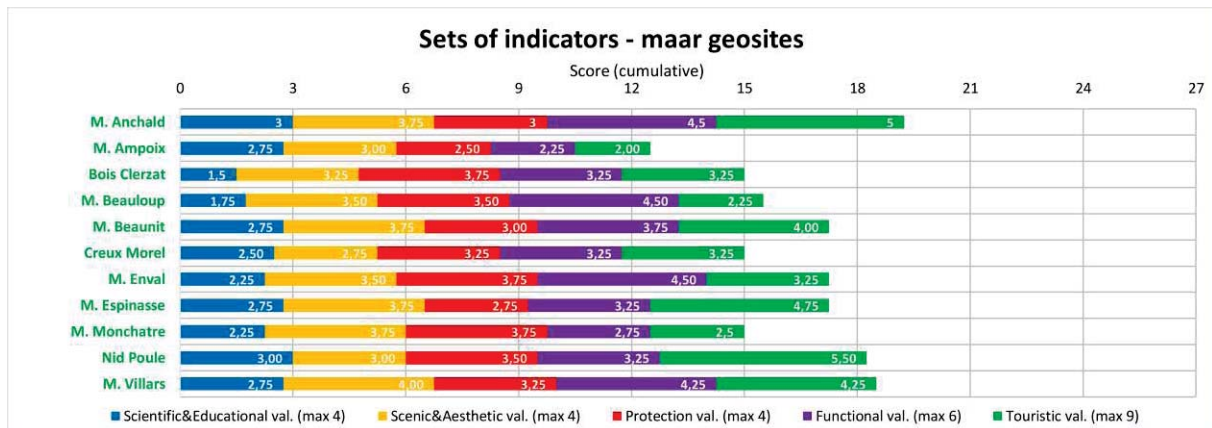


Fig. 2.21 Scores for sets of indicators for the method of VUJIĆ ET AL. (2011) for maar geosites

II/D/2/c/vii Quaternary volcanism - lava domes

Lava domes (Figs. 2.15 and 2.22) are important testimony of more differentiated magmas of the *Chaîne des Puys*. Most of these domes are well studied locations, rare landforms both in an international, national and local (property) context, with significant didactic potential about the evolution of local magmatism.

The highest *Scientific/Educational Values* are awarded to the complex lava dome of *Puy de Dôme* (D-DOM) and the trachytic plug of *Puy Chopine* (D-CHO). Even the lower scoring (1,75-2,25 points) locations, namely *Puy des Grosmanaux* (D-GRO), *Puy de Montchar* (D-MCR), *Grand Sault* (D-GSA) are scientifically important locations – especially the better studied *Puy des Grosmanaux* (VAN WYK DE VRIES ET AL. 2014) – but they are harder to interpret, due to their dense forest coverage. In case of the *Protection Values* two contradictory trends are represented in the slightly different values: many of the domes are among the most frequented sites, meaning significant path erosion

on the vulnerable trachytic slopes, which is addressed with slope protection measures of stairs, fences, with different level of efficiency. Although *Puy de Dôme* (D-DOM) receives the highest number of visitors, therefore the highest exposure to anthropogenic erosion, these measures tend to be more effective here (3,75 points), than at other sites with less traffic and partially working protection measures (e.g. *Grand Sarcouy* D-GSY – 2,5 points), or less frequented sites without dedicated protective infrastructure (*Puy Chopine* D-CHO, 2,75 points).

While the *Functional Values* - representing mostly less site-specific indicators about the background infrastructure - are mostly similar (3-5 points), the current (geo)touristic development of the sites can be well traced in the *Touristic Values*. The *Puy de Dôme* (D-DOM) is outstanding (8,75 points) with its well developed touristic infrastructure of the visitor centre, restaurants and accessibility both on the touristic train (*Panoramique des Dômes*) and well-maintained trails. The range of sites between the *Petit Puy de Dôme* (D-PPD) and *Le Cliersou* (D-CLI) with 4-6 points are all available on a dedicated touristic trail or a simple track, and some of these sites bear not just a protective infrastructure noted before, but some interpretative panels too (e.g. D-CLI, D-GSY). This latter is lacked currently at the three sites with the lowest *Touristic Values* (D-GRO, D-GSA, D-MCR, 1-75-3 points), the *Puy de Montchar* (D-MCR) and *Grand Sault* (D-GSA) being currently unavailable on any kind of track.

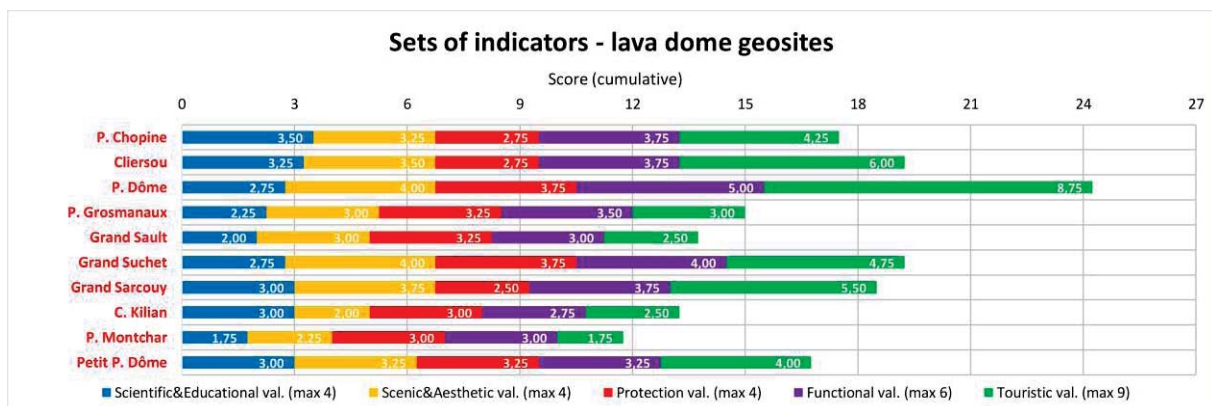


Fig. 2.22 Scores for sets of indicators for the method of VUJIČIĆ ET AL. (2011) for lava dome geosites

II/D/2/c/viii Quaternary volcanism - scoria cones

Finally, the most numerous cluster of geosites is associated with the scoria cones of the World Heritage property. The GAM matrix (Fig. 2.23) suggests two main scenarios: the largest group of the sites are associated with *Main* and *Associated Values* ranging from moderate to high. For eight sites, the *Main Values* are comparable to the previous category, mostly with entries of elevated scores, but the *Additional Values* are higher, suggesting a higher current geotouristic potential. *Puy de Lemptégy* (S-LEM) is an outstanding geosite, both in terms of *Additional* and *Main Values*. Together with the *Puy de Dôme* (D-DOM) and the *Grotte de la Pierre* (L-GPR) from other clusters,

they are the ‘flagship’ geosites of the property, with high scientific relevance, already advanced protection measures and sophisticated forms of geoeducation and geotourism. *Lemptégy* is perhaps the most outstanding in terms of protection, as while the original landform has been removed, the uncovered geological features are strictly protected, and used for intensive educational purposes.

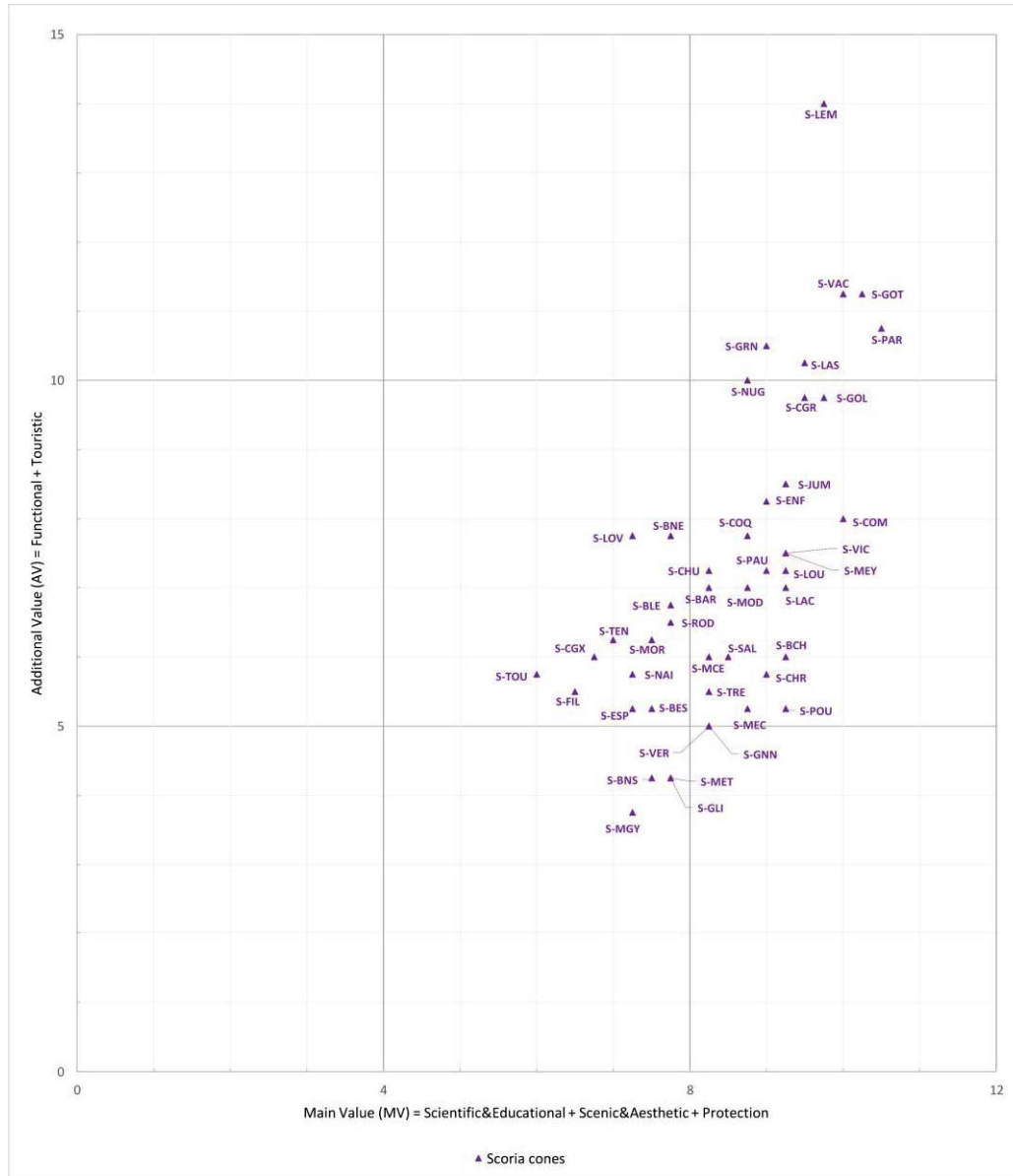


Fig. 2.23 The GAM matrix for scoria cone geosites

Among the eight scoria cones mentioned before, most of the sites have high *Scientific/Educational Values* (Fig. 2.24, 2,75-3,25 points). They contain some of the best examples of different morphologies and magmatic compositions of local scoria cones, such as *Puy de la Vache* (S-VAC) and *Puy de Lassolas* (S-LAS) for large, basaltic, horseshoe-shaped craters, or *Puy des Goules* (S-GOL) as a perfectly round-shape cone of trachybasaltic composition. The *Scenic/Aesthetic Values* are significant (3,25-4 points), as they are relatively large and iconic, well-fitting elements of the landscape, mostly with a varying level of forest coverage, from being almost closed at *Puy de la*

Nugère (S-NUG) and patchy at *Puy de Combegrasse* (S-CGR) for example. Although these sites are among the most frequented destinations of the property, their *Protection Values* are still mostly high, due to direct protective initiatives. The wooden-step access of the *Puy de Pariou* (S-PAR 3,25 points) was mentioned before (II/D/2/b/viii), partially similar solutions were used at *Puy de la Vache* too (S-VAC, 3,25 points). The score of *Puy de Grave Noire* (S-GRN 2,75 points) is slightly limited compared to the others, because of the vulnerability of slopes in the abandoned scoria quarry and the threat of urban spread in the vicinity.

The more advanced (geo)touristic development of these geosites is well manifested in the elevated scores of *Additional Values* (9,75-11,25 points), as mentioned before. It is interesting to note that the *Functional Values* are comparable with other entries from the rest of the scoria cone geosites (3,75 – 4,25 points). Exceptions are the *Puy de Grave Noire* (S-GRN) due to the strong background infrastructure of the nearby urbanized environment and the *Puy de Lemptégy* (S-LEM), in a tourism-boosted, developed background infrastructure, together with the nearby *Vulcania* adventure park. This indicates that the main difference between these eight geosites (and *Lemptégy*) and the majority of other scoria cones lies in the dedicated touristic development and infrastructure. Besides the I) trails - showing protective aspects discussed previously –, there are II) guided tours (organized by local stakeholders or distant school groups, visitors), III) interpretation panels (e.g. at *Puy de Combegrasse* S-CGR), IV) parking lots at the starting point of trails (for example at *Puy de Combegrasse* S-CGR, *Puy des Goules* S-GOL), V) or easily available restaurant and visitor centre facilities (the nearby *Puy de Dôme* for *Puy de Pariou* S-PAR or the ‘*Maison de Parc des Volcans*’ for *Puy de la Vache* S-VAC and *Puy de Lassolas* S-LAS). These developments are represented in the current values of these sites (5,25-7,25) and might serve as a model for some of the sites, to be discussed in the next, more numerous group of scoria cones.

Between the more than 35 geosites, not discussed before, it is hard to make a clear distinction or categorization, as different considerations resulted in the wide range of *Main* and *Additional Values*. For example the lowest *Additional Values* were calculated for *Puy de Montgy* (S-MGY), as it is currently inaccessible on any kind of trail. This was paired with high *Protection Values* (3,5 points), due to the minimal vulnerability of the site by path erosion or future economic (forestry) exploitation, which elevated the *Main Values* (7,25 points), despite the currently limited scientific knowledge and low didactic potential of the site (1 points).

The lowest scoring examples of the X-axis, the *Main Values* also show different scenarios. Two sites, the *Puy de la Toupe* (S-TOU) and *Puy de Ténuzet* (S-TEN) give an important insight to the inner structure of scoria cones, like the example of *Lemptégy*. This is only mildly exploited now with some special research visits, but the didactic potential of the sites are significant, therefore the

Scientific/Educational Values are elevated (2,75 points). However, the *Protection Values* are the lowest for both sites (1,75 points), as active quarrying threatens the sites with the destruction of some important elements of the geological evolution of the scoria cones. The stability of the easily erodable slopes will be only ensured in the future, when rehabilitation works are done, but is likely to be more effective, than for other, currently abandoned and scarcely rehabilitated scoria quarry sites (such as *Puy de l'Enfer* S-ENF, *Puy de Paugnat* S-PAU).

Those sites, where the *Main Values* are elevated or high (above 8 points), and the *Additional Values* are in the upper half of moderate values (between 7-9 points) contain geosites that are scientifically important without significant current protective issues, and they are already partially exploited for geotourism, or they could be in the future. For example, the *Puy de Côme* (S-COM) is probably the most representative example of a scoria cone with a nested twin crater, a dominant element of the landscape (*Scientific/Educational Values* - 3,25, *Scenic/Aesthetic Values* 3,75 points). Although access is strictly prohibited to the top by the owner of the site, in reality, it is a frequented site, located close to other popular geosites and destinations (*Puy de Dôme*, *Vulcania*, *Puy de Parion*). With an effective and respective site management strategy, a dedicated path respecting the vulnerable slopes and the flora and fauna elements (especially in the crater region), the geotouristic potential of the site (*Touristic Values* - 4,5 points) might be elevated, without posing a significant threat to the integrity of the site (*Protection Values* 3 points currently, due to the legal protection and partially limited tourist influx). Generally, most of the similar sites, such as *Puy de Louchadière* (S-LOU), *Puy de Paugnat* (S-PAU), *Puy de Jumes* (S-JUM) are already reachable on dedicated tourist trails, the *Puy de Vichatel* (S-VIC) even possesses an advanced site management with the ecological clearing of the crater area with sheep. However, interpretation of important geological features is still missing (in forms of in-situ panels or easily browsable information collection on the web or a mobile application, referenced at the site). Installation of such facilities could improve the *Additional Values*, especially the *Touristic Values* of these sites, that should be backed with scientific reconnaissance campaigns to supplement the findings of already existing papers and monographs, and a development strategy, respecting the integrity of the sites.

Scoria cone geosites, where the *Additional Values* are even lower than 7 or 6 contain scientifically important sites, such as *Bois de Chanat* (S-BCH 3 points), one of the oldest scoria cones of the Quaternary activity of the *Chaîne des Puy*s (GUÉRIN 1983, BOIVIN ET AL. 2017), or highly representative horseshoe-shaped cones, like the *Puy de Pourcharet* (S-POU 3 points) or *Puy de Charmont* (S-CHR 2,25 points). Other sites are less-studied, and consequently their didactic potential is more limited, especially compared to other sites (e.g. *Puy de Nain* S-NAI - 2 points, *Puy de la Goulie* S-GLI 1,5 points). The *Scenic/Aesthetic Values* are also often slightly lower, compared

with the rest of scoria cones (e.g. *Puy des Bannières* S-BNS - 2,75 points, *Puy de Moreno* S-MOR - 2,25 points, this latter associated with its smaller size, an important indicator of the GAM survey). The *Protection Values* (2,75-3,5 points) are comparable to most of the previously discussed geosites, but the elevated values are mostly connected to the minimal vulnerability of sites by touristic visits and minor threat by non-respective forestry works.

Almost none of these latter sites here are available on a marked touristic trail, but a part of the sites (such as *Puy de Salomon* S-SAL, *Puy de la Rodde* S-ROD, *Puy des Verrières* S-VER) are mostly visitable on forestry tracks. However, some of the sites are currently completely unavailable on any track (such as *Puy de Pourcharet* S-POU, *Puy des Bannières* S-BNS). These differences, the availability of nearby touristic facilities as restaurants or visitors centres at nearby sites (in terms of *Touristic Values*), and the number of natural and cultural values in the vicinity (*Functional Values*) are reflected in the slight differences on the *Additional Values* scale (4,75-6,75 points).

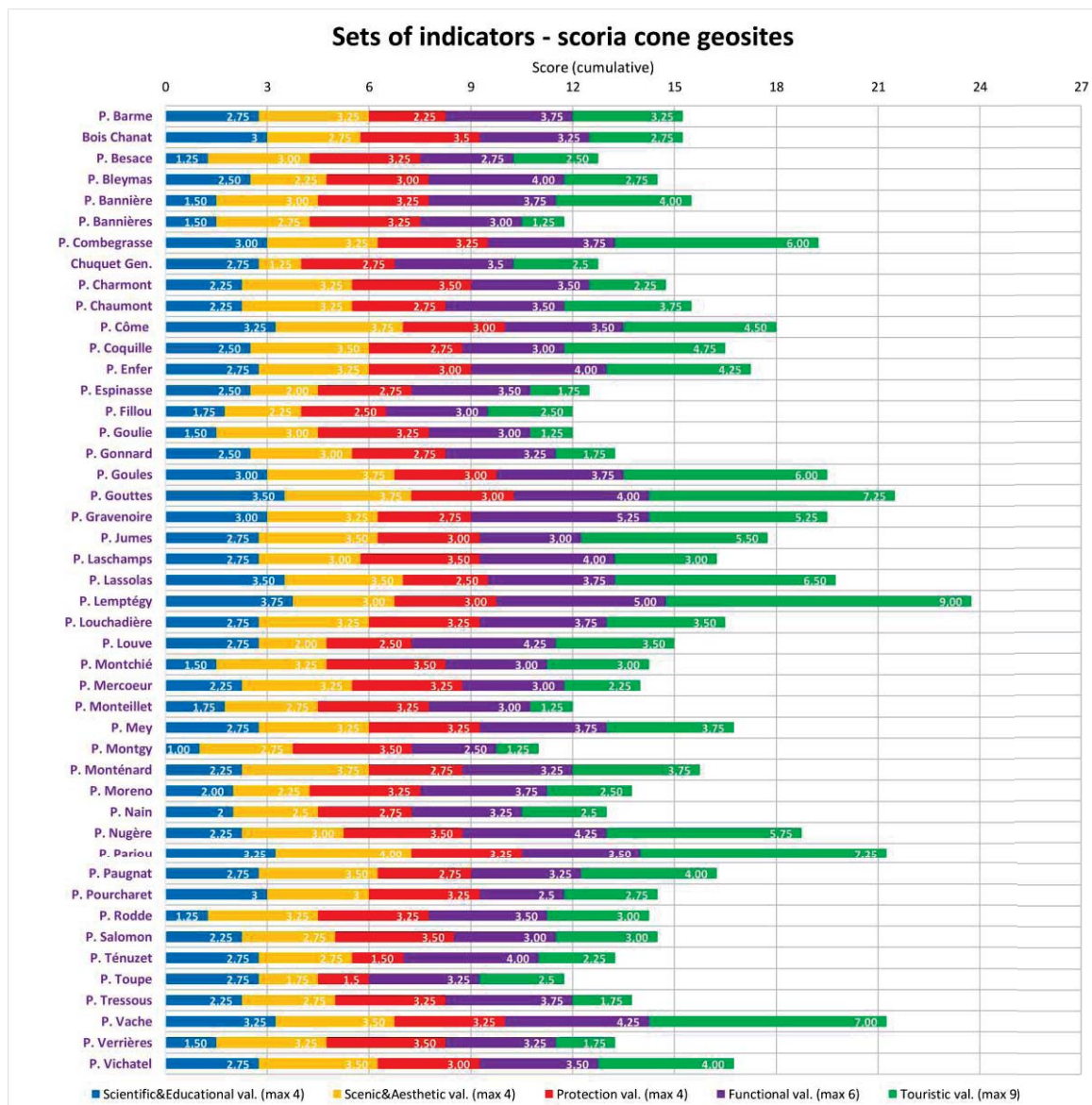


Fig. 2.24 Scores for sets of indicators for the method of VUJIĆ ET AL. (2011) for scoria cone geosites

II/D/2/d Methodological comparison of the chosen evaluation techniques

The methodological description of this chapter (II/D/1) already discussed the principal reasons for choosing the two respective geosite assessment methods. The French national workflow by DE WEVER ET AL. (2006, 2014 and 2015) ensured the compatibility of the World Heritage property's inventory with the national inventory, the INPG. The VUJIČIĆ ET AL. (2011) method, the GAM has been used effectively in several countries, with a strong indicator structure for characterizing the geotouristic potential of geosites. The interpretation of the results of both methods showed that the quantitative indicators recorded different aspects of the same geosites, as the sets of indicators differ. For example, touristic indicators are not evaluated numerically by the method of DE WEVER ET AL. (2015). On the other hand, even similar indicator sets, namely the scientific criteria – supposed to be a principal and obligatory element in all assessment methods (BRILHA 2016) – gave slightly different results, connected to the different quantitative assessment criteria.

Due to the high number of geosites in the inventory, a detailed, site-by-site description would exceed the limits of this study. *Chapter IV* about the preliminary geosite inventory of *Dallol* in Ethiopia presents such approach, where a detailed, comparative analysis is given for each indicator group of the three assessment methods used (VUJIČIĆ ET AL. 2011, REYNARD ET AL. 2016, BRILHA 2016). Here, *Fig. 2.25* illustrates the differences between scientific values and protection indicators. Summarized scores of each indicator group were recalculated to a percentage of the maximum available score, and plotted on a comparative chart, dividing them into four quartiles.

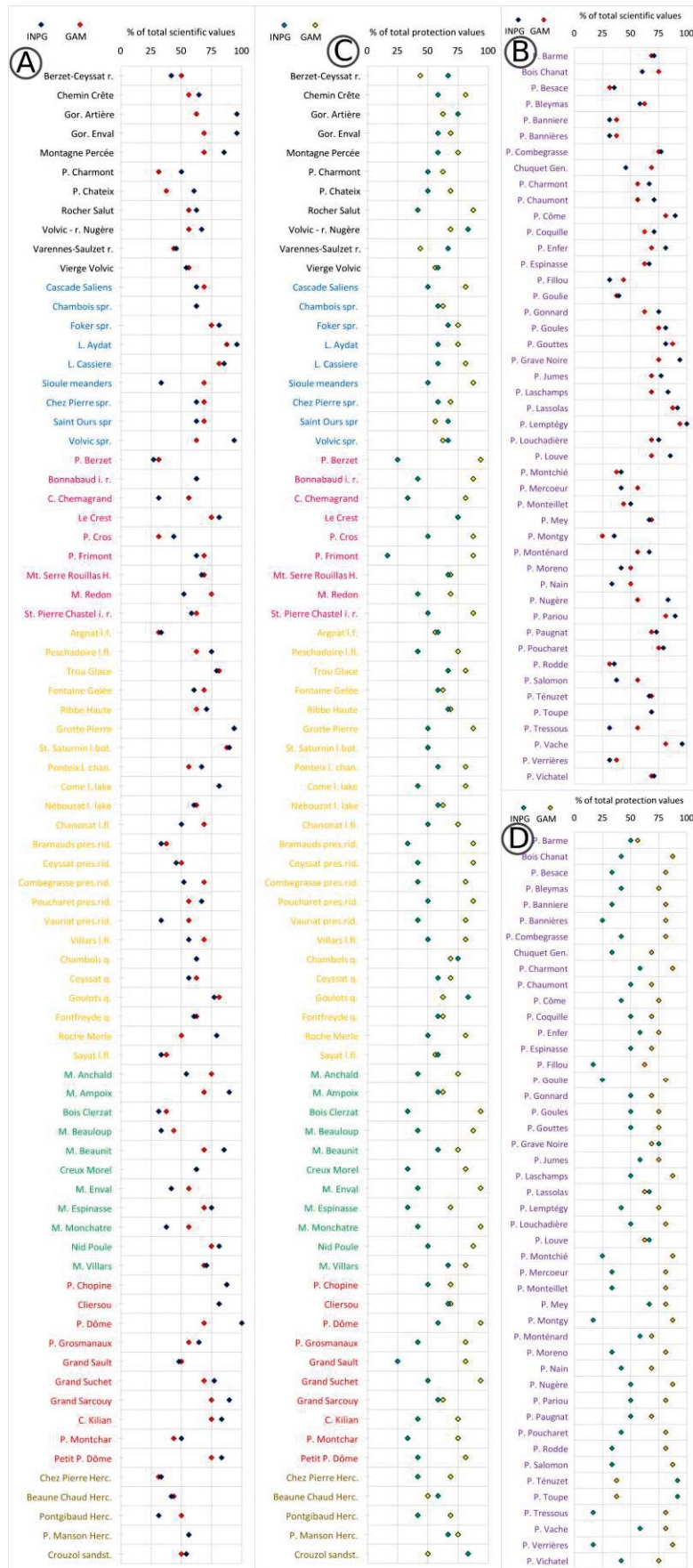


Fig. 2.25 Results of the VUJIĆ ET AL. (2011) and DE WEVER ET AL. (2015) method evaluations, recalculated to percentages. A: non-scoria cone geosites by scientific indicators, B: non-scoria cone geosites by protection indicators, C: scoria cone geosites by scientific indicators, D: scoria cone geosites by protection indicators

The average difference between the scientific values of the DE WEVER ET AL. (2015) method with 7 indicators and the VUJIČIĆ ET AL. (2011) method with 4 values is 9,59%. But this contains geosites where the difference is 35,4 % (Meanders of the *Sioule* H-MSI), or the *Grotte de la Pierre* (L-GPR), where there is no difference on this hypothetical comparative scale. Fig. 2.25 does not suggest a definitive trend in the differences, it is possible to see very similar or highly different value pairs in low (3rd quartile between 25-50 % of values), medium (2nd quartile) and high scientific importance categories. The outcrop of the lava base at *Saint-Saturnin* (L-LBS), the highest scoring geosite of the lava flow cluster, the *Vierge de Volvic* fault line outcrop (F-VVO) from the medium range of scientific values or *Puy de la Goulie* (S-GLI) with its limited scientific values were all evaluated in a similar manner by both methods (2,8% difference between each). It is easy to find examples for the other end, such as the highly important site of *Narse d'Ampoix* (M-AMP, 20,83 % difference), *Puy de Chaumont* (S-CHM, 14,58 %) or the rather low scoring *Croix Chemagrand* (I-CCG, 25 %).

A more consequent trend is that DE WEVER ET AL (2015) – INPG method values are generally higher (in 76 cases). The VUJIČIĆ ET AL. (2011) – GAM values were higher in 38 cases, and there were 10 cases when the two methods gave the same percentages on the hypothetical comparative scale. The reason of this might be the different answer structure of the two evaluations. Although both of them uses a Likert-scale, the value for each point is defined by VUJIČIĆ ET AL. (2011), like the level of publications about the site (local to international). In the DE WEVER ET AL. (2015) evaluation, this is limited to only some answers (e.g. the *Rarity*, also with a regional to international scale), in other cases the end values are defined only (e.g. no interest to remarkable for *Educational Interest*).

The differences of protection values are more consequent and easier to explain. In 103 cases from the 124, the *Protection Values* of the VUJIČIĆ ET AL. (2011) are higher, often with a significant gap (70,8% for *Puy de Frimont* I-FRI). This is connected to the different structure of this indicator group. The higher the *Protection Values* are in the GAM by VUJIČIĆ ET AL. (2011), the better protection of a site is. On the contrary, the high *Protection & Vulnerability* scores by the DE WEVER ET AL. (2015) method indicates protection problems, or the high vulnerability of the site. A structural issue of the French national workflow is visible in some scenarios, where I), the gap between the two percentages is minimal, or II) the DE WEVER ET AL. (2015) type ones exceed the other mark. *Geoheritage Interest* by the number of ‘heritage stars’ calculated from the scientific and educational indicators is used as an input value for the *Protection & Vulnerability* values. In those cases, where I) a relatively high *Geoheritage Interest* is accompanied with elevated natural and/or anthropogenic vulnerability, and II) the VUJIČIĆ ET AL. (2011) method also gave lower scores due

to the similar considerations of vulnerability; the previously mentioned ‘inversion’ or close percentage values are observable (e.g. at the *Crouzol* sandstone outcrop O-SCR, *Puy de Ténuzet* P-TEN or the spring of *Saint-Ours* H-SSO).

In terms of the structure of the assessment method (the content and type of questions), the main difference between the two methods is clearly visible. The main focus of the DE WEVER ET AL. (2015) and the national inventory (INPG) is definitely the recording and assessment of the scientific importance of potential geosites that justifies their inclusion in the final inventory, after regional and national validation. This is accompanied by the *Protection & Vulnerability* indicators that assess those factors that could affect the scientific integrity of the geosites. Both of these indicators are assessed quantitatively, backed up with longer, textual descriptions. Touristic and economic considerations, additional heritage values also appear in the forms as textual descriptive fields, but they are not assessed numerically. In contrast, the method of VUJIČIĆ ET AL. (2011) assesses all indicators in their five groups quantitatively. Textual description fields are not proposed in the original paper, but the inventory can be expanded with such fields, depending on the objectives of the users.

Quantitative assessments have strong advantages for the relatively quick evaluation of sites, the comparability of results and the potential of their visualization that can facilitate decision making through charts, maps, etc. VUJIČIĆ ET AL. (2011) proposed a robust, clear form of visualization with the GAM matrix, where *Main Values* indicate the geoheritage importance of the sites, while *Additional Values* depict the current geotouristic potential of geosites. The methodological paper of DE WEVER ET AL. (2015) rather proposed the cartographic visualization of geosites, based on their ‘heritage star’ numbers and the different geological frameworks. AUBERGER (2018) in turn suggested a *Geoheritage Importance – Protection & Vulnerability* matrix as well. This was used in the present chapter as well, together with charts on the individual indicator groups, as they can show important information on the evaluation of the sites that are partially ‘hidden’ by the aggregation of their results.

Quantitative assessments can overcome the subjectivity of textual descriptions with a well-constructed indicator structure and clear questions in the forms. However, as this study demonstrated (and discussed later in *chapter IV* too) that this structure affects the ‘final ranking’ of the geosites, therefore potentially their geoconservation initiatives as well. This is the point where semi-quantitative methods, such as DE WEVER ET AL. (2015) has an advantage, as the longer textual descriptions can nuance further considerations that were somewhat confined by the content of the assessment questions, or the answer thresholds that were used for example in the VUJIČIĆ ET AL. (2011) method. For this latter method or similar ones with a high number of indicators (27

in this case), a parallel textual evaluation of each indicator might be complicated or time consuming. But a field of general remarks, or a short summary, containing supplementary or clarifying information is something that can be considered during a ‘standalone usage’ of a method.

On the other hand, parallel, comparative utilization - as demonstrated in this chapter and *chapter IV*, or comparative studies of KUBALIKOVÁ (2013), ŠTRBA ET AL. (2015) or SZEPESI ET AL. (2018) - could balance the shortcomings of the methods, and the multi-aspect evaluation functions as a further layer of improving the objectivity of geosite assessment.

II/D/2/e Selected geoconservation recommendations, based on the inventory and the assessments

The geosite interpretations with both methods have already discussed some geoconservation and geotouristic issues, such as the underrepresentation of several geological-geomorphological frameworks in the national inventory, or didactic potential of sites which have better scientific and touristic interpretation. Here, some potential recommendations are discussed briefly for the effective protection and management of the unique geoheritage of the area, underlining and supplementing the previous sections.

II/D/2/e/i Systematic scientific reconnaissance of the area

The *Chaîne des Puys - Limagne Fault* is often considered as a cradle of volcanology, many generations of volcanologists and geoscientists have studied and interpreted its features from GUÉTTARD (1751) and SCORPE (1825) to the modern analysis (e.g. CONDOMINES ET AL. 1982, MIALLIER ET AL. 2004, MARTEL ET AL. 2013, see more references in BOIVIN ET AL. 2017). Many aspects, such as the dating or the geochemical analysis of volcanic products are already advanced for some of the eruption centres. Recent techniques can open new frontiers, such as the dense LIDAR coverage of the area (CRAIG 2011) in the geomorphological description of landforms, which combined with techniques such as paleomagnetism can lead to reinterpretation of volcanic evolution (e.g. PETRONIS ET AL. 2019).

Strongly building on existing studies and ongoing projects, such as the study of the pre-eruption topography and its role in hydrogeology (Projet CAPRICE: <http://lmv.uca.fr/projet-caprice/>), systematic research projects should focus both on the ‘white spots’ of the area, and the reinterpretation of existing results, where necessary. There is a significant gap especially on the study of the *Limagne Fault*, the hydrological regime of the area or even the relief inversion. This was well visible in the scientific values of both geosite assessment methods.

The outcomes of these studies and research projects can be interpreted at least on three levels. First of all, they are important on their ‘own right’, as scientific outputs, summarizing research phases and functioning as inputs for further studies. They are also primary inputs for geoheritage.

Valid scientific information can change the knowledge on the importance of already-known geosites, new potential sites might be identified and they could be direct or indirect justifications for geoconservation initiatives. The interpretation of sites in geoeducation and geotourism should also rely on validated scientific knowledge. For example, geotourist trail planning, that might be further enhanced at the property (see below), should also rely on a robust scientific background, which is then translated to a well-understandable story for visitors.

II/D/2/e/ii Gap analysis of the national geosite inventory (INPG), in the World Heritage property

The dedicated inventory of the property, besides adding new, previously not inventoried sites, is also composed of geosites that are smaller elements of the large, holistic geosites of the national inventory in the World Heritage area with 15 sites. Even the assessment of these smaller, standalone units confirmed that these sites bear high scientific values, which further reinforces their selection. However, the dedicated geosite inventory of the property also confirmed that key geological frameworks are currently missing from the national inventory. There are further sites that might be represented with one similar example, but outstanding values can be also justified for other elements of the same phenomena.

The *Limagne Fault* is completely under-represented in the national inventory, which is a significant lack, considering that it is a key element in the justification of the Outstanding Universal Value of the World Heritage nomination (PDD-CG 2012). Both assessment methods have shown already considerable scientific importance for some of the selected geosites in the fine-scale inventory, which can be further improved with more scientific work (see the previous point).

Two sites, the *Gorges d'Artière* (F-GAR) and *Gorges d'Enval* (F-GEV) are prevalent with their fault facets and tectonically conditioned valleys. The viewpoints of high didactic potential, such as *Montagne Percée* (F-MPE) or the '*Vierge de Volvic*' site (F-VVO) also reached significant scores. Either the inclusion of one representative site in the national inventory, or the nomination of a longer section of the fault zone with several examples from the dedicated inventory should be considered.

The concept of relief inversion appears on the national geosite list through the example of the *Plateau of Gérgovie* (AUV0026), although this site is located just outside the World Heritage perimeter. However, none of the large inverted relief areas of the property, namely the *Montagne de la Serre* and the Pliocene lava flow remnant series at *Bonnabaud* and *St. Pierre-le-Chastel* are listed on the national inventory, although even their smaller elements were evaluated as significant features during this study.

Therefore, the reconsideration of the national inventory is recommended from this aspect. As the repetition of similar features should be avoided according to the methodology (DE WEVER ET

AL. 2006, 2014, 2015), individual nominations should point out the differences, compared to *Gérgovie* (e.g. different geological era and potential source, morphological differences

In summary, a gap analysis of the national geosite inventory is recommended at the World Heritage property's area, concerning not only the previously mentioned faulting and relief inversion geological frameworks, but also other phenomena and landforms, such as the proper representation of scoria cone morphological types, chemical composition, or the *Plateau des Dômes*, which is also an element of the World Heritage property. Such gap analysis or re-evaluation project facilitated by the World Heritage title might be expanded to other, non-internationally protected territories of the area of competence of *DREAL Auvergne-Rhône-Alpes*, the local coordinating body of the INPG.

II/D/2/e/iii Geoconservation through the symbiosis of territorial management and site use

The *Chaîne des Puy-Limagne Fault* was inscribed with a dedicated geoheritage focus (criterion viii) on the World Heritage list in 2018. This focus is well represented in the inscription document as well (PDD-CG 2012). However, it was also explained in details that both the core and the buffer zones are semi-natural territories, with large areas covered by economically valuable forests, significant fields of grazing for cattle, with some recent, re-opened fields on the top of scoria cones (e.g. at *Puy des Goules*, *Puy de Vichatel*, *Puy de Combegrasse*). Although the population density is low, there are still several communities mostly in the buffer zones and especially the eastern ones in the *Limagne* fault zone are prone to suburbanization.

The quantitative indicators on the protection and vulnerability of geosites and their interpretation both presented several issues that are connected to the 'usage' and conditions of the sites, highly affected by their relevant activities. Roadside outcrops (mostly for the fault line and the lava flow cluster) are prone to natural erosion. As a preventive measure, road management authorities often tend to use stabilization techniques, which partially or completely destroy the geoheritage values of a site, as it was demonstrated through some examples by PETRONIS ET AL. (2019) and VEREB ET AL. (2020A). Land-use types, especially agriculture and forestry management may also be a threats to the integrity of geosites, especially to their slope stability, but also the existence of micro- and macro landforms. Massive cleanup of forests for timber production could lead to increased runoff, therefore elevated erosion on the vulnerable slopes of scoria cones, while the pressure ridges on the lava flow fields (e.g. close to *Ceyssat*, *les Bramauds*) might be destroyed for gaining more land and facilitating the routes of the machinery. Tourism is also a source of 'hazard' for the stability of slopes, although rather as linear erosion along tracks. This latter threat has been already addressed at some of the geosites (as *Puy de Dôme*, *Puy de Parion*, *Le Clierson*), but there is a room for improvement at existing sites and new examples should be designated in the future.

The inventory and the assessment of the geosites already addressed some of these issues and even more will arise during the constant updating of the inventory, and the effective geoconservation works and projects. An active and proactive cooperation between the relevant authorities of natural- and geoconservation (e.g. *DREAL, Conseil Départemental*) and stakeholders (landowners, management authorities) would be ideal, where all parties are informed about both the conservation needs and any planned site management issues and developments, affecting the integrity of a geosite. Besides being aware of the currently inventoried geosites, preventive surveying and regulatory assessments should be also further enhanced in the future, for example following similar practices of archeology before construction works.

II/D/2/e/iv Geotouristic development of geosites

The previous section already mentioned tourism, as an important economic activity and site usage factor, but rather from its nature as a potential threat to the integrity of geosites. On the other hand, geosites are the backbone of (geo)tourism, touristic development projects can foster geoconservation efforts (e.g. on slope stabilization), and revenues can help financing further geoconservation initiatives. The ‘World Heritage Convention’ concentrates on the justification of the ‘Outstanding Universal Value’ of the site and its effective management and protection (UNESCO-WHC 2017). But most of the application files mention tourism as an integral and important element of local development and part of the site management, the *Chaîne des Puy-Limagne Fault* is not an exception to this (see the relevant parts of PDD-CG 2012).

The quantitative assessment of tourism related indicators (*Additional Values*) and their interpretation with the method of VUJIČIĆ ET AL. 2011 already highlighted that geotouristic development of geosites is highly variable in the property. The *Puy de Dôme, Lemptégy* or the *Grotte de la Pierre* are on an outstanding level, in terms of their interpretation and associated tourist facilities. One of their main challenges now is their popularity, being congested compared to other sites, bringing threats from tourist pressure. Scoria cones and lava domes, like *Puy de Parion, Puy de Combegrasse, Puy des Goules, Le Clierson*) are ‘enhanced’ with protective facilities to reduce linear path erosion, and equipped with interpretation panels (installed with mostly central funding), and further ‘developed destinations’ are planned to be added, such as *Puy de Chaumont*. There are also community driven projects, like the development and management of the *Gorges d’Artière* by *Ceyrat-Boisséjour Nature*.

Indicators of didactic potential in both assessment methods, and the aesthetic considerations in the GAM by VUJIČIĆ ET AL. (2011) highlighted that there are several, currently undeveloped geosites that could be exploited for tourism. This covers the signage or even the designation of trails and the planning of interpretation solutions (whether in-situ panels or alternative solutions).

It concerns sites that are already visited and maybe developed on a certain level (e.g. *Cascade des Saliens*, *Montagne Percée*) and currently unknown site for visitors (e.g. *Puy de Pourchalet*, The quarry of *Montagne de la Serre* at *Rouillas-Haut*). However, it must be noted that while the geosite evaluations might justify the possibility of such developments, the long-term effects have to be carefully considered. Touristic utilization of geosites should not lead to the degradation of their integrity in terms of scientific and aesthetic values, not only in terms of geoheritage, but also considering associated biodiversity or cultural heritage values.

Developments should also consider carefully the 'needs', the expectations of visitors and their motivation of tourism and habits during leisure time. An experimental study on this issue is presented in the last part of this chapter (*section II/E*), but further surveys and background materials should process these questions, in order to find a healthy balance and symbiosis between geoconservation issues and economic activities, namely tourism. The bottom line is that the property is protected at World Heritage level as an integral site from the view of science, and this should not be forgotten, when planning any activity.

II/E Evaluation of selected geosites with visitors' feedback

The overwhelming majority of geosite assessment methods rely on the evaluation of small groups of experts (especially geoscientists, but incorporating potentially the feedback from other heritage experts, regional developers, site managers, etc.). Involvement of the general public in decision making and even in research projects is a growing trend, with methods such as crowdmapping (BROWN ET AL. 2017). In the domain of geoheritage, TOMIĆ & BOŽIĆ (2014) published the first such framework, the M-GAM (Modified Geosite Assessment Model). Although it should be noted that some individual questionnaires at geosites in geoparks or protected natural areas were used before.

In this section, the first French (and Western European) application of the M-GAM is presented through its usage at the *Chaîne des Puy – Limagne Fault* World Heritage site. This small-scale and preliminary research is connected to the similar projects in Central and Southeastern Europe and its results are to be shared with the local Auvergnat tourism development stakeholders (*Departmental Council of Puy-de-Dôme*, *AgroParisTech*). Due to the limited number of answers so far, it should not be considered as a statistically robust dataset, but it can already give an insight to some geotouristic trends in the World Heritage area, giving a valuable supplement to the parallel geoheritage evaluation missions, described in *section II/D*.

II/E/1 Methodology

II/E/1/a *The background of the M-GAM method*

The M-GAM method is based on the importance value (Im), the evaluation of the importance of each indicators of GAM-method (VUJIČIĆ ET AL. 2011) by lay-person, non-expert visitors. The calculation of the M-GAM value of a geosite is a simple function of the multiplication of the GAM-values of experts with the Im , as it was summarized in *Table 1.1 (chapter I/C)*.

The original work of TOMIĆ & BOŽIĆ (2014) was based on the feedback of 96 replies in the *Lazar Canyon* in Serbia, and one year later, BOŽIĆ & TOMIĆ (2015) published an updated study with a sample of 293 responders, from multiple canyon-themed geosites in Serbia. In both cases, a general, averaged Im value was given for each assessment indicator, and then used for calculating the M-GAM values of all the geosites of the study.

PÁL & ALBERT (2018) started an M-GAM research campaign in the *Bakony-Balaton UNESCO Global Geopark* in Hungary with a different approach. Instead of using averaged Im values for all the geosites in the area, they used a site-specific approach, assuming that the Im of indicators should be defined for each site, only averaging the site-specific answers and also partially evaluating the individual answers for each site. According to them, this could give a more in-depth overview about the geotouristic potential and the potential for future developments, than the averaged Im values.

Other studies have also used the method for certain topics, with geosites selected from a geological framework. These were urban geoheritage (PETROVIĆ ET AL. 2017), hydrology (MILJKOVIĆ ET AL. 2018) and speleology (ANTIĆ & TOMIĆ 2020) respectively.

II/E/1/b *The usage of the M-GAM in the Chaîne des Puys – Limagne Fault*

From the high number of regional-level geosites defined in *section II/D*, **20** were selected for the M-GAM research project. The selection criteria were as follows:

- The spatial distribution gives an overview of the majority of the World Heritage area, only the Western buffer zones and its extended lava flows (*'cheires'*) are somewhat under-represented, although they are also less frequented by visitors.
- The inclusion of all major geoscientific frameworks of the area, aka. fault line outcrops, inverted relief and hydrology geosites and most importantly the testimonies of the Quaternary volcanism, namely scoria cones, maars and lava domes.
- After consultations with the *Departmental Council of the Puy de Dôme*, only those sites were included that are publicly available at least on a marked touristic trail. With this limitation, important sites, such as the national level geosites of *Puy de Côme* and *Puy de Lachamps* were omitted, situated in non-public, strictly protected or closed areas.

- The inclusion of already well-interpreted, geotouristically developed sites, such as the two flagship destinations, the *Puy de Dôme* and *Puy de Lemptégy*, but less-known sites, with the lack of detailed geological interpretation too, such as *Mont Redon*.

At each site, a weather-resistant, plastic printed sign was installed - respecting the environment, using existing information panels where possible - containing the call for the participation, a brief description of the project and the QR-code and link to the site's questionnaire. These opened a site-specific Google Form application, which was the data collection interface. Here, the participant rated the importance of the 27 indicators of GAM, on a Likert Scale of 0-4, with a small explanation possible to each value, based on the questionnaire format of PÁL & ALBERT (2018). The 0-4 scale was used as a tourist-friendly solution to avoid decimal values, later they were recalculated to the GAM format of 0-1 scale. Besides the evaluation of the indicators, some demographic questions were also included to get an overview about the flow and motivations of geotourists. The following data was collected, in a strictly anonymous form: *sex, age group, level of education, hometown and the distance to the visited site, experience in geotourism, interest in geotourism and the frequency of hiking*. Although the data was collected in Google Forms, detailed analysis was carried out in Microsoft Excel, allowing a more in-depth comparison of results.

Data collection was started with the installation of the M-GAM sheets at the sites between 24/07 and 05/08/2019. For the present phase in this thesis, data collection was closed on 05/05/2020, allowing a 9-month operation period. However, the sheets and the Google Forms will remain operational and there are plans for an extension and methodological improvements as well, as described later.

II/E/2 Results and discussion

84 answers were recorded during the nine months data collection campaign. This number is not sufficient for extrapolating well-established visitor trends for the geosites, but it is a valuable input, that could supplement the assessment information of *section II/D* or other, previous touristic movement questionnaires in the region. Putting this amount in context, it shows a definitely low reply activity, considering the number of visitors at each sites, which generally exceeds thousands, or even tens of thousands (*Puy de Lemptégy* S-LEM and *Puy de Dôme* D-DOM). However, comparing it with the responder numbers of TOMIĆ & BOŽIĆ (2014), entirely based on personal interviews (96 answers) and PÁL & ALBERT (2018), where the self-filling sheet was combined with interviews (147 answers), it is on an acceptable level.

Two sites received no feedback (*Puy de Jumes* S-JUM and *Puy de la Nugère* S-NUG), four sites had only one answer, making them insufficient for seeing different evaluation patterns between different visitors. On the contrary, 7 sites had a reply activity higher than 5, with *Puy de Lemptégy*

receiving 16 answers. This corresponds to the popularity of the site, although it must be noted that the other flagship geosite of the World Heritage property, the *Puy de Dôme* (D-DOM) received only 3 answers, just as *Puy de la Vache* (S-VAC), a popular scoria cone.

II/E/2/a Importance factors

Importance factors (*Im*), calculated from the answers of each responder are summarized in two forms. The original M-GAM study and later applications of PETROVIĆ AL. (2017), MILJKOVIĆ ET AL. (2018) and ANTIĆ & TOMIĆ (2020) used a generalized *Im* value, based on the average of numerous sites, most of them corresponding to a geological framework. With the same approach, summarizing values for all geosites of the property, and separate values for the principal geological frameworks - the crucial phenomena of Quaternary volcanism and other features - were calculated. The *Im* for each indicator of the GAM/MGAM is summarized on Fig. 2.26 by the *Main Values* indicator and Fig. 2.27 by *Additional Values*. For comparison, the calculated importance values of BOŽIĆ & TOMIĆ (2015), which had the highest, published responder input so far are also indicated.

The bubble matrix clearly shows that for most of the indicators, the opinion on their importance is significantly different in France and in the Serbian example. For example, from the scientific values which BRILHA (2016) considered as the crucial consideration for any geosite inventory, the *Rarity* or the *Representativity* of a site was more important for the Serbian (geo)tourists than for their French counterparts, no matter which feature type we choose (Fig. 2.26). On the other hand, geoscientific issues of *publications* are equally considered less important, just as the *level of interpretation* of a site. It underlines a general trend that tourists are not necessarily picking their destinations for the acknowledged heritage value of a natural site (a geosite in this case), but they are rather attracted by aesthetical values (Fig. 2.26). An additional important factor during visiting a site is its touristic development, as it can be seen at Fig. 2.27. A need for interpretation is clearly visible (Fig. 2.27), although the form is different: visitor centres are welcome in both countries (high *Im* values generally for each geological framework), but in France it seems that (geo)tourists have a higher preference for organized visits, than in Serbia, where the interpretation panels - assuming a higher dependence on individual forms of visit - are more prevailing. This interpretation could help planning the message approach to target the interest of the visitors more effectively, integrating information about the scientific importance of a site or about the importance of protection, an aspect, which was considered less relevant at the French geological frameworks.

Without going into the details here, these charts clearly show a blurring effect of summation. *Im* for the same indicator can be significantly different between different geological frameworks. At the *level of interpretation* for example, tourists visiting scoria cone and lava dome geosites in the *Chaîne des Puys - Limagne Fault* gave higher scores than at maars, outcrops of the *Limagne Fault* or the

inverted relief features in the south. It is quite likely that this is connected with their different level of presentation, as generally more information (interpretative panels or a visitor centre) are available for the scoria cones and lava domes, as they are the flagship features of the World Heritage area. However, a difference like this is not detectable, if the importance factors are calculated only for the whole area.

II/E Evaluation of selected geosites with visitors' feedback

	Rarity	Representativeness	Knowledge on geoscientific issues	Level of interpretation	Viewpoints	Surface	Surrounding landscape and nature	Environmental fitting of sites	Current condition	Protection level	Vulnerability	Suitable number of visitors
Bolzić & Tomić (2015) - avg. 293 sites	0.82	0.86	0.58	0.66	0.76	0.71	0.83	0.61	0.81	0.82	0.57	0.53
Chaîne des Puys - Limagne Fault - avg. 18 sites	0.39	0.43	0.46	0.56	0.55	0.75	0.55	0.46	0.59	0.84	0.52	0.50
Fault line geosites - avg. 3 sites	0.43	0.69	0.50	0.56	0.51	0.61	0.41	0.45	0.42	0.52	0.44	0.52
Inverted relief geosites - avg. 2 sites	0.59	0.38	0.38	0.38	0.38	0.75	0.50	0.38	0.75	0.63	0.50	0.63
Maar geosites - avg. 3 sites	0.38	0.58	0.56	0.62	0.46	0.83	0.58	0.55	0.54	0.40	0.43	0.51
Lava dome geosites - avg. 2 sites	0.58	0.54	0.63	0.67	0.63	0.63	0.50	0.50	0.46	0.67	0.54	0.50
Scoria cone geosites - avg. 6 sites	0.37	0.59	0.36	0.59	0.60	0.77	0.63	0.43	0.66	0.54	0.40	0.46

	Accessibility	Additional natural values	Additional anthropogenic...	Vicinity of emissive centers	Vicinity of important road network	Additional functional values	Promotion	Organized visits	Vicinity of visitors center	Interpretative panels	Number of visitors	Tourism infrastructure	Tour guide service	Hostelry service	Restaurant service
Bolzić & Tomić (2015) - avg. 293 sites	0.66	0.74	0.52	0.5	0.64	0.64	0.38	0.44	0.17	0.26	0.59	0.57	0.60	0.63	0.53
Chaîne des Puys - Limagne Fault - avg. 18 sites	0.59	0.63	0.53	0.70	0.83	0.76	0.59	0.40	0.89	0.63	0.88	0.71	0.46	0.63	0.53
Fault line geosites - avg. 3 sites	0.59	0.51	0.45	0.60	0.71	0.77	0.74	0.45	0.44	0.52	0.72	0.64	0.43	0.54	0.46
Inverted relief geosites - avg. 2 sites	0.59	0.75	0.76	0.50	0.75	0.50	0.83	0.76	0.89	0.60	0.49	0.59	0.54	0.64	0.60
Maar geosites - avg. 3 sites	0.60	0.61	0.57	0.77	0.89	0.84	0.87	0.48	0.73	0.48	0.88	0.74	0.59	0.71	0.44
Lava dome geosites - avg. 2 sites	0.75	0.42	0.50	0.58	0.58	0.47	0.67	0.44	0.71	0.54	0.51	0.64	0.58	0.56	0.56
Scoria cone geosites - avg. 6 sites	0.44	0.72	0.56	0.80	0.68	0.67	0.59	0.55	0.89	0.46	0.89	0.74	0.46	0.49	0.46

Fig. 2.26 & 2.27 Importance factors for the Main and Additional Values for the geological frameworks the M-G-AM survey

II/E Evaluation of selected geosites with visitors' feedback

	Rarity	Representativeness	Knowledge on geoscientific issues	Level of interpretation	Viewpoints	Surface	Surrounding landscape and nature	Environmental fitting of sites	Current condition	Protection level	Vulnerability	Suitable number of visitors
Gorges de l'Arrière - Affluement de la faille de Limagne	0.50	0.50	0.83	0.86	0.83	0.69	0.80	0.75	0.50	0.56	0.86	0.81
Gorges d'Enval - Affluement de la faille de Limagne	0.50	0.50	0.80	0.80	0.50	0.50	0.25	0.25	0.25	0.50	0.25	0.25
Viège de Volvic - Affluement de la faille de Limagne	0.38	0.53	0.83	0.83	0.41	0.66	0.47	0.34	0.50	0.50	0.50	0.50
Lac d'Aydat	0.58	0.46	0.83	0.87	0.71	0.96	0.58	0.50	0.75	0.67	0.50	0.50
Montagne de la Serre	0.75	0.50	0.80	0.80	0.50	0.75	0.50	0.50	0.75	0.75	0.75	0.50
Mont Redon	0.25	0.25	0.25	0.25	0.25	0.75	0.80	0.25	0.75	0.50	0.25	0.75
Puy de Dôme	0.67	0.58	0.75	0.83	0.75	0.75	0.75	0.75	0.67	0.83	0.83	0.75
Grand Sarcouy	0.50	0.50	0.80	0.80	0.50	0.50	0.25	0.25	0.25	0.50	0.25	0.25
Maar de Beaunit	0.38	0.30	0.80	0.85	0.39	0.95	0.80	0.55	0.55	0.50	0.55	0.50
La nasse d'Espinasse	0.50	0.50	0.58	0.67	0.50	0.75	0.75	0.67	0.50	0.42	0.42	0.38
Maar de Villars	0.38	0.28	0.80	0.84	0.53	0.78	0.59	0.44	0.50	0.28	0.25	0.50
Puy de Combegrasse	0.25	0.28	0.38	0.45	0.53	0.88	0.40	0.35	0.55	0.40	0.45	0.60
Puy des Gouttes	0.13	0.50	0.80	0.80	0.75	0.75	0.63	0.50	0.75	0.50	0.63	0.25
Puy de Jumes												
Puy de Lempély	0.58	0.50	0.89	0.82	0.69	0.84	0.91	0.89	0.77	0.64	0.73	0.45
Puy de Louchadrière	0.50	0.80	0.38	0.70	0.80	0.70	0.80	0.60	0.70	0.50	0.80	0.70
Puy de la Nugère												
Puy de Pariou	0.17	0.25	0.17	0.67	0.67	0.75	0.92	0.33	0.57	0.57	0.57	0.42
Puy de Paugnat	0.19	0.50	0.19	0.50	0.38	1.00	0.69	0.19	0.68	0.56	0.38	0.44
Puy de la Vache	0.08	0.08	0.17	0.13	0.42	0.50	0.25	0.17	0.50	0.50	0.58	0.33

Fig. 2.28 Importance factors for the Main Values for the geosites of the M-GAM survey

II/E Evaluation of selected geosites with visitors' feedback

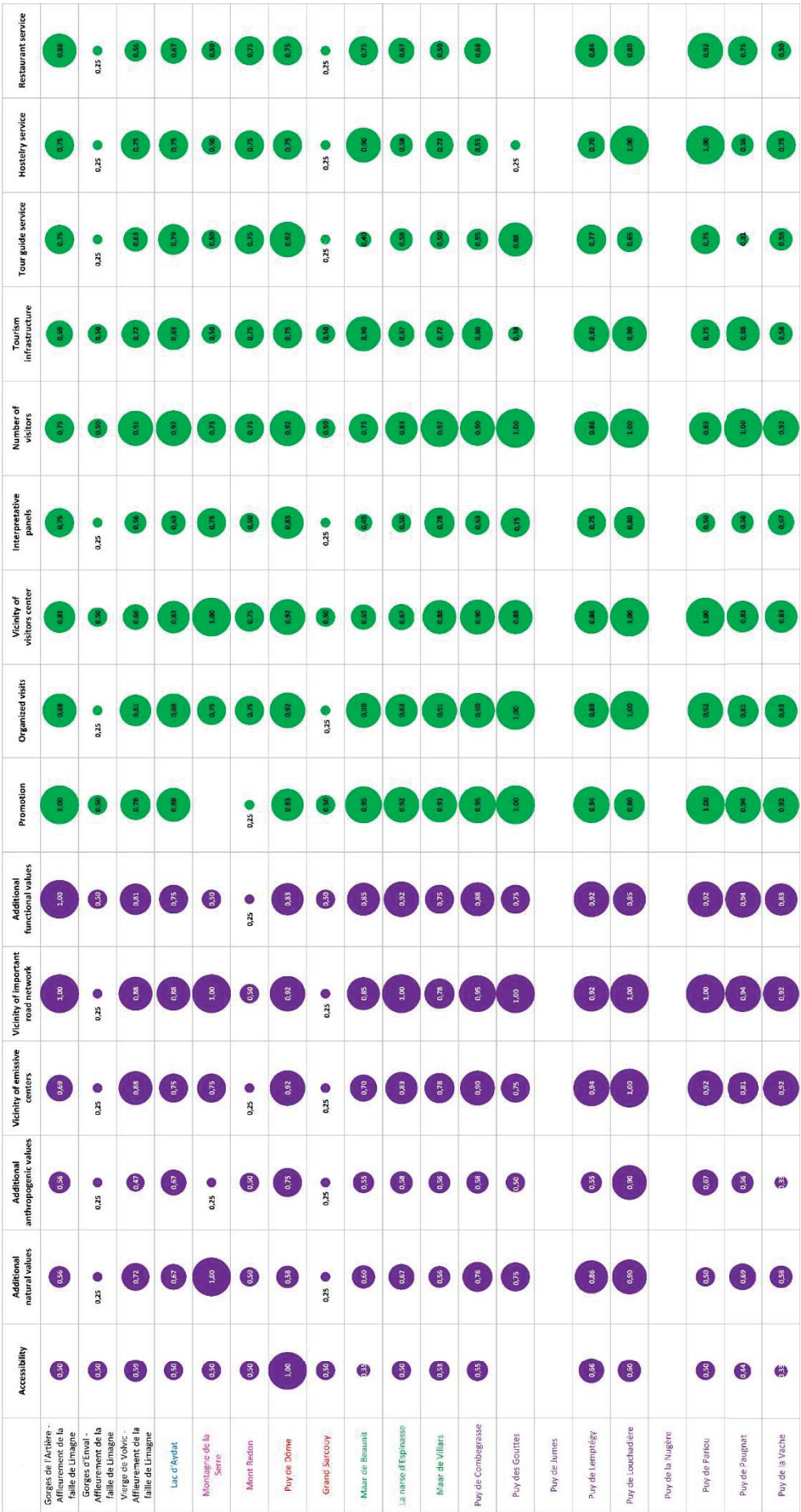


Fig. 2.29 Importance factors for the Additional Values for the geosites of the M-G-AM survey

This was a key consideration for PÁL & ALBERT (2018), when they used the site-specific summation of importance factors from the answers, instead of calculating a global value for a whole area or for a geological framework. Following the same approach, the importance factors for each M-GAM selected geosites of the World Heritage property are summarized in Fig. 2.28 and 2.29, by the *Main* and *Additional Values* respectively. These charts show a more in-depth feedback about the needs and expectations of (geo)tourists about a site, which is different even between sites of the same phenomena (e.g. scoria cones). It is formed by the characteristics of the site itself, but also by the nature of visitors (number of responders, their interest in geosciences, etc.). This data could be analysed site-by-site and indicator-by-indicator, but this would exceed the limit of this work. It should be rather carried out during the site-specific planning of the management by authorities. Here, only some interesting phenomena are pointed out, that show the strength of the site-specific importance factor approach of the Hungarian research team (PÁL & ALBERT 2018).

- The blurring effect of the averaging of importance factors are clearly visible comparing the points of scientific values (e.g. *Rarity*, *Representativeness*) of scoria cones in general (Fig. 2.26), with the significantly scattering values of the individual sites (Fig. 2.28), such as *Puy de Louchaïdère* (RAR: 0,5, REP: 0,6), compared with *Puy de Parion* (RAR: 0,17, REP: 0,25).
- Visitors were specially concerned about the *environmental fitting of sites*, where outcrops differ sharply from the surrounding flora and environment (e.g. *Gorges de l'Artière*) or human interaction changed the form significantly with quarrying (*Puy de Louchaïdère*, *Puy de Lemptégy*) or with significant infrastructure (*Puy de Lemptégy* and *Puy de Dôme*)
- Generally, the higher the number of visitors per site, the more concerned they are about the *suitable visitor number* at a geosite. This is observable at easily reachable, frequented sites (e.g. *Maar de Villars*, *Gorges de l'Artière*), but not in all cases. *Puy de Dôme* also received high scores, while *Puy de Lemptégy* not. At the less frequented site of *Puy de Louchaïdère*, people were more concerned about this indicator, than at the more popular attraction of *Puy de la Vache*.
- The *vicinity of important road network* was almost unanimously important for most of the visitors, underlining that most sites are already reachable by car, and probably indicating that most of the visitors reach them this way. The low scoring three sites (*Gorges d'Enval*, *Grand Sarcony*, *Mont Redon*) are slightly further from direct car access.
- Besides the *Functional Values* of road network, the other indicator with the greatest agreement of *Im* values was the *Promotion at Touristic Values*. It can indicate at least two things: visitors have already chosen these destinations influenced by a promotion campaign or guidebook, so the high points reflect a satisfaction in these initiatives. It can also mean

($I_m=1$), M-GAM values might be the same, but never higher than the GAM values. The higher the difference between the X,Y axis position of the two datasets is, the more different the (geo)tourists see the current geotouristic potential and the intrinsic values of the site, compared with the experts' evaluation. The lower the position on the X axis, the less-important the indicators of *Main Values* are for them, meaning that they are not so concerned about the scientific, protection, etc. (aka. intrinsic) values of the site or that such message was not taken through effectively at the respective geosite.

The different perception of *Additional Values* (the Y axis difference) marks how important the touristic and (partially tourism related) infrastructure elements are for them when choosing a destination, and how satisfied they are with the current development level of a geosite. In both cases, the examination of these differences could help the management authorities prioritizing developments: strengthening the message about the intrinsic values, or considering touristic developments at a site.

Differences are well-visible on the GAM-M-GAM matrix too (Fig. 2.30), but they can be interpreted better being quantified and plotted as on Fig. 2.31. Here, the difference values are plotted in the following manner: ΔMV is plotted against ΔAV , where $\Delta MV = G_MV - M_MV$ and $\Delta AV = G_AV - M_AV$, 'G_' and 'M_' marking the GAM and the M-GAM values of a geosite respectively. The higher the difference on the X axis, the less important the *Main Values* are for visitors. With the same consideration, higher values on the Y (ΔAV) axis signifies the more different opinion of visitors on *Touristic* and *Functional values*, comparing with the evaluators.

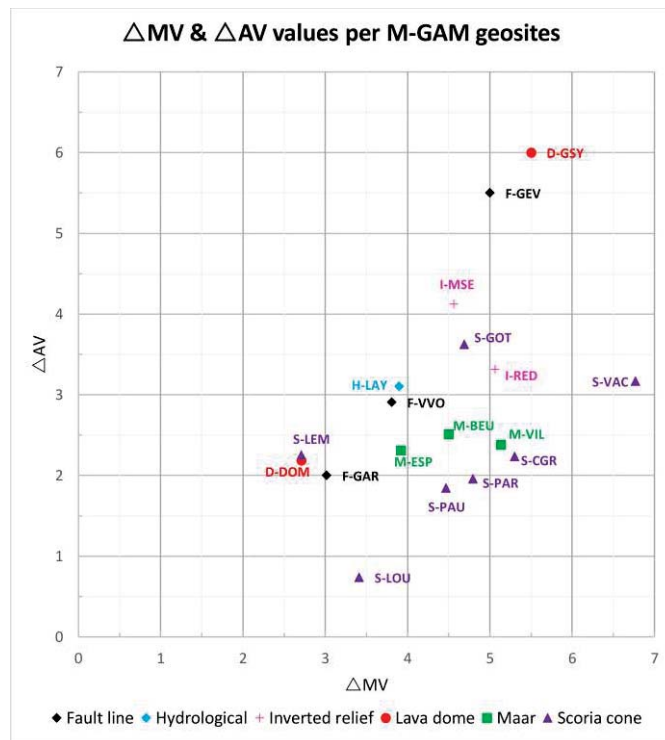


Fig. 2.31 ΔMV - ΔAV matrix of the M-GAM survey

Based on the results and *Figure 2.30* and *2.31*, the general trend is that the visitors are rather satisfied with the current geotouristic potential or they evaluate the importance of these indicators in a similar manner to experts (ΔAV smaller than ΔMV). In contrast, *Main Values* were not considered so important by the visitors of the *Chaîne des Puys – Limagne Fault*, or the message about the importance of these sites - manifested in the higher MV points of the experts' in GAM compared to the pointing of visitors by M-GAM – was not transmitted effectively. This could indicate a strategy, working to enhance more effective geoconservation (e.g. enforced protection of sites by stabilization, limiting tourist flow, etc.) and a more effective and stronger message on the interpretation of the scientific importance of the property.

On the example of some of the 'protruding' values, the usage of M-GAM in prioritizing in geosite development can be demonstrated. *Puy de Louchadière* (S-LOU) with the lowest ΔAV indicates, that visitors were satisfied with the current geotouristic potential of the site (accessibility, facilities, etc.), or they see its current state very similarly to the experts'. In contrast, at another scoria cone site, the *Puy des Gouttes* (S-GOT), both the ΔAV and ΔMV are outstanding, just as in case of *Gorges d'Enval* (F-GEV). This supposes that these sites should be prioritized in geosite management, carefully considering their intrinsic values and also improving their geotouristic potential.

Finally, in case of a third scoria cone example, the *Puy de la Vache* (S-VAC), the ΔMV was the highest, with a slightly higher than the average ΔAV value. It can indicate that tourists did not appreciate the exceptional scientific importance of the site – although being probably the best horseshoe-shaped scoria cone in the region and the source of the longest local Quaternary lava flow with *Puy de Lassolas* - or that visitors were not so concerned about the protection and vulnerability of the site.

II/E/2/c Statistics on demographics

As it was noted before, the number of answers is not enough for a statistically robust dataset. However, the supplementary questions collected on demographics and relationship to (geo)tourism already show interesting information.

Fig. 2.32 summarizes the demographic characteristics of the responders. The intellectual class with a higher-education degree is dominant (*Fig. 2.32 B*), the only primary school answer is probably connected to a young family member, while the secondary education responders can be either connected to blue-collar workers, or university studies in progress. In terms of age group (*Fig. 2.32 C*), adults are dominant (82%), with a negligible junior (less than 18) percentage (2,3%) and a senior group, which is comparable to the dissected sub-groups of adults, but less significant to the whole age group. The dispersion of adult age groups is generally consistent, but young adults (19-25, 26-

35) are somewhat less numerous than mature adults (36-45, 46-60). These data rather show the willingness of participation in an online survey, than the real demographic composition of visitors. Distortions that may occur here, and should be updated in similar surveys later are the following:

- It is likely that several visitors came as a family, while only one member filled in the questionnaire, or maybe just the adults, underrepresenting young visitors.
- Senior generations might not be able open to online forms of surveying, due to technical difficulties or general distrust. Therefore, the group of senior people were certainly under-represented, a personal interviewing would give a different age group pattern.

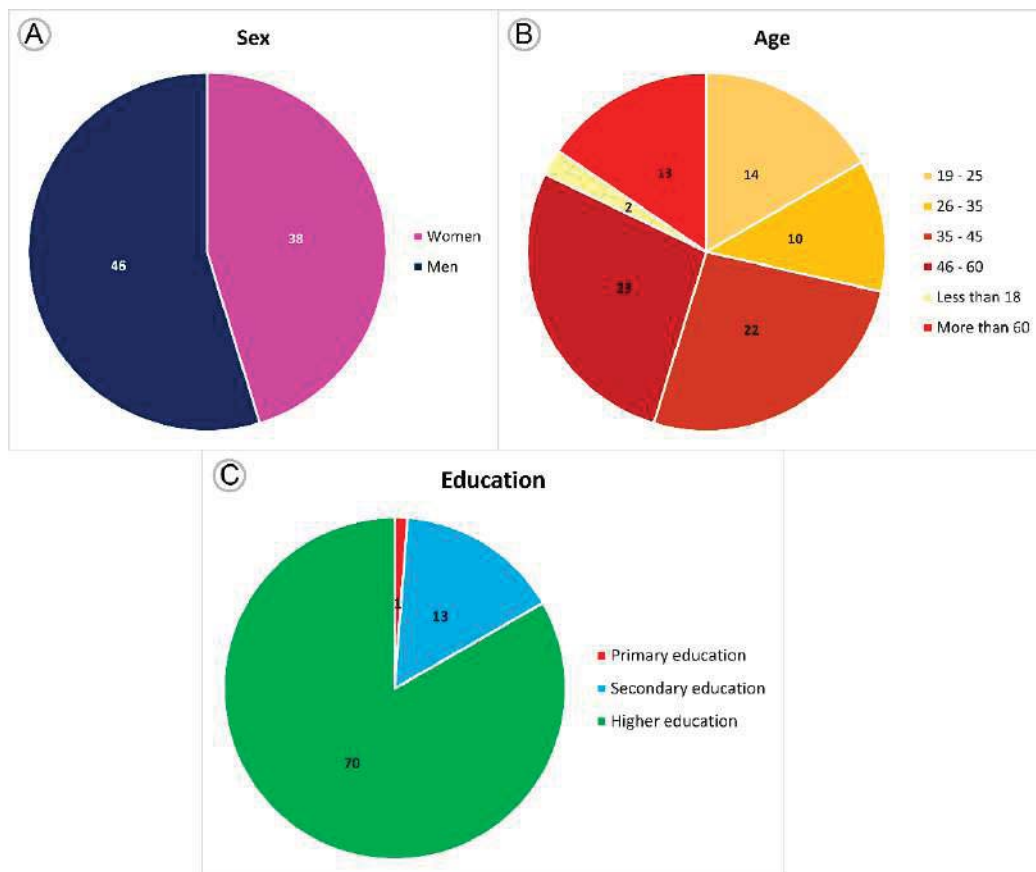


Fig. 2.32 Demographical answers of the M-GAM survey

The geographical distribution of visitors can be seen on Fig 2.33. Nearly 60 % of the visitors came from *Clermont Auvergne Métropole* or the *Grand Clermont* territorial unit, clearly marked by the close distances of 0-25 km (Fig.2.33 A) and their home distribution (Fig. 2.33 B). Visitors from the 25 – 100 km distance categories (9.4 % in total) are naturally associated with the *Auvergne-Rhône-Alpes* region. What is interesting to see that each responder on a regional level arrived from the ‘eastern side’ of the area, no answers came from the Western side municipalities, like from *Aubusson*, *Ussel* or *Pontgibaud*. Here, it must be noted that geosites on the western part of the World Heritage area were underrepresented. In terms of the geosite destinations of visitors, all landform types were well-represented (e.g. maars, inverted relief sites), although scoria cones were prevailing.

destination selection during planning their trips – planning to visit a territory like the *Chaîne des Puys* - *Limagne Fault* with predominantly geological, natural values – or a significant open-mindedness in this direction, which is promising for planning further initiatives in geotourism.

Finally, the chart on hiking frequency (Fig. 2.34 C) shows that the (geo)tourists in this survey could be associated with active tourism or lifestyle in general (76 % of monthly and weekly active groups). In terms of geotouristic development, it could indicate that geosites where the availability requires some physical activity could also reach out a visitor group, with a well-chosen strategy between geoconservation and tourism marketing.

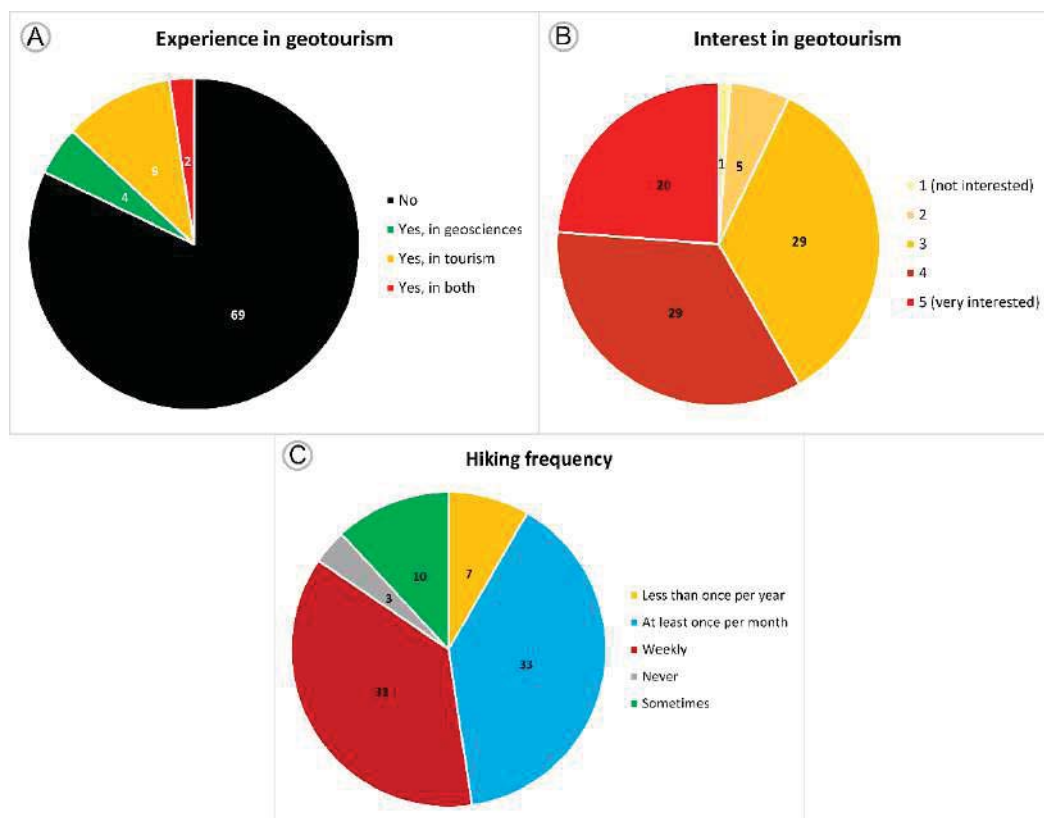


Fig. 2.34 Tourism related answers of the M-GAM survey

II/E/2/d Perspectives

The M-GAM survey of the World Heritage property has been an experimental project for this thesis, not being a principal outcome, being integrated to the work plan in a later phase. But it clearly relies on the dedicated geosite inventory of the property, organically and valuably supplementing that. Here, a selection of some conclusions are presented, but this data could be principally used and further analysed in two fields: I) a site-specific evaluation by local touristic stakeholders, comparing with other tourist surveys II) a geosite inventory focused comparison, with other M-GAM surveys, carried out so far.

Some drawbacks that could be improved in the future were already mentioned in sections II/E/2/a-c. Some of them were related specifically to the local application (e.g. omitting personal

interviews in this phase), while other considerations (such as providing accessibility also in foreign languages) might improve the survey quality in other research areas too.

The higher the number of responders, the more robust the dataset is, showing visitor patterns. All M-GAM survey missions so far (such as BOŽIĆ & TOMIĆ 2015, PÁL & ALBERT 2018 and also the present project) were supported at a certain level by managing authorities (permit for data collection), but being independent studies, only partially or not -integrated to other touristic surveys. Therefore, they were hindered with the limited outreach potential of the research group. This should be improved with a broader collaboration with touristic authorities and management bodies, which could be manifested in advertising campaigns (e.g. providing small rewards or prizes for responders) and adding questions that fit the perspective of these partner institutions too.

The number and complexity of questions however should be treated carefully. From a data mining perspective, the plethora of indicators is welcome, but difficult to answer questionnaires could reduce the willingness of participation. This is a drawback for example for the (M-)GAM survey itself, which uses 27 indicators, some of them are probably more difficult to interpret by the general public, even if we tried to make them easy in this survey.

The inclusion of visitors' feedback with geosite inventories was only used extensively so far with the M-GAM. Most national geosite inventories are not based on this method, but rather on a national framework (see *chapter I/E*). However, as many of them are also at least partially based on quantitative indicators, they could be evaluated by visitors with a similar approach. Even the evaluation of some qualitative (textual description) fields should be integrated to such questionnaires. The French national inventory, the INPG only uses 10 quantitative indicators in total (see DE WEVER ET AL. 2015 and *chapter I/E*), most of them are somewhat easier to interpret than the complex (M-)GAM values. Therefore, one of the main perspectives and recommendation of the present work is to initiate a similar study not just in the *Chaîne des Puy – Limagne Fault*, but in other French areas too, therefore including visitors' feedback in the INPG.

III THE URBAN GEOHERITAGE OF CLERMONT-FERRAND: FROM INVENTORY TO MANAGEMENT¹

III/A Introduction

In this paper, we present how geoconservation and geoheritage inventorying can be adapted to an urban context, using the example of the city of *Clermont-Ferrand*, in the centre of the *Auvergne* region of the *Massif Central*, France (Fig. 2.1). We identify all geological outcrops and landforms in the city and include them in a local inventory, assessing their geoheritage values. Using this inventory, we address some key issues of urban geoconservation and the possible popularization of geoheritage within a city.

According to LIMA ET AL. (2010), geosite inventories and their assessment methods should consider the *topic*, the *scale*, the *scope* and the *values*. Here, the *topic* is the geoheritage of *Clermont-Ferrand*, the multiple landforms and geological features associated with tectonic, volcanic and sedimentary processes related to major continental rifting. Examples include Quaternary lava flows and maars, Tertiary graben-infilling sediments with fossils, and erosion features, such as inverted relief (Fig. 3.1). The city is located next to a UNESCO World Heritage site, the *Chaîne des Puys – Limagne Fault* Tectonic Arena, and shares the same basic geological framework. The *scale* is that of the administrative unit of *Clermont-Ferrand*, a clearly-defined 43 km² area (Fig. 2.1). The *scope* is defined by the urban context, with a need to create an inventory that could foster effective geoconservation of geosites in the highly urbanized area and lead to reflection on their educational and geotouristic potential. Finally, the *values* are defined by the applied inventorying method (DE WEVER ET AL. 2015), with scientific importance being the priority, accompanied by associated values (such as education and tourism).

France has an advanced system of national geosite inventory (DE WEVER ET AL. 2015) and five national geosites are located in the city of *Clermont-Ferrand*. These give a good overview of the area's geodiversity on a national and even local level. However, some locally important features are missing, as they do not achieve the level of an 'outstanding example' of a geological feature on a national or regional level. Furthermore, for the five national geosites listed, the inventory does not specify the location of each outcrop or detail all the features in the case of geosites of significant areal extent, such as the extensive lava field associated with the *Puy de Grave Noire* scoria cone. In

¹This chapter has been published as VEREB V., VAN WYK DE VRIES B., GUILBAUD M.N., KARÁTON D. (2020) The urban geoheritage of Clermont-Ferrand: from inventory to management. *Quaestiones Geographicae* 39(2):5-31. doi: [10.2478/quageo-2020-0020](https://doi.org/10.2478/quageo-2020-0020). The chapter is 99% identical to the paper, only Fig. 1. is removed (being identical to Fig. 2.1 in chapter II), just like the description of INPG (available in chapter I/C).

this case, the exact elements representing the constituent features of the national geosite, specifically the outcrops within the urban fabric, have not yet been explicitly inventoried.

Our first source of information for locating potential geosites was pre-existing databases, historical maps and photographs, and oral discussions with local experts. We also compiled a simplified urban geomorphological map, which allowed us to have an overview of the city's main geomorphological features and its geodiversity, and helped identify areas with potential geosites ('geodiversity hotspots'). Finally, a thorough, highly-detailed, street-by-street survey of the whole city was the major way we obtained our information.

From the fieldwork, more than 50 sites were recorded and assessed, following the database format and semi-quantitative assessment method by DE WEVER ET AL. (2015). Underground elements, in particular the caves dug into the Clermont tuff ring, under the medieval city centre, were omitted to respect privacy, and we also omitted a detailed assessment of the heritage stone potential of the city. However, considering the flexibility of the inventory, these elements could be included in a future phase.

In the discussion, we underline the importance of site-specific management strategies in an urban environment through the example of selected geosites and geodiversity sites. The educational and geotouristic potential of these sites is illustrated through the proposal of geotouristic routes. We consider the possibilities for future development and look at issues such as the involvement of citizens in geoconservation (e.g., crowdmapping), the management of geosites in private areas, and the cooperation of adjacent municipalities in highly urbanized areas. Finally, we look at the relationship of the city with the nearby natural UNESCO World Heritage site, which shares the same geological context, and also some of the same peripheral urban problems.

III/A/1 Urban geoheritage

Urbanization is a global phenomenon, seen in the constant increase of urban population – reaching 56% globally (UN DESA 2018) – and in urban sprawl that is the dynamic growth of areas covered by infrastructure, housing projects, industrial facilities and so on. This sprawl constantly diminishes natural or semi-natural areas, destroying their biotic and abiotic values, or placing them into a new, urban context. Densification of existing urban areas at the expense of remnant natural spaces also adds to the loss of natural environment.

To address these problems, multiple and often interdisciplinary studies have examined the complex interactions of the urban environment with natural elements, for example, urban geology combining engineering and risk management (DE MULDER 1993; HUGGENBERGER ET AL. 2011), and urban geomorphology considering the relationship between landforms and the urban fabric (e.g., COOKE 1976; THORNBUSH 2015).

Research on urban geoheritage, which aims to understand the complex interactions between geodiversity elements and the urban environment and its potential for geotourism, is an emerging domain of geoheritage studies. Several studies have discussed the geotouristic potential of cities by designing special itineraries (e.g., ROBINSON 1982; DEL LAMA ET AL. 2015; PICA ET AL. 2018) and others have addressed the assessment and conservation of geoheritage in urban areas (PICA ET AL. 2016; ZWOLIŃSKI ET AL. 2017; ERIKSTAD ET AL. 2018). A separate, but linked theme is the description of heritage stones, which reveal the importance of locally-extracted, natural building materials in the cityscape and in cultural heritage (PŘIKRYL & TÖRÖK 2010; PEREIRA ET AL. 2015; BROCX & SEMENIUK 2019).

REYNARD ET AL. (2017) synthesized the principal considerations of urban geomorphological heritage. An urban geomorphological site could be either any geomorphosite situated within the limits of the urban space (*sensu lato* definition) or solely a site that helps understand the interactions between geomorphology and urban development (*sensu stricto*).

Geoheritage in the urban context could:

- I) contribute to the landscape, the cityscape,
- II) be a constraint, but also an advantage to urban development,
- III) provide resources, such as exploitable stone or an aquifer,
- IV) cause or be affected by natural hazards,
- V) a potentially vulnerable element to encroaching urbanization.

Urban geoconservation requires a different approach due to the high vulnerability of sites and the specific management challenges of an urban context compared to rural areas. Human impact and disturbance is severe, with frequent construction works, a tendency to reduce natural areas, and often significant throughflow of people. Indirect forms of protection for geoheritage through biodiversity or natural diversity reserves are less common in cities than in rural or natural areas. Direct protection of geoheritage values is also limited, as geoheritage inventories dedicated to cities are still scarce and are rarely integrated into urban planning (e.g., the example of *London*, GLA 2009).

Landforms are often covered up, therefore, the reliance on indirect information sources (e.g., historical maps, satellite images, drilling data) is more common than in geosite inventories and assessments of natural or semi-natural areas, and field evaluation is often limited or challenging. Potential sites are often already disturbed or partially destroyed, therefore, scientific values such as representativeness or integrity are often much lower than in rural places and the effectiveness of standard assessment methods could be limited.

III/A/2 Geographical and geological context of Clermont-Ferrand

Situated in central France, the city of *Clermont-Ferrand* is the historic capital of the *Auvergne* region, and the capital of the *Puy-de-Dôme* department (Fig. 2.1). The administrative area of the city, home to ca. 140,000 people, is concentrated on the central-western section of the *Grand Limagne* plain, while its agglomeration, the *Clermont Auvergne Métropole*, extends eastward to the *Allier* river valley (a tributary of the *Loire*). Westwards, the *Métropole* communities of *Orcines* and *St. Genès Champanelle* are located in the domain of the *Chaîne des Puys – Limagne Fault* World Heritage area. This designation does not directly affect the territory of the city itself (*sensu stricto*), but the chain of monogenetic volcanoes (locally called *puys*) rising from the elevated *Plateau des Dômes* provides an iconic background to the cityscape, uplifted by the *Limagne* Fault. The fault, part of the World Heritage site, has a direct boundary with the city and the geology whose outstanding nature justified the UNESCO site continues into the city.

Earliest traces of human occupation date back to the Neolithic, with a remnant of a dolmen at the national geosite of *Puy de la Poix*. The important Gallo-Roman settlement of *Augustonemetum* was situated on the *Butte de Clermont*, as was the medieval city of *Clairmont*, the latter being of international historic importance as the location of the Council of Clermont that called the First Crusade in 1095. The present day administrative unit of *Clermont-Ferrand* was created in 1630 with the unification of *Clairmont* and *Montferrand*, both of them preserving their historical centres, with important cultural monuments and the widespread use of local rocks for building, such as the *Volvic* Stone.

Massive urbanization occurred in the 19th and 20th centuries due to the growing economic importance of companies such as *Michelin* (the headquarters of this global company are still in *Clermont-Ferrand*), and the regional cultural and economic influence of the city. Large-scale neighbourhoods were constructed, covering up the eastern alluvial plains of the small *Tiretaine* and *Artière* rivers, and sprawling onto the flanks of plateaus capped by lava flows at the city's limits (Fig. 3.1). These developments form the present day, highly urbanized area, which continues to expand.

The cityscape is formed by major elements of the geology of the Massif Central including the *Limagne Plain*, *Limagne Fault* and the adjacent features of the volcanic *Chaîne des Puys*. They are expressed in the relief and can be directly seen in outcrops.

The city centre of Clermont has been located since Roman times at the edge of the *Maar de Jaude* (also called the *Maar de Clermont-Chamalières*), a late Pleistocene phreatomagmatic crater, completely filled by sediments and lava flows (Fig. 3.1). The main square (*Place de Jaude*) is situated on the boundary of the 1.5 km – diameter maar crater, dated at 160,000 years (BOIVIN ET AL. 2017). The maar's ejecta, a tuff ring, forms the '*Butte de Clermont*', where the medieval core of the city is located,

including its emblematic black cathedral. The phreatomagmatic sequence of the tuff ring is well exposed in the so-called ‘*Caves de la Butte de Clermont*’. These are hundreds of cavities dug below the houses from Roman times, and used for a multitude of purposes, including cellars to store wine or cheese.

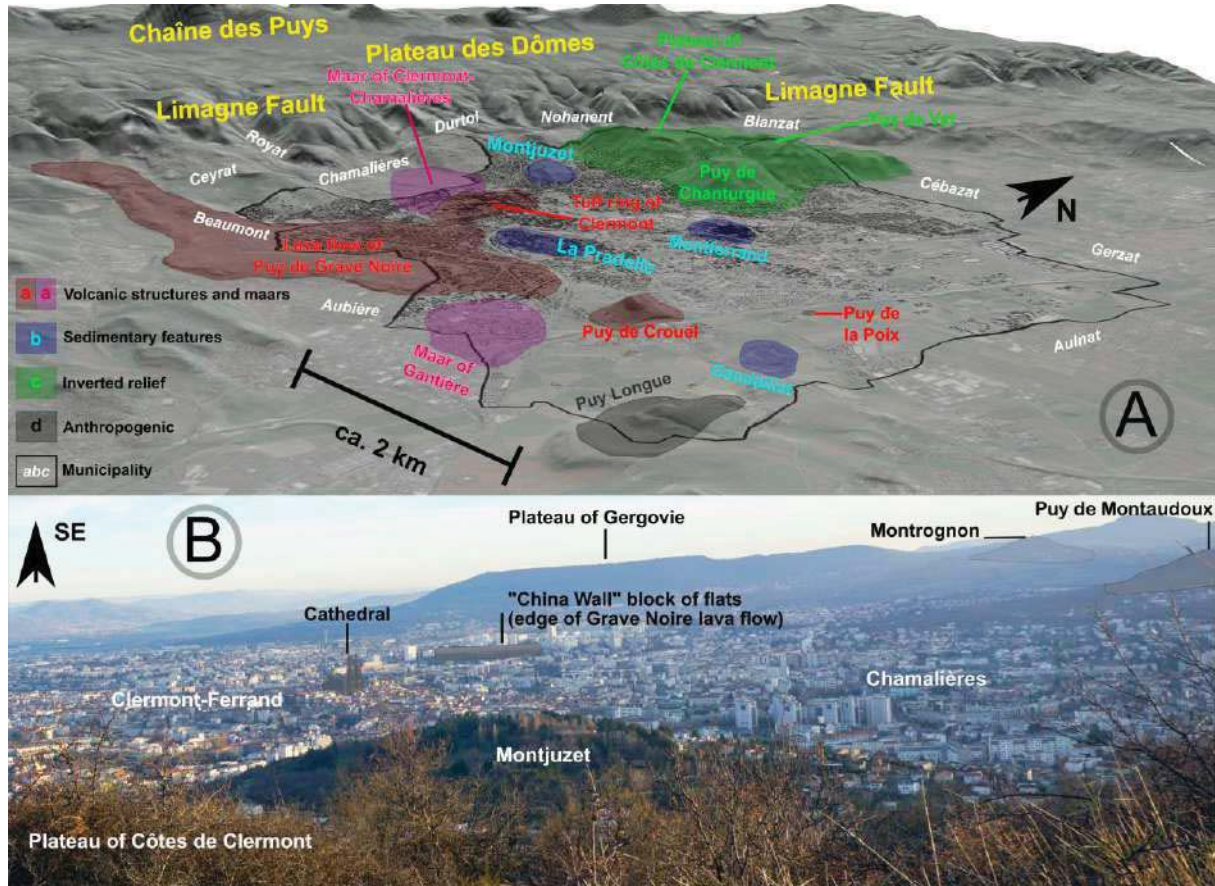


Fig. 3.1 The main geological – geomorphological features of Clermont-Ferrand. A: A DEM (CRAIG 2013) view from southeast, indicating the extension of built-up areas as well (OSM 2020). B: the view of the city from its highest point, the Plateau of Côtes du Clermont. The Plateau of Gergovie in the background is an inverted relief feature as well, but outside the city limits

Northwards, the hill and park of *Montjuçet* conserves the remnants of Oligocene rift sedimentation, with reported stromatolites, and is covered by Quaternary tephra layers from the *Chaîne des Puy*s volcanoes that may crop out in building sites and as rare outcrops on the hillsides. Neighbourhoods of the northeast perimeter of the city are built on Oligocene sediments that form the flanks of inverted relief lava flows. *Montferrand*, with its historical architectural centre, is also located on Oligocene sediments and a probable alluvial terrace. A cluster of high-standing Miocene lava flows (Plateau of the *Côtes de Clermont*, *Puy de Chanturgue*, *Puy de la Mouchette* and *Puy de Var*) border the *Nohanent* and *Blanzat* municipalities. They also form the highest relief of the city, reaching 600 meters on the Plateau of the *Côtes de Clermont*.

The eastern and southern parts, which represent 60% of the total city area, are dominated by alluvial and colluvial deposits that are part of the *Limagne Plain* and are associated with the *Tiretaine* and *Artière* rivers (Fig. 3.1). Residential areas and industrial districts have nearly completely covered

this territory but the destruction of the fluvial geomorphological microforms probably occurred during the medieval agricultural activity, of which a few scattered fields remain.

However, the predominantly flat, alluvial plain is intersected with some important geological features. The Oligocene sedimentary quarry of *Gandaillat* and the only source of bitumen in France at *Puy de la Poix*, are located close to the eastern perimeter of the city near the airport. Further south, *Puy de Crouël* is an exhumed peperite volcanic neck from the Miocene, while the *Maar de la Gantière* – infilled by sediments and almost invisible in the present topography – is another representative of the late Pleistocene maar volcanism of the Limagne plain (Fig. 3.1).

The border with the *Aubière* and *Beaumont* municipalities and the areas south of the *Butte de Clermont* are dominated by the lava flows of the *Puy de Grave Noire* scoria cone that were emplaced ca. 60,000 years ago (BOIVIN ET AL. 2017). Constituting a small plateau of recently formed inverted relief, the lava flow front is exposed in numerous outcrops that display fundamental aspects of the internal structure of the flows and their complex interaction with the subsurface. The lava flows follow paleostreams that still feed springs, some of which can be observed along the flow front.

Finally, the district of *Les Ormeaux*, south of the city centre, is constructed on a slope of eroded Oligocene sediments topped by the volcanic neck of *Montaudoux*, itself just outside the city borders, in the municipality of *Ceyrat* (Fig. 3.1).

III/B Methodology

To compile the geoheritage inventory of *Clermont-Ferrand*, we followed the guidelines of REYNARD ET AL. (2016), taking into consideration the definitions proposed by BRILHA (2016) and the existing urban geoheritage inventories, such as that of *Rome* (PICA ET AL. 2016) and *Poznań* (ZWOLIŃSKI ET AL. 2017). REYNARD ET AL. (2017) highlighted that the selection of potential urban geomorphosites often requires a significant reliance on bibliographical sources, as field identification might be hindered by the physical coverage of features either by buildings or vegetation.

Publications about the geological and geomorphological features of *Clermont-Ferrand* only address some geoscientific aspects, as they are mostly focused on the volcanological context of *Chaîne des Puys* (e.g., HARRIS ET AL. 2014, BOIVIN ET AL. 2017) or the sedimentary processes of the *Limagne* (ROCHE ET AL. 2018), and because descriptions of outcrops and landforms are limited.

Historical maps of *Auvergne*, such as the one of LA JONCHÈRE & DÉSBRULINS (1739) or DESMAREST (1823), clearly depict the geomorphological context of the city, specifically the *Limagne Plain* and the *Limagne Fault*, along with principal units like *Montjuzet* or *Puy de la Poix*. Detailed city maps from the 19th century by numerous editors (e.g., BLANZAL 1864, JULIOT 1898), the sheets of national cartographical campaigns (e.g., *Carte d'état-major*, the cartography series of

Institut National de l'Information Géographique et Forestière [IGN]) and orthophotos after the Second World War, are also valuable for tracking changes in land use, the suppression of natural and agricultural areas, and the densification and expansion of the city. In some cases, these documents provide evidence of ancient outcrops or quarries that have now been destroyed or converted into housing complexes or commercial centres.

After the initial bibliographic study, we created the simplified geomorphological map of *Clermont-Ferrand*. As demonstrated by DEL MONTE ET AL. (2013) in Rome, the identification of the main landforms and geomorphological processes on geomorphological maps that are often covered by an urban fabric could help in the location of potential geoheritage areas. Besides giving a general overview of the geodiversity of the whole area, certain ‘geodiversity hotspots’ could be highlighted by a higher density of different phenomena. These could help in the field identification of geosites (Fig. 3.2). The map covering the whole administrative area is based on the 5 m resolution LiDAR dataset of *Clermont Communauté* DEM (CRAIG 2013), also using for comparison the digitized, local sheets of the Geological Map of France at 1/50000 (BRGM 2020), and the topographic maps of IGN (2020).

Finally, potential geosites revealed by the bibliography research and areas with high geodiversity were investigated by detailed, street-by-street field work. All outcrops or landforms located in public areas were recorded. Sites located in private land, but well-visible from the street were also inventoried. As noted before, privacy was the principal reason for the exclusion of the *Caves de la Butte de Clermont*, which will be discussed in detail below.

Field data was recorded with the open-source framework of ODK (Open Data Kit) Collect and Aggregate application (VEREB ET AL. 2018A) and then converted to a Microsoft Access database. The inventory database closely followed the structure of the French National Inventory and its central database, the iGéotope (DE WEVER ET AL. 2015), the background and structure of which is already described in *chapter I/C*.

By closely following the framework of the INPG, it means that the selected geosites at a local level can easily be incorporated into the national inventory in the future, if the representativity justifies it. A slight modification we made was the addition of some descriptive fields (e.g., identification of canton and cadastral number inside the city), which could be of administrative help in the city municipality where the database is to be integrated. The identification number of geosites has also been adapted to the local context using the following naming standard: CFxxyy, where xx is the official number of the city canton, while yy is the individual number of the site.

III/C Results

III/C/1 The simplified geomorphological map of Clermont-Ferrand

The majority of the city area is a widespread alluvial and colluvial plain (Fig. 3.2), as noted in section III/A/2. Fluvial microforms commonly associated with changes in the location of river channels or areas of sediment deposition were not observed, probably because they have been eradicated or highly modified by urbanization. This area on the map only displays anthropogenic features such as buildings and road networks, and some residual (e.g., *Montferrand*) or exhumed (e.g., *Puy de Cronël*) landforms.

In contrast, a high diversity of geomorphological and geological features is observable in the western part of the city area (Fig. 3.2). The Quaternary lava flow of *Grave Noire* in the southwestern part of the city forms an inverted relief capped by relatively erosion-resistant trachybasalts and bordered by steep slopes that suggest the existence of outcrops. The northern part of the city, with the plateaus of the *Côtes de Clermont*, the *Puy de Var*, smaller sedimentary residual features, such as *Montjuzet*, and slopes articulated by several small ravines and ridges is also a favourable area for good exposures.

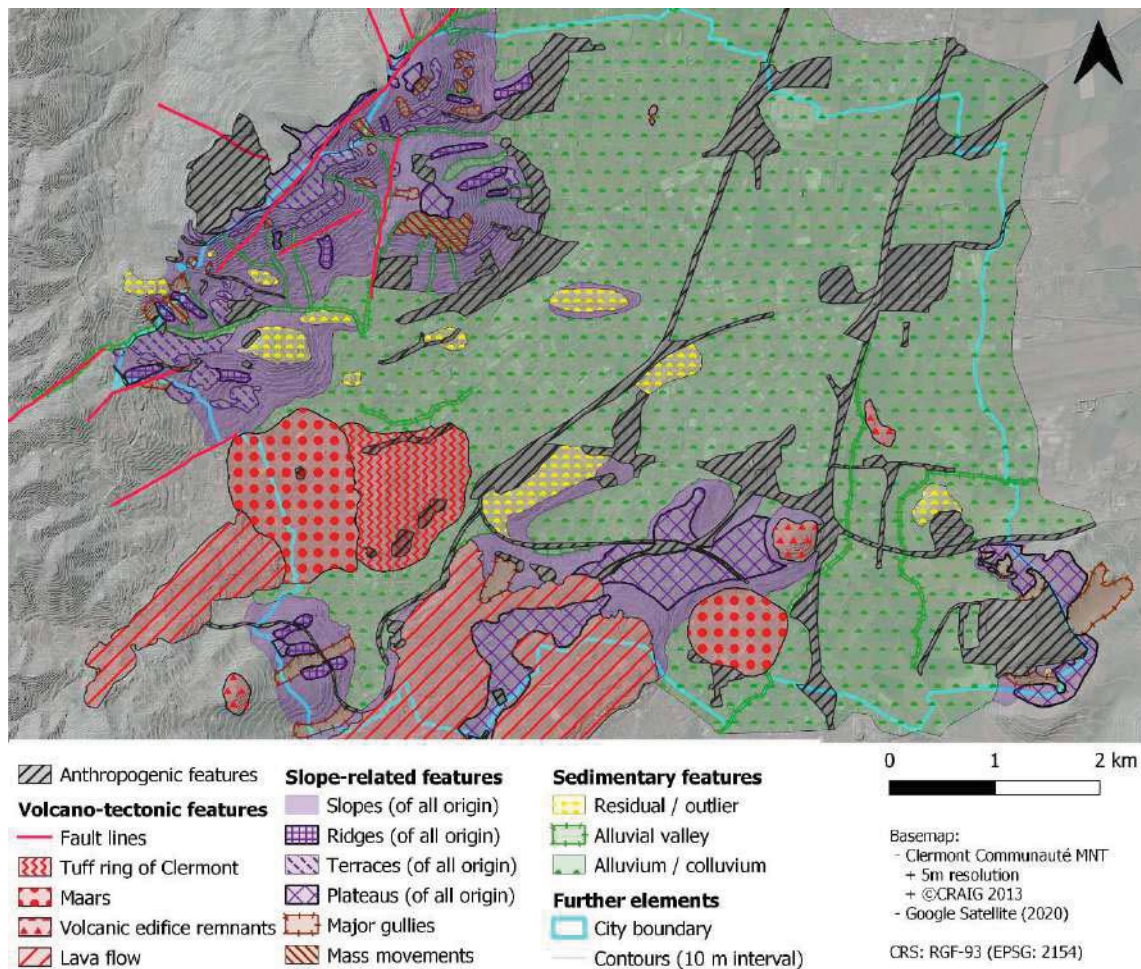


Fig. 3.2 The simplified geomorphological map of Clermont-Ferrand

III/C/2 The urban geoheritage inventory of Clermont-Ferrand

A total of 53 sites were recorded and assessed with the INPG methodology as of 2019 (Fig. 3.3, Table 3.1).

The geosites in the inventory are organized geographically in two main clusters: the sedimentary features and inverted relief in the north (22 sites), and the lava flow of *Puy de Grave Noire* in the south (26 sites). The local geosites of the *Grave Noire* lava flow can be considered as distinctive representations of the national geosite ‘AUV0088’ as they represent individual outcrops of this collective feature (Fig. 3.3).

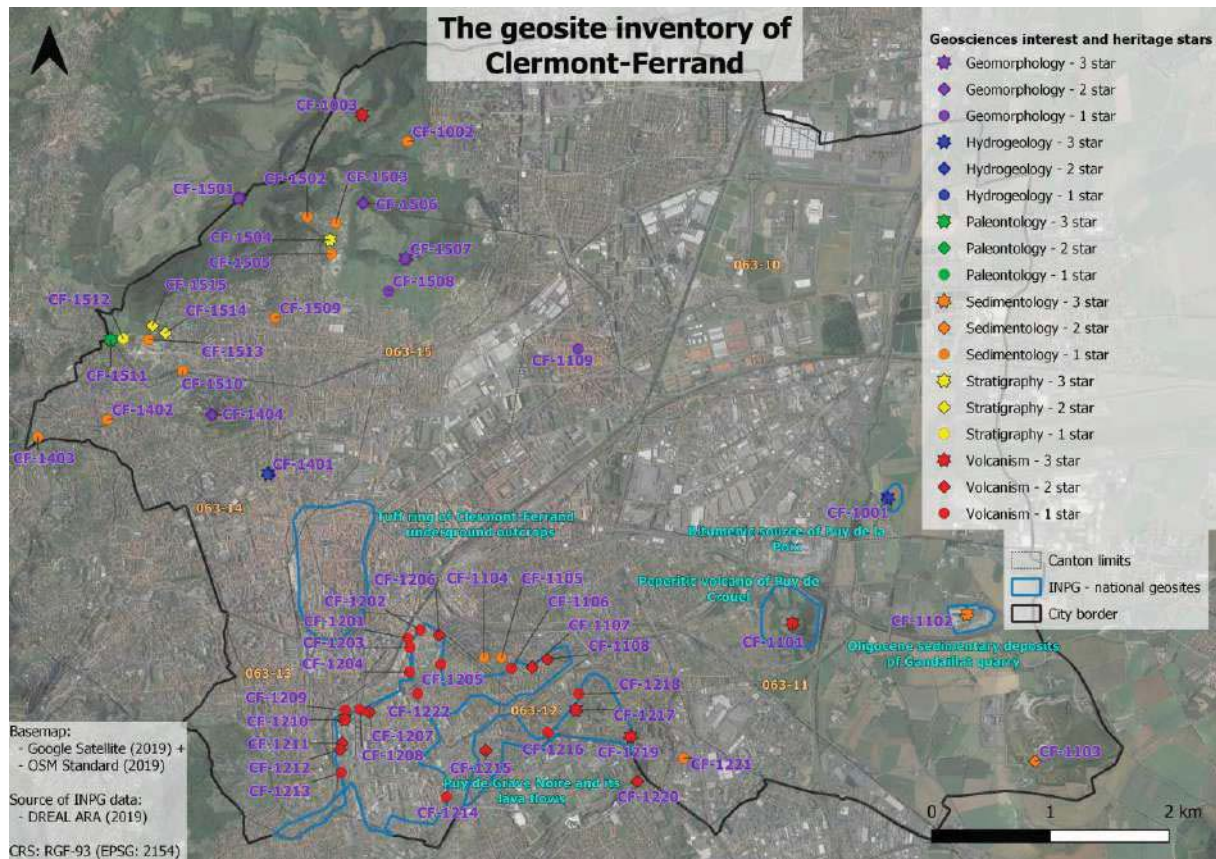


Fig. 3.3 Geographical distribution of geosites and geodiversity sites in Clermont-Ferrand according to the local inventory

Individual, isolated sites include the Petrified Source of *Saint-Ahyre* (CF-1401), the outcrop of the sedimentary infill of *Maar de la Gantière* (CF1221), and the national level geosites of *Puy de Crouël* (CF1101 in the *Clermont-Ferrand* inventory, AUV0093 in the national inventory), *Puy de la Poix* (CF1001 – AUV0094) and the quarry of *Gandaillat* (CF1102 – AUV0097). These latter sites have not been divided into smaller units according to their microforms, because they have limited spatial extent. Most of the other geosites are small outcrops compared to the city scale, therefore they have been recorded as point type features as well. Some sites that should also be considered as geomorphosites (REYNARD ET AL. 2009) have been marked as points according to the database structure of INPG, although they cover larger areas that could be specified in additional maps and

included as annexes to the inventory, like the plateau of *Puy de Var* (CF1003) or the park of *Montjuzet* (CF1404).

The results of the quantitative evaluation are summarized in *Figures 3.4* and *3.5* according to the two main criteria of INPG: I) the *geoheritage interest*, and II) *protection and vulnerability*, respectively. Indicators are visualized by the scores of each individual criterion, permitting a detailed analysis of each indicator, as well as their total score.

Fig. 3.4A shows that geoheritage interest values cover a wide range, and that every site has reached a minimum total score of 10 points or 1 geoheritage interest star (cf. DE WEVER ET AL. 2015). This confirms that all of the selected sites have a certain level of geoheritage value, therefore, their inclusion in a geoheritage inventory is justifiable.

Several studies on the inventorying and assessment of geosites (e.g., REYNARD ET AL. 2016, BRILHA, 2016) recommend that only sites of exceptional or high value (especially from a scientific perspective), selected from an initial list of potential geosites should be considered as geosites and included in a final inventory. Sites in the present inventory with a low total score and low scientific value might be viewed as sites not fulfilling this geosite requirement (e.g., CF1105, CF1208). However, the urban context significantly raises the vulnerability of sites, and those sites that are not listed in an official inventory would be more likely to undergo destruction or irreversible modification. Even sites of limited scientific importance, such as minor outcrops or small landforms can have important additional values (e.g., recreation spots for locals or habitat for flora and fauna). Taken together, they have a greater cumulative importance, combining to create a geodiversity background worthy of protection.

In order to ensure the inclusion of every surviving geological outcrop, geomorphological landform and other important geoscience elements in the inventory, but also acknowledging the necessity to rank the sites especially for their scientific value, we combined the INPG method with the terminology of BRILHA (2016). The latter distinguishes between ‘geosites’, which are sites with high scientific relevance, and ‘geodiversity sites’, which are sites with low to moderate scientific significance but high additional value (e.g., for supporting biodiversity). The *Geoheritage Interest Rating* scale of 0–3 (stars) has then been used to classify sites into geosites and geodiversity sites in the following way (*Fig. 3.4A*):

- 0–1 star or 0–20 points: geodiversity sites, 28 sites out of a total of 53.
- 2 stars or 21–30 points: classification into the geosite or geodiversity site category was carried out with a second, subjective consideration of scores for each indicator by experts.

This is based on their knowledge of the values of the site that could complement the

objective pointing system. In all, 13 out of 53 sites were classified by the experts' validation in the following manner:

- Geosites (later referenced as confirmed geosites, together with the 3 star sites): CF1108, CF1207, CF1211, CF1212, CF1220, CF1404
- Geodiversity sites: CF1103, CF1107, CF1206, CF1215, CF1506, CF1514, CF1515
- 3 stars or 31–48 points: geosites, 12 out of 53 sites

Since the *Primary Geological Interest (PGI)* has the highest weighting coefficient (4), all sites with the maximum value (3) have been effectively classified as geosites (Fig. 3.4B). All sites that scored the highest value (3) for *Secondary Geological Interest (SGI)* and *Rarity* also fell into the category of geosites, while sites with *PGI*, *SGI* or *Rarity* values of 1 fell into the category of sites to be validated by experts as geosites or geodiversity sites (those with *PGI* values >2 ended up as geosites). Therefore, the sites of highest scientific importance are all confirmed as geosites.

Preservation status strongly correlates with the *heritage star* ranking (Fig. 3.4B). The group of 3-star sites or confirmed geosites only includes one site with slight preservation problems (CF1511 – 185 rue Nohanent: stromatolites) and only 4 out of the 13 sites in the 2-star category received 1 or 0 point for preservation. In contrast, for the geodiversity sites or 1-star sites, only 3 out of 28 received good preservation status scores (2). Not only has preservation affected the geoheritage ranking of these sites, but also the scores of specific individual indicators. The lack of preservation induced limited *Educational Interest* (27 of 28 sites receiving 1 point or less) and even their *Primary Geological Interest* and *Rarity* was generally lower; only 10 sites out of 28 received a value of 2.

However, it must be noted that increased preservation efforts would probably not cause a rise in *Primary Geological Interest* or *Rarity* values. Apart from where cleaning up vegetated sections or excavation would bring to light new parts with a higher geoheritage interest, rarity and geological interest rates will remain unchanged even with increased preservation status.

The score for *Educational (or pedagogical) Interest* has been calculated by combining several considerations into one value in the quantitative evaluation, but it can be explained in detail in the textual fields of the INPG sheets (Fig. 3.4B). Each site could present a coherent story for geology and geography students in higher education, but geosites that are the best examples of a given phenomenon have been given higher scores than, for example, a 'standard' outcrop of *Grave Noire* lava flow or Oligocene sediments. The criteria of *Accessibility* and *Preservation* status of the site are considered separately during the evaluation process, but they affect the *Educational Interest* values as well: sites located in private areas, or that are highly eroded and/or vegetated receive lower scores for *Educational Interest*.

III/C Results

Table 3.1 The list of current geosites in the geoheritage inventory of Clermont-Ferrand.
GS / GDS means a site that was classified as geosite (GS) or geodiversity site (GDS) on the basis of expert decision (final decision in parenthesis)

GEOSITE ID	NAME OF GEO(DIVERSITY) SITE	GEOHERITAGE INTEREST SCORE	NUMBER OF GEOHERITAGE INTEREST STARS	VULNERABILITY AND NEED FOR PROTECTION	STATUS BY GEOHERITAGE STARS	PRIMARY GEOLOGICAL INTEREST
CF-1001	Puy de la Poix - bitumen spring	37	3	8	geosite	hydrogeology
CF-1002	R. Cheval - Oligocene sediments	20	1	8	geodiversity site	sedimentology
CF-1003	Puy de Var - inverted relief	37	3	8	geosite	volcanism
CF-1101	Puy de Crouel - peperitic volcanic neck	46	3	6	geosite	volcanism
CF-1102	Quarry of Gandallat - Oligocene sediments	40	3	8	geosite	sedimentology
CF-1103	Puy Longue - Anthropogenic garbage deposit	23	2	10	GS / GDS (GDS)	sedimentology
CF-1104	R. Oradou 62 - Oligocene sediments	18	1	7	geodiversity site	sedimentology
CF-1105	R. Oradou 98 - Oligocene sediments	14	1	7	geodiversity site	sedimentology
CF-1106	R. Oradou 98 - Grave Noire lava flow	14	1	7	geodiversity site	volcanism
CF-1107	R. Oradou 118 - Grave Noire lava flow	21	2	11	GS / GDS (GDS)	volcanism
CF-1108	R. Oradou 128 - Grave Noire lava flow	26	2	9	GS / GDS (GS)	volcanism
CF-1109	Montferrand – marls mount	17	1	8	geodiversity site	geomorphology
CF-1201	R. Pont-de-Naud 21 - Grave Noire lava flow	14	1	5	geodiversity site	volcanism
CF-1202	R. Marivaux 9 - Grave Noire lava flow	20	1	6	geodiversity site	volcanism
CF-1203	R. Docteur Chibret 2 - Grave Noire lava flow	16	1	6	geodiversity site	volcanism
CF-1204	Av. Léon Blum 65- Grave Noire lava flow	11	1	6	geodiversity site	volcanism
CF-1205	R. Neuf Soleils 38- Grave Noire lava flow	18	1	6	geodiversity site	volcanism
CF-1206	Résidence Cheops 2 - Grave Noire lava flow	23	2	8	GS / GDS (GDS)	volcanism
CF-1207	R. Henry Andraud 21 - Grave Noire lava flow	30	2	9	GS / GDS (GS)	volcanism
CF-1208	Pilon of the viaduct of Saint-Jacques - Grave Noire lava flow	11	1	6	geodiversity site	volcanism
CF-1209	R. Pont Saint Jacques 62 - Grave Noire lava flow	11	1	4	geodiversity site	volcanism
CF-1210	R. Desdesvies du Dèzert 20 - Grave Noire lava flow + spring	34	3	10	geosite	volcanism
CF-1211	Cité Universitaire Dolet - Grave Noire lava flow	28	2	9	GS / GDS (GS)	volcanism
CF-1212	Imp.Dr. Cohendy - Grave Noire lava flow	25	2	10	GS / GDS (GS)	volcanism
CF-1213	R. Étienne Dolet 60 - Grave Noire lava flow	14	1	8	geodiversity site	volcanism

CF-1214	R. Roty 35 - Grave Noire lava flow	14	1	8	geodiversity site	volcanism
CF-1215	Al. Rocailles 2 - Grave Noire lava flow	26	2	8	GS / GDS (GDS)	volcanism
CF-1216	Av. Landais 8 - Grave Noire lava flow	20	1	8	geodiversity site	volcanism
CF-1217	Creux de l'enfer - Grave Noire lava flow	41	3	8	geosite	volcanism
CF-1218	R. Louis Dabert 20-24 - Grave Noire lava flow	14	1	8	geodiversity site	volcanism
CF-1219	Saint-Astrimoine - Grave Noire lava flow	33	3	12	geosite	volcanism
CF-1220	Margerite tram stop - Grave Noire lava flow	31	2	9	GS / GDS (GS)	volcanism
CF-1221	R. Étienne et George Sauvestre - Alluvial infill of Maar de Gantière	16	1	8	geodiversity site	sedimentology
CF-1222	Av. Léon Blum 76 - Grave Noire lava flow	14	1	7	geodiversity site	volcanism
CF-1401	Saint-Alyre - travertine spring	44	3	7	geosite	hydrogeology
CF-1402	R. Durtol 85 - Oligocene sediments	16	1	7	geodiversity site	sedimentology
CF-1403	R. Farnettes 31 - Oligocene sediments	16	1	8	geodiversity site	sedimentology
CF-1404	Montjuzet - Oligocene sedimentary residual	27	2	8	GS / GDS (GS)	geomorphology
CF-1501	Plateau of Côtes de Clermont inverted relief	37	3	8	geosite	geomorphology
CF-1502	Ch. Mouchette 40 - Oligocene sediments	20	1	8	geodiversity site	sedimentology
CF-1503	Al. Écureuils 1 - Oligocene sediments	16	1	9	geodiversity site	sedimentology
CF-1504	R. Blanzat 245 - tephra and paleosol	40	3	10	geosite	stratigraphy
CF-1505	R. Blanzat 237 - Oligocene sediments	20	1	9	geodiversity site	sedimentology
CF-1506	Puy de Chanturgue - Miocene lava flow quarry	24	2	8	GS / GDS (GDS)	geomorphology
CF-1507	Puy de Chanturgue - landslides	32	3	8	geosite	geomorphology
CF-1508	Puy de Chanturgue - gullies with sedimentary flank outcrops	16	1	6	geodiversity site	geomorphology
CF-1509	R. Puyou 7 - Oligocene sediments	16	1	8	geodiversity site	sedimentology
CF-1510	R. Bouys 43 - Oligocene sediments	14	1	7	geodiversity site	sedimentology
CF-1511	R. Nohant 184 - stromatolites	35	3	10	geosite	paleontology
CF-1512	R. Victor Charretton 18 – Oligocene sediments	16	1	9	geodiversity site	stratigraphy
CF-1513	Rue V. Charretton x - Oligocene sediments	20	1	8	geodiversity site	sedimentology
CF-1514	Rue V. Charretton y - Oligocene sediments	23	2	9	GS / GDS (GDS)	stratigraphy
CF-1515	R. de Trémonteix - Oligocene sediments	27	2	8	GS / GDS (GDS)	stratigraphy

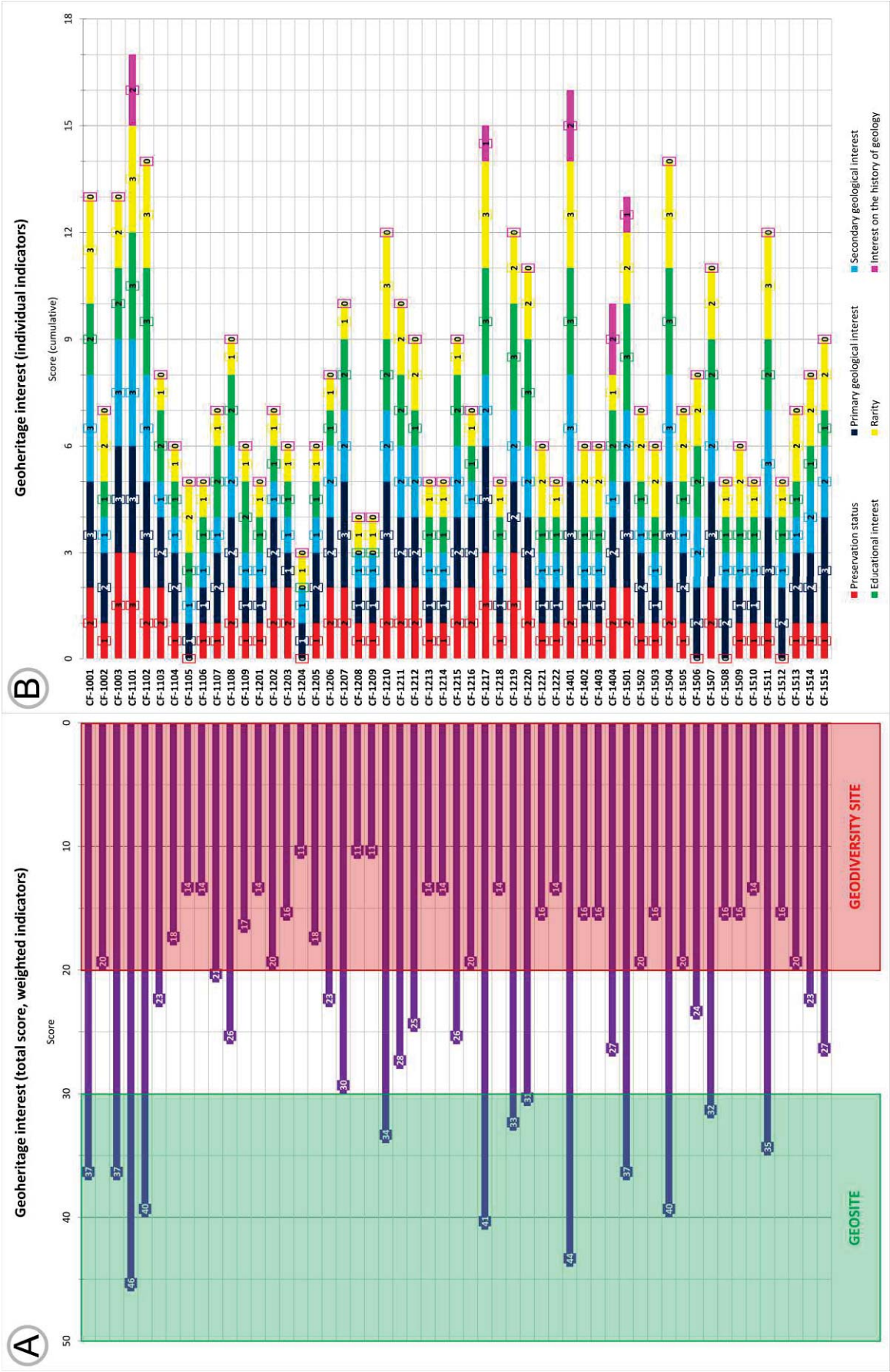


Fig. 3.4 Quantitative assessment of Geoheritage Interest of the local geosites and geodiversity sites of Clermont-Ferrand with INPG

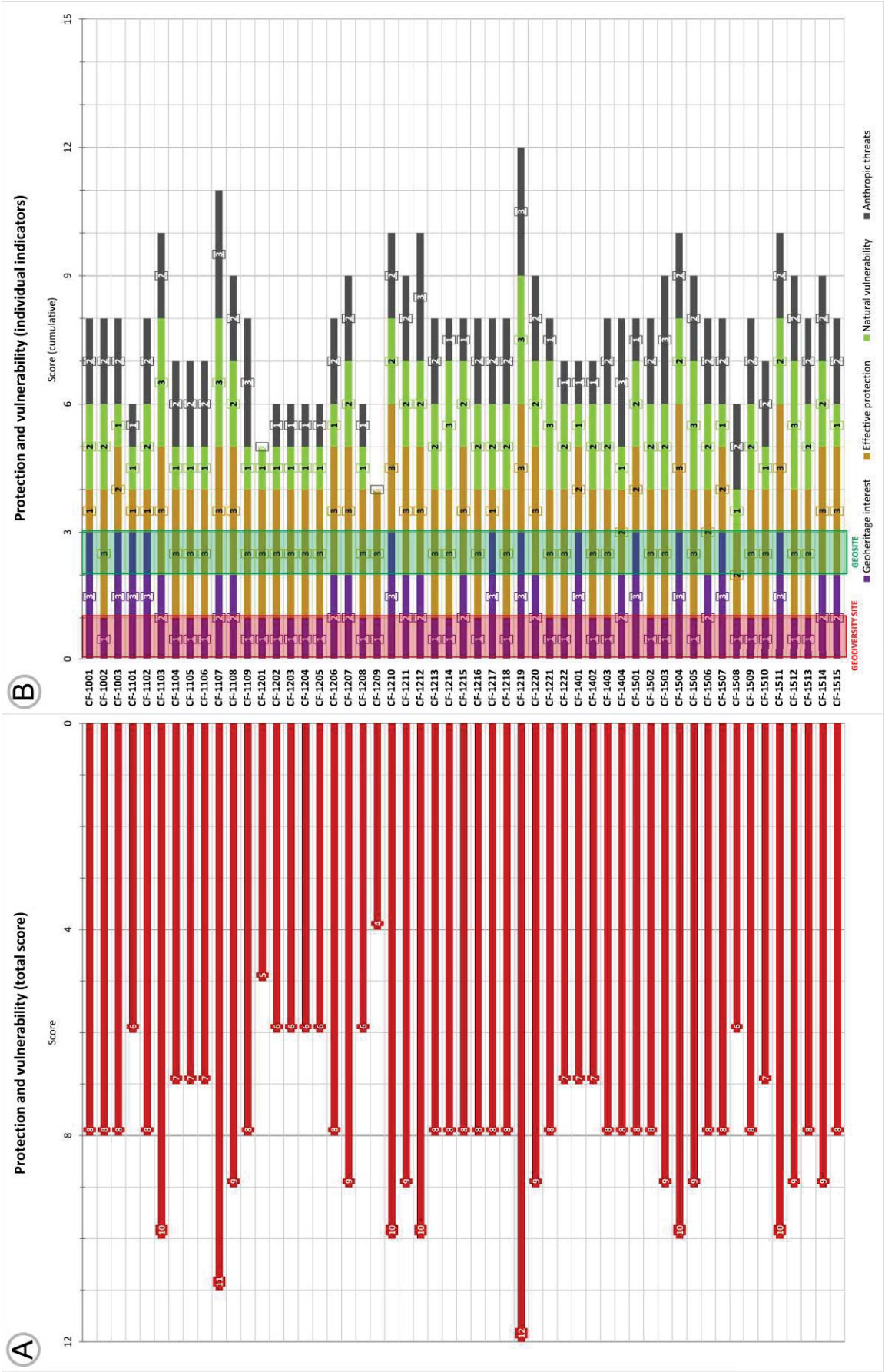


Fig. 3.5 Quantitative assessment of Vulnerability and Protection of the local geosites and geodiversity sites of Clermont-Ferrand with INPG

In the *Geoheritage Interest* ranking of the city inventory, sites included in the national geosite inventory (INPG), namely *Puy de la Poix* (CF1001 in the local, AUV0094 in the national inventory), *Puy de Cronël* (CF1101 – AUV0093) and the quarry of *Gandaillat* (CF1102 – AUV0097), all gained high scores and have been categorized as 3-star geosites. This clearly demonstrates that the most important elements of the geodiversity of *Clermont-Ferrand* have already been recognised on a national level.

As noted before, the national geosite of *Puy Grave Noire* and its lava flows (AUV0088) has been divided into 24 local sites located in the southwest part of the city. Three of these sites were categorized into the highest, 3-star group: the outcrops of *Saint-Astrimoine* (CF1219), *Rue Desdevises du Dèzert 20* (CF1210) and the geomorphosite of *Creux de l'Enfer* (CF1217). Together with some quality outcrops of lesser-ranked sites, such as the tramway stop of *Margeride* (CF1220) or *Rue Henry Arnaud 21* (CF1207), they offer the best representations of the overall, holistic site; therefore, their references should be included in the national inventory as well.

The highest-ranking category of the inventory also includes other key sites and elements of the geodiversity of *Clermont-Ferrand* (and the broader context of the *Limagne Plain* and *Limagne Fault*) that are under-represented in the national inventory. Inverted relief of the Mio-Pliocene volcanism of the *Auvergne* is only represented so far in the INPG by the Plateau of *Gérgovie* (AUV0026). We suggest that the plateaus of *Côtes de Clermont* (CF1501) and *Puy de Var* (CF1003) are equally valuable representations of relief inversion, and their inclusion in a national level inventory should be considered. This is supported by their outstanding geoheritage interest in our local inventory. The Petrified Source of *Saint-Alyre* (CF1401) also represents an important element: the Quaternary travertine deposits of the *Limagne*, a feature that is currently not represented on the national list.

The *Vulnerability and need for protection* values are moderate to high, underlining the fragility of geological outcrops and geomorphological landforms in an urban context (Fig. 3.5). However, *Geoheritage Interest* directly affects the *Vulnerability and need for protection* total score, because the number of heritage stars is used as an input value (DE WEVER ET AL. 2015). Hence, the higher the *Geoheritage Interest* is, the higher the need for *Protection and vulnerability* total score will be. This emphasizes the need for independently assessing the level of *Effective Protection* for 2 or 3-star geoheritage sites, although even sites with low *Geoheritage Interest* (1-star) have moderate *Vulnerability and need for protection* scores, which indicates that action should be taken to guarantee their preservation.

Note that 42 of the 53 sites lack *Effective Protection* so far, either physically in the form of slope stabilization or regulatory in the form of a legislative framework. An example of such protection for biodiversity and archaeology is the protection of CF1505 (Plateau of *Côtes de Clermont*).

III/D Discussion – perspectives and proposals on geoconservation and geotourism

The inventory of geoheritage sites in *Clermont-Ferrand* illustrates that the city has a significant geoheritage, but that it is highly vulnerable due to the urban context, calling for dedicated geoconservation initiatives. The geosites have significant potential as a resource for citizens and visitors because they are natural spots and are hence important for maintaining and improving the city environment. They are also attractions for geotourism and education about geosciences, raising environmental awareness and improving resilience to natural hazards.

Here, we present some key considerations and future projects, some of which are already under discussion with local authorities, as the inventory is on the way to being integrated into the city planning process. This progress could be turned into a geodiversity action plan (DUNLOP ET AL. 2018) for the city of *Clermont-Ferrand*, which would be the first plan of this type dedicated to geoheritage management for a city in France. Such a plan is urgently needed, as the sites we have identified have undergone degradation and destruction even during the writing of this paper

III/D/1 Geoconservation

One of the principal reasons for compiling the present local-level geoheritage inventory in addition to the existing national one has been to give a powerful tool to the city municipality for the customized, site-specific management of urban geosites (PROSSER ET AL. 2018).

With the above evaluation of geoheritage aspects, geosites should also be examined for: I) biodiversity importance (e.g., habitat for flora and fauna elements), II) relevance to cultural heritage, by inviting experts to record the potential connotations of each site in that respect, and finally III) safety and conservation by engineers and landscape architects who can survey the sites to find creative ways to ensure safety, while preserving this heritage and integrate it in a sustainable way within the urban fabric.

III/D/1/a Slope stability

As the majority of geosites on the current list are outcrops with steep slopes or cliffs, stabilization is highly important for safety, especially in the vicinity of infrastructure such as roads or buildings.

The lithological context of the sites controls much of the conservation scenario. For example, the outcrops of the Oligocene marls, limestones and clays have gentle slopes that are often covered with colluvium or scree (*Fig. 3.6*). Depending on the local slope conditions, they can be relatively stable, however, potential landslides might occur following heavy rain when the mixture of permeable and impermeable layers tends to be mobilised (e.g., at CF1104 and CF1105, CF1502 to CF1505). They are often stabilized by natural and planted vegetation. Such growth may be effective

from an engineering viewpoint and desirable for preserving habitats, but it could greatly diminish the geoheritage values of the site by reducing the level of exposure. Therefore, each site should be considered individually to create a solution that allows a compromise to be found between the preservation of geoheritage and biodiversity.

The trachybasaltic lava outcrops of the *Grave Noire* lava flow are the most resistant to erosion, and can sustain steep slopes, even vertical or overhanging walls. In that case, natural fractures of the rock further opened up by the action of ice and roots, or undercutting created by quarrying or roadcuts can lead to rockfalls. Unstabilized rock surfaces can be hazardous, but stabilization attempts that do not consider the geological values could significantly modify or even eliminate the geoheritage value of a site (Fig. 3.7).



Fig. 3.6 Common conditions of an exposure of Oligocene sedimentary outcrops; example of CF1515 geosite at Rue de Trémonteix. Soil and colluvium top the small exposure, with a grassy talus

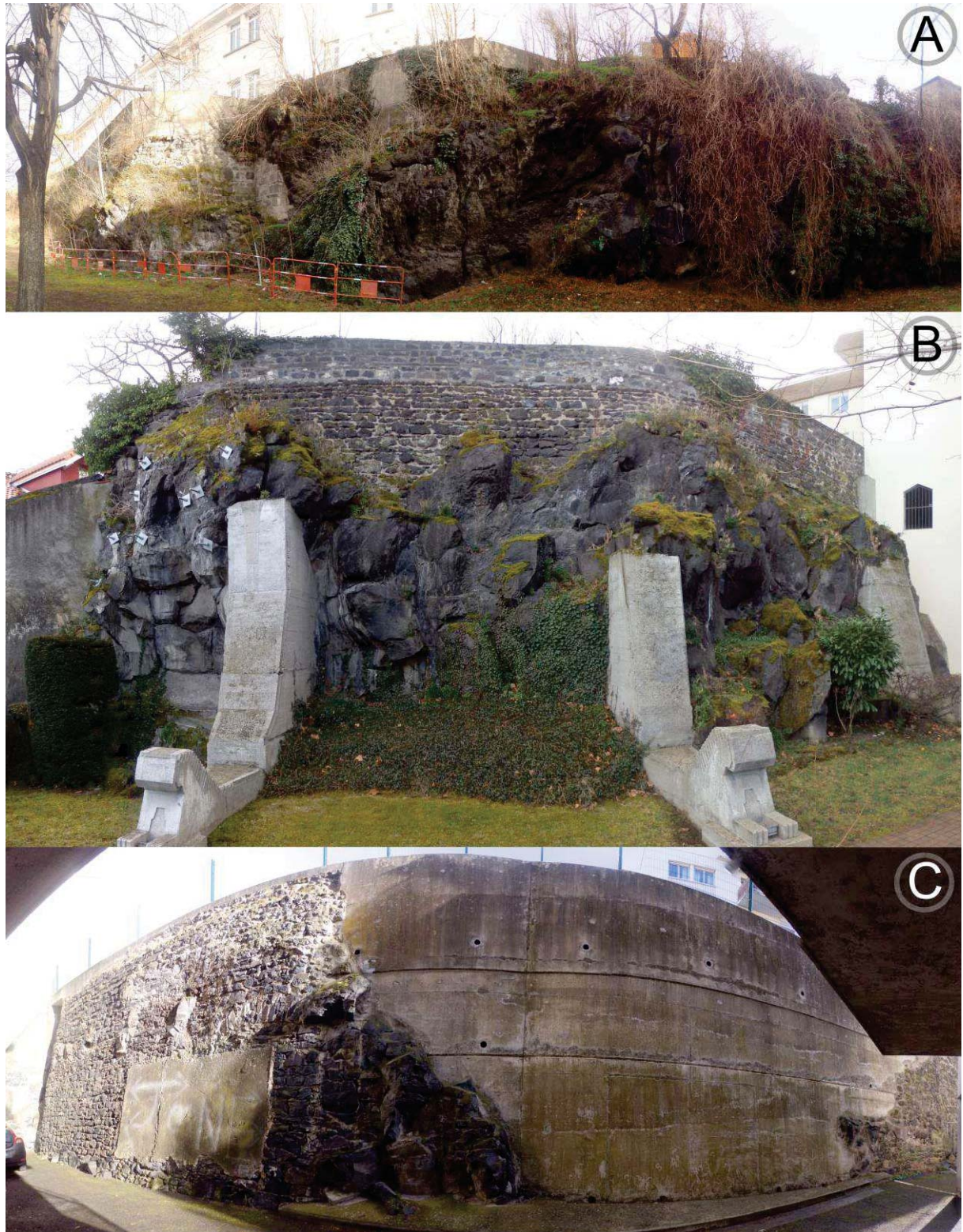


Fig. 3.7 Three examples of slope stabilization of outcrops of Grave Noire lava flow.

- A: a still unconsolidated site at Rue Henry Arnaud 21 – CF1207. The temporary fence suggests an acknowledgement of some hazard, the danger is that poorly thought out remediation may destroy the sites values;*
- B: a gentle and intelligent solution of stabilization that preserves geoheritage value at Résidence Cheops 2 – CF1206, and adds some architectural value;*
- C: a brutal solution that mostly destroyed geoheritage value at Rue Pont de Naud 21 – CF1201. Note the older more harmonious stone wall on the left side is a more reasonable way to stabilise the rock.*

III/D/1/b Ecological value of geosites

Geological outcrops and landforms as well as hydrological sites, besides their geoheritage interest, usually function as habitats for wildlife. The partial covering of sites by vegetation inevitably hides some geological elements, but it can also have a protective function (see above), and enhance the aesthetic value, while additionally aiding biodiversity. Natural cracks in lavas and loose material of some sedimentary rocks can house a significant insect population, while larger cavities such as natural caves in lavas or cellars in the tuff ring of *Clermont-Ferrand* are used by small mammals (e.g., bats) and birds. Biodiversity appears as an additional value in several inventories, but its detailed assessment in the present inventory should be carried out separately by appropriate experts.

III/D/1/c Subsurface geoheritage

This study has primarily focused on the surface elements of geodiversity, specifically outcrops, landforms and hydrological elements. However, the subsurface elements of *Clermont-Ferrand*'s geoheritage also have significant value. The main example of these are the so-called 'caves' or cellars of the *Butte de Clermont* that are already acknowledged on a national level as site 'AUV0092' of the INPG. A detailed, exhaustive, publicly available record or even a restricted-access inventory for local authorities of the exact location of the cavities is not yet available. A municipal non-exhaustive inventory connected to cadastral and architectural documentation exists, and the *Association of the Old Cellars of Clermont* (ACAVIC) has an extensive list of cellars with references to geoheritage values, in addition to the documentation of their dimensions and cultural references (archaeological evidence, history of construction, type of use). However, the latter inventory is not publicly available, due to privacy concerns. The centuries-old structure of the cellars and natural caves could be a potential hazard for the surface buildings without effective stabilization. They were often used as garbage dumps during the 20th century and especially after World War II (ACAVIC 2001), and quite a few remain unexplored. The inclusion of the privately-owned cellars and caves in an official inventory might press the authorities to carry out necessary stabilization work and take action to remove the garbage of the previous decades. Although these actions are desirable from a conservation viewpoint, the accompanying costs and the potential of regular future checks or taxation make many landowners prefer to conceal the existence of cavities under their properties (ACAVIC: personal comm.).

Taking into consideration the present situation and the significant geoheritage potential of the cavities, several measures should be taken in the short to mid-term:

- In order to visualize the distribution of the currently known cellars, while still respecting privacy, the data inventoried by ACAVIC and the municipality could be compiled in the form of a heatmap, following the example of NISIO ET AL. (2017) for *Rome*, Italy, where only the density of caves and cellars in certain areas is observable, and their exact coordinates are not shown.
- An action plan could be implemented by the municipality for the comprehensive management of cellars, in particular with respect to cellar stability and so on, but also allocating financial resources to help landowners carry out the necessary structural surveys and reinforcement work.
- A comprehensive inventory of cellars could be compiled using the data already compiled by ACAVIC and the municipality, and extending it to other areas with possible caves and cellars such as the *Montferrand* district, which is built on marls, and their geoheritage potential should be assessed,
- The cellars that show the most representative outcrops of the tuff ring and associated features, or are of historical importance (confirmed gallo-roman and medieval structures and exceptional archaeological findings), could be opened for tourists following well-known examples, such as the catacombs of *Paris* or the underground necropolises of *Cappadocia*. A public cellar might be turned into an underground visitor centre or a small museum, presenting this unique heritage of *Clermont-Ferrand*. Many bars have cellars beneath them, and the lower levels could be opened up to customers as features of geoheritage interest.

III/D/1/d Citizens in geoconservation

The issue of private property is also an issue for surface elements of geoheritage. Only those sites that are located in public areas or private ones that are directly visible from the streets have been inventoried in this first phase. There are several outcrops in private gardens (e.g., CF1202, see below) or in buildings (e.g., CF1210) that might have scientific significance, or at least have additional value, such as forming habitats for flora and fauna. Their management, such as adequate slope stabilization, could only be carried out effectively if they are inventoried and assessed from geoheritage, biodiversity and engineering viewpoints as well. We note that while they may be in private property, often the rock itself is the responsibility of the municipality, who could then interact with the inhabitants to develop a community-based action plan of such sites.

The inclusion of these sites in an inventory would only be possible with the broadest cooperation of citizens and the municipality, and can be done with a campaign to record privately

owned outcrops, sharing good management practices especially in terms of slope stabilization and the allocation of financial funds for the latter. A possible way of inventorying could be participatory mapping or crowdmapping (BROWN ET AL. 2017), where the owners themselves report the existence of an outcrop or interesting geomorphological landform in their properties and ask for help about their effective management, respecting the heritage values.

An example of the importance of raising the issue of geoheritage values of an outcrop in a private area is the CF1202 (*Impasse Dr. Cobendy*) geosite, previously owned by one of the authors of the present study, then sold to a neighbour (VEREB ET AL. 2018B). The steep walls of this *Grave Noire* lava flow outcrop have had sporadic block falls during the past 20 years. After a small, but significant rock fall in 2017, reported by the owner to the municipality, the latter confirmed that the safety of the cliff was their responsibility. Their agents first proposed massive concrete coverage to stabilise the cliff (as seen in *Fig. 3.7C*). With the inclusion of this site in the inventory, we have been able to draw the attention of local authorities and neighbours to the geoheritage and associated biodiversity values of the outcrop, leading to the original plan being abandoned. The council proposed a less-damaging stabilization technique of bolting and wire mesh, partially preserving the integrity of the site. One property owner made a special request for his part of the outcrop to be kept as it was (after removing loose blocks), therefore bare, unadulterated rock is still observable in some places. The part of the outcrop that is well stabilized and protected by vegetation was left untouched (*Fig. 3.8*).

This case study clearly demonstrates that the municipality agents still have little knowledge of the concept of geoheritage, and tend to apply ‘off the shelf’ methods for site security instead of considering the value of the site and looking for measures that can be adapted to the natural site itself. However, once discussion is opened between private owners and the authorities, and with pressure from local inhabitants, compromises and acceptable solutions can be found. The integration of the inventory into the city plans will help in creating awareness of the benefits that result from applying more inventive strategies to secure unstable slopes. But the role of individual citizens is vital as well.

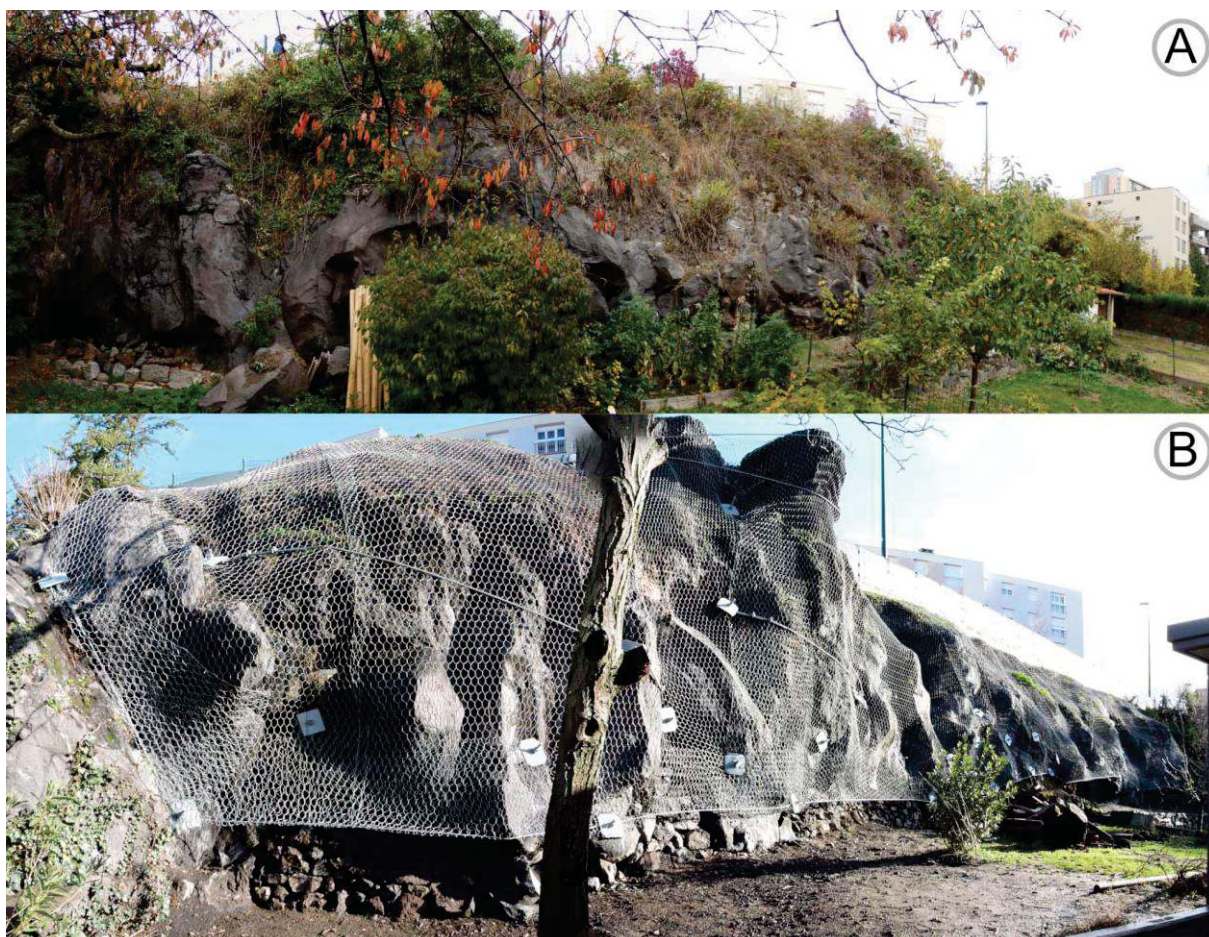


Fig. 3.8 The outcrop of Grave Noire lava flow at Impasse Dr. Cobendy (CF1212) A: before the stabilization, B: after the stabilization with bolting and mesh. While we still think that the meshing is an overreaction, it is a compromise between total destruction and the perceived hazard

Participatory mapping is not the only way to promote the active participation of city dwellers in geoconservation. A number of outcrops in private gardens are already well integrated into the microlandscape as they are used as elements of decoration, and some outcrops are even preserved within building walls. Recognition of these in the inventory can reward the owners and help them further value this geoheritage.

Local communities could help in the daily management of some public geosites as well, maintaining vegetation and regularly supervising the cleanliness of the sites, especially if they are used as recreational sites. The park of *Creux de l'Enfer* (geosite CF1217) would be a good site to develop this type of initiative.

Privately-owned geological outcrops or cavities could be ‘opened’ and showcased for visitors on dedicated days, following examples of cultural heritage such as the project ‘Budapest 100’, which is a yearly Hungarian civil urban initiative that gives people free access to 100-year-old buildings (BUDAPEST 100 2020). The ‘*journées du patrimoine*’ (heritage days) that take place one weekend a year in France is a similar event during which heritage sites with normally restricted access (mostly historical buildings) can be visited. The success of such initiatives promotes its growth every year,

and in 2019, the ACAVIC association organized a visit for members of the general public to selected caves of the *Butte de Clermont*.

The aesthetic value of specific geosites can also be amplified and used to drive local businesses. A good example of this is the CF1210 geosite (*Rue Desdevises du Dèzert 20*) that is located in the backyard of a 3-storey building constructed along the walls of an ancient quarry in the *Grave Noire* lava (*'carrière de Mourleval'*, GLANGEAUD 1901). The owners of the building, an architectural firm, adapted the former garage to provide a view of a spectacular ca. 10 m-high lava outcrop with a pond at its base fed by a natural spring, converting it into an attractive place that they use as an art gallery.

III/D/1/e *The interactions between culture and geoheritage, heritage stones*

Cultural connotations of the presently inventoried geosites should be examined in more detail as well, by local history experts. Examples are the strategic importance of positive landforms such as *Montferrand* raised platform, the Plateau of *Côtes de Clermont* with the oppidum (ancient Roman settlement) of *Augustonemetum*, the *Butte de Clermont* with the medieval constructions and ancient uses of the caves, and the *Creux de l'Enfer* ('Hell's Hollow') park, where there are legends and stories relating to the spiky reddish lava outcrops.

A future phase of the inventory and the geodiversity action plan of the city municipality could also deal with what represents a close connection between cultural and geological heritage, namely the heritage stones (BROCX & SEMENIUK 2019). The '*Base Mérimée*', the national architectural inventory of France, currently contains 123 sites for *Clermont-Ferrand* (POP 2019). An overwhelming number of them, 101 sites, use an iconic dark trachyandesitic, finely-vesiculated rock that was quarried from the neighbouring town of *Volvic*. It is planned to nominate this rock, locally known as '*Volvic stone*', to the Global Heritage Stone Resource. Volvic stone is used either as a construction material or an ornamental stone. Several buildings, such as the famous black cathedral of *Clermont-Ferrand* or many houses in *Montferrand*, are entirely constructed from this light-weight, and hence, malleable rock. The Basilica of *Notre Dame du Port*, which is part of the World Heritage Sites of the Routes of Santiago de Compostela in France (UNESCO 1998), also features local building materials, such as the arkose of the *Plateau des Dômes*. In addition, modern 20th century buildings, such as the '*Galleries de Jaude*' or the former hospital-sanatorium of *Sabourin*, use imported sedimentary stones that have not yet been described. Considering such potential, the historic areas of *Clermont* and *Montferrand* should be examined in detail from a heritage stone viewpoint and the most representative buildings could be included in geotours of the city.

III/D/2 Geoeducation

The *Chaîne des Puy-Limagne Fault* Tectonic Arena encompasses two world-renowned examples of geosciences education, the *Vulcania* theme and adventure park on volcanism, and *Lemptéguy*, a quarried-out volcano turned into a unique, open-air educational site. Both are situated only 15 km from *Clermont-Ferrand*. They are often frequented by local and national school groups, as are the exhibitions of the *Henri Lecoq* museum in the city that contain a variety of examples of ex-situ geoheritage in its geological department. However, the local geosites of the city, such as lava outcrops and nationally important sites like *Puy de Cronël* or *Puy de la Poix*, are generally overlooked by the public education system; geography students seldom visit them, and information about the geology of the city is not included in the curriculum.

As the city hosts a major university, which includes one of the largest European research institutes in volcanology and geoscience, some geosites such as the *Saint-Astrimoine* outcrop of the *Grave Noire* lava flow (CF1219) or the quarry of *Gandaillat* (CF1102) are regularly visited by university students. On the other hand, other sites were not well-known or described before the present inventory due to the existence of other representative examples, and the limited studies that exist on the specific geology of the city. The inventory will allow local outcrops to be more widely used for high-level education, with the city itself being viewed as a field site.

The general geological description of a geosite is a requirement for the INPG during the inventorying and assessment process. University courses could help add material to the sites and students could help with the monitoring as part of their training. A more detailed description of outcrops, paleontological examination of less known outcrops such as CF1002 at *Rue de Cheval* or small-scale research projects on the paleotopography of landforms, such as that of *Montferrand*, could easily be integrated into the inventory.

Twenty of the more than fifty geosites have received high or the highest scores in the evaluation of pedagogical interest (2–3 points). Not all of them are easily interpretable at the level of elementary or secondary education, but a collection of sites should be selected that could give an excellent tool for teachers to illustrate the basic phenomena of Earth processes at easily accessible examples: the sites are often only a short tram or bus ride away from schools. Such sites include the Quarry of *Gandaillat* (CF1102) for sedimentation and fossils, *Puy de Cronël* (CF1101) for Miocene volcanoes (offering a wide panorama for the Quaternary volcanism of the *Chaîne des Puy*s as well), Plateau of *Côtes du Clermont* (CF-1501) for geomorphological inversion and outcrops of the *Grave Noire* lava flow (e.g., CF1207, CF1219, CF1220) to illustrate effusive volcanism.

III/D/2/a Geoheritage for improving resilience

Geosites can be used to improve the resilience of people to natural hazards and improve environmental awareness as well. The lava flow outcrops of the *Grave Noire* lava flow through the city, and together with its clearly visible source, the *Puy de Grave Noire* scoria cone, provide a good illustration of the eruption of a small, monogenetic volcano, a hazard scenario that is still possible for *Clermont-Ferrand*. Tens of schools are built on the lavas or near to their front, and this can be used to raise awareness about the local geology and related volcanic hazards. Renewal of activity in the *Chaîne des Puys* is possible, and future eruptions could affect the city (LATUTRIE ET AL. 2015). The current position of the *Grave Noire* lava as a topographic high, while it originally filled a valley, also indicates the scale of changes to a landscape (driven by erosion) that can take place in ‘just’ 50,000 years. Inverted relief is a key element of the nearby UNESCO site’s story, and is also perfectly represented in *Clermont-Ferrand*.

The anthropogenic site of *Puy Longue* (CF1103) is the landfill site for *Clermont-Ferrand*, and could also be used for educational purposes. It has become an iconic, visible part of the city landscape, after only several decades of use, thus showing the large-scale environmental effects of human consumption and waste deposition. With dedicated tools of interpretation, such as guided tours for citizens to selected sites, information panels, thematic exhibitions, awareness about these issues could be raised.

III/D/3 Geotourism

Clermont-Ferrand is the tourist hub of the *Auvergne*, a region to which many visitors come for its beautiful landscape, which is strongly linked to its geoheritage values. The city is a gateway to the countryside, especially the *Chaîne des Puys*, a popular national destination since the 19th century that has gained increasing international recognition, especially since the 2018 World Heritage nomination. It is part of the Regional Natural Park of Auvergne Volcanoes as well, together with *Puy de Sancy*, a popular ski resort, and *Monts du Cantal*, both built on large, highly eroded stratovolcanoes. The iconic landscape of *Puy-en-Velay*, with its exhumed volcanic necks, is also often visited from a base at *Clermont-Ferrand*.

Several considerations that have been discussed above about geoconservation and geoeducation also apply to geotourism. The caves of the *Butte de Clermont* have a huge geotouristic potential for their high historical and cultural values, which could be developed through the creation of a visitor centre and organised tours on a more regular basis. Heritage stones could easily be integrated into cultural tourism, especially at the *Basilica of Notre Dame du Port* and the Cathedral of *Clermont-Ferrand*, which are World Heritage sites along the ‘Routes of Santiago de Compostela’.

Urban geoheritage can be promoted through geotours offering a dedicated tourist (and educational) package. Inspired by examples in *London* (ROBINSON 1982), *São Paulo* (DEL LAMA ET AL. 2015) and *Rome* (PICA ET AL. 2018), we propose four initial itineraries (Fig. 3.9) that provide an overview of the geodiversity of *Clermont-Ferrand* and could be included in the tourist strategy and promotion of the city.

- ‘The Grand Geotour of *Clermont-Ferrand*’ gives a complete overview of the geodiversity of the city, with the best examples of different geological-geomorphological phenomena. It is subdivided into two sections.
 - The Grand Geotour North section that starts at *Montferrand* and ends in *Clermont* historic centre gives an overview of sedimentary landforms (*Montferrand* and *Montjuzet*), inverted relief (Plateau of *Côtes de Clermont*), mass movements (*Puy de Chanturgue* landslide), Oligocene sedimentation in the Limagne basin (e.g., *Rue Nohanent 184*), travertines (*Saint-Alyre*) and heritage stones in central *Montferrand* and *Clermont*.
 - The Grand Geotour South section starts with ancient geological features in the *Limagne Plain*, such as the Oligocene sedimentary quarry of *Gandaillat*, the unique bitumen spring of *Puy de la Poix* and the exhumed Miocene volcanic neck of *Puy de Crouël*, before passing through several sites of Pleistocene effusive volcanism exemplified by the *Grave Noire* lava (e.g., *Rue Henri Arnaud 21*, *Creux de l’Enfer*) and ending up at sites of Quaternary explosive volcanism (*Maar de Clermont-Chamalières* and *Butte de Clermont*) that are shared with the northern section of the tour.
- ‘Go with the flow’ (fr: ‘*Suivre la coulée*’): as its name implies, it focuses on the ca. 60 ka *Grave Noire* lava that forms a plateau in the districts of *Cézeaux*, *Saint-Jacques* and others, and extends to the municipalities of *Beaumont* and *Aubière*. It contains almost all of the visible outcrops of this unit, ranging from the most representative larger sites (*Rue Desdevises du Désert 20*, *Creux de l’Enfer*, tramway stop of *Margeride*) to some with limited size and scientific value. Although some sites may appear similar and hence uninteresting to the general public, they all have distinct points of interest that could be conveyed through informative panels or guides. The entire circuit helps to raise awareness about the scale of this type of volcanic feature and its importance to the urban fabric.
- ‘Inversion Ideas’: this trail climbs the series of lava-capped plateaus in the northwest part of the city (*Puy de Var*, Plateau of *Côte du Clermont*, *Puy de Chanturgue*) that best exemplify the phenomena of inverted relief, as well as some selected sedimentary outcrops of the

Oligocene infill of the *Limagne* Basin (e.g., *Rue de Cheval*, *Chemin de Mouchette 40*) and the marls of *Montferrand*.

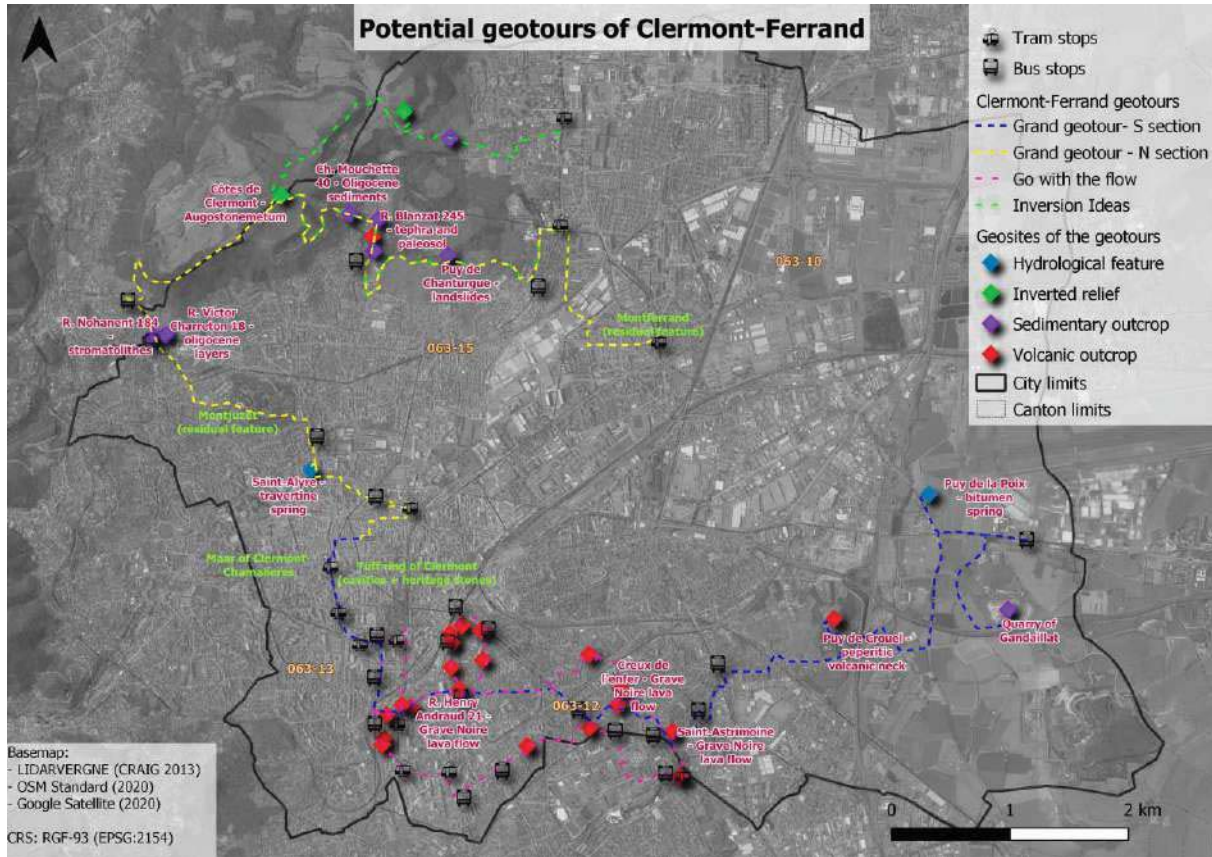


Fig. 3.9 The proposed geotouristic routes in Clermont-Ferrand with the names of the most important geosites along the tracks

Starting points are defined for all these geotours except for the circuit of ‘Go with the Flow’. However, the easy accessibility by public transport of almost any section of these routes (Fig. 3.9) means that they could be cut into multiple segments, or only selected sections could be visited by (geo)tourists. The southern section of the Grand Geotour is possible to do on foot or by bicycle while the northern section and the ‘Inversion Ideas’ are more easily done on foot due to the steeper topography. The ‘Go with the flow’ circuit is ideal for running, jogging or cycling, which could make this long loop more enjoyable.

So far, the only interpretation panels about geological importance are placed at *Puy de la Poix* and on the western edge of the Plateau of *Côtes de Clermont*. There are a few other sites with panels on biodiversity (*Montjuzet*, *Creux de l’Enfer*) and history (Plateau of *Côtes de Clermont* – oppidum of *Augustonemetum*). Permanent panels could be installed, especially at the sites with highest significance (3-star), but a viable alternative is the integration of these routes into a mobile application similar to the GeoGuide app that is available in *Lausanne* and *Rome* (PICA ET AL. 2018). These routes, or their edited forms, should also be published in the ‘*Balades Géologiques*’ series of the Geological Society of France (DE WEVER ET AL. 2015).

III/D/4 Territorial extension of the inventory

Previous work on urban geoheritage (e.g., DEL LAMA ET AL. 2015, PICA ET AL. 2016, ZWOLIŃSKI ET AL. 2017) concentrated on large cities with populations of several hundred thousand to several million, whereas this work addresses a smaller, provincial city (ca. 140,000 inhabitants). Urban geoheritage inventories and geodiversity action plans can be implemented in smaller urban centres (towns) as well as for rural areas (villages). Besides complementing the city's inventory, another objective in the future should be its geographical expansion, by incorporating the surrounding administrative units as well. Such inventories would be especially valuable in the case of *Clermont-Ferrand* for the villages that are located within the neighbouring World Heritage site.

Clermont-Ferrand is the centre of the *Clermont Auvergne Métropole* that includes neighbouring villages and towns such as *Royat*, *Aubière* and *Saint-Genès-Champanelle*, which are undergoing rapid growth and urban sprawl. The *Métropole* has already asked if this inventory can be expanded to cover the whole of the area under their administration. Some of these communities lie partially within the protected areas of the UNESCO World Heritage site of the *Chaîne des Puys – Limagne Fault* or within those of national designations such as the Regional Park of the Volcanoes of Auvergne. While the elements of geoheritage that are located within these protected areas should be effectively conserved, geodiversity often overlaps into adjacent urbanized areas, where it is threatened with destruction. Conversely, urban growth can sprawl into the UNESCO site, through the villages that lie in the buffer zones, or even within the site, and these areas are in need of dedicated geoheritage inventories to deal with this. Geosites have already been destroyed or damaged in the UNESCO territory, though a lack of such an inventory (PETRONIS ET AL. 2019, VAN WYK DE VRIES ET AL. 2019).

A good example of shared geoheritage around the borders of *Clermont* is the scoria cone of *Puy de Grave Noire* and its lava. The cone itself and the proximal part of the lavas are located at the very edge of the core zone of the World Heritage site, but most of its lavas are located within the city limits. Therefore, some of the most representative outcrops are located in the dense urban areas and they are highly vulnerable. Actual preservation of these geosites should be based primarily on the geoheritage management strategy of the corresponding municipality, but there should also be an effort to synchronize geoconservation efforts with all adjacent municipalities and with the authorities in charge of protecting the designated natural areas as well, such as representatives of the World Heritage site.

III/E Conclusions

In this paper, we presented the geosite inventory of the city of *Clermont-Ferrand* starting with the concept and methodology involved in the compilation process, moving to the discussion of future steps and applications, underlining the impact of the urban context on geoconservation.

We described the first, most important phase of the inventorying, which consists of recording the surface elements and associated phenomena, specifically geological outcrops and geomorphological landforms. In the future, a second phase may consist of inventorying the cellars dug into the tuff ring under the city centre (and possibly other cellars throughout the city), after clarifying the legal and privacy issues of these properties. A third phase could use community mapping, where each property owner could report a potentially valuable geosite in their private property (e.g., outcrop in the garden), asking for help with sustainable geoconservation (e.g., stabilization of slopes with less destructive and less invasive solutions) from the city authorities. Finally, a fourth phase might include the detailed inventorying of heritage stones, requiring close coordination with cultural heritage experts and possibly a different database and assessment format.

The principal role of urban geoheritage inventories is to record those elements of geodiversity that form islands in urbanized areas. This context calls for a different approach. Thus, sites in natural areas that are considered insignificant can acquire value in the urban context, as they represent the few remaining exposures of a geological feature, a habitat for wildlife or an organic element of the cityscape. We have shown that the sites can be rated, based on their scientific value, and this can be used as a tool to prioritize their management. However, this does not mean that sites with lower scientific value should be excluded from an urban inventory. Importantly, we found that, at least in *Clermont-Ferrand*, a site that is included in an official register is less likely to be significantly modified or destroyed, as demonstrated by the example of *Impasse Dr. Cobendy* (CF1212) *Grave Noire* lava flow outcrop.

This inventory, restricted to the boundaries of *Clermont-Ferrand*, has been compiled with the intention of providing input for the municipality towards a dedicated geoconservation strategy, including the creation of a geodiversity management plan (DUNLOP ET AL. 2018), a pioneering initiative yet to be used in France. We presented some key considerations that could be included in such an action plan or in the management strategy of the municipality. Important considerations that should be tackled not just in the present inventory, but in future initiatives in other areas are:

- ensuring the stabilization of slopes with a holistic approach including geodiversity, biodiversity and engineering aspects,
- assessing limiting factors and future potential of geosites in private areas, and
- exploring geoeducation and geotourism perspectives.

Given the continuing trend of massive urbanization globally, more and more geodiversity elements will be incorporated into an urban context, and hence, excluded from direct or indirect forms of protection such as rural geoparks, World Heritage sites or national parks. As a result, the creation of urban geoparks such as the Hong Kong UNESCO Global Geopark should be encouraged.

As a concluding remark, urban geoheritage inventories and action plans have the potential to raise the awareness of authorities on the conservation of geodiversity elements, and are opportunities to involve citizens in the appreciation of geological features as integral parts of natural heritage.

IV GEOHERITAGE AND RESILIENCE OF DALLOL AND THE NORTHERN DANAKIL DEPRESSION IN ETHIOPIA¹

IV/A Introduction

Geologically active areas, such as volcanic domains, are often powerful tourist attractions (ERFURT-COOPER 2011). When assessing such sites for geoheritage and geotourism, natural risks should be carefully considered. The 2019 tourist disaster at *White Island*, New Zealand, emphasises that volcanoes and hydrothermal systems should only be visited with extreme caution, with a high degree of advanced planning.

In this paper, we take a holistic approach to geoheritage and geohazard resilience at *Dallol*, Ethiopia. In a three-step study, we start by identifying and monitoring hazards, then move on to inventorying and assessment of geosites, and finally bring both together to outline a preliminary management plan for the area, taking into account resilience to geohazards and the global importance of the geoheritage.

In the first part on monitoring, we present the geothermal activity at *Dallol* and the adjacent *Black Mountain*, where geoheritage features change frequently. A simple workflow of satellite image interpretation gives an overview of monthly activity patterns, from which a series of hazard maps have been made and published, which could be used to improve the resilience of visitors to the area by providing more up-to-date information and increased awareness of risks.

Following this, we present the first preliminary geosite assessment of northern *Danakil* using three distinct methods, VUJIĆIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016), in order to assess their scientific importance in a quantitative manner and also to measure their touristic potential numerically. Comparison of the methods provided a broad summary of the diverse and varied considerations of geoheritage from three different viewpoints, based on numerous criteria.

Finally, combining the monitoring results and the geoheritage assessment, we propose a preliminary geoheritage management plan as a template that could be adopted and modified by local actors, to protect the site, protect the visitors and promote sustainable development of the area.

¹This chapter has been published as VEREB V., VAN WYK DE VRIES B., HAGOS M., KARÁTSÓN D. (2020) Geoheritage and Resilience of Dallol and the Northern Danakil Depression in Ethiopia. *Geoheritage* 12(82): 1-34. doi: 10.1007/s12371-020-00499-8. The chapter is identical to the paper, therefore it includes the original satellite image interpretation dataset, up to Oct. 2019. The Appendix (summary of methods) can be consulted in *chapter I/C*

IV/A/1 The Global and Ethiopian Context of Geoheritage and Geohazards Resilience

Geoheritage and geoconservation is a multi-disciplinary approach and a new domain in geosciences, which has been evolving constantly, predominantly over the last three decades, but with early initiatives traceable back to the nineteenth century (BROCX & SEMENYUK 2007; BUREK & PROSSER 2008; REYNARD & BRILHA 2018). International recognition was widely fostered by the formation of the geoparks movement (ZOUROS 2004; JONES 2008; UNESCO-IGGP 2015), and the recognition of abiotic elements in nature protection by the International Union for Conservation of Nature (DUDLEY 2008). However, the domain is still lagging behind biodiversity and cultural heritage management, as noted by BRILHA (2018A), and the terms used in geoheritage are scarcely mentioned in key documents of the United Nations and their associated organisations and programmes.

Resilience is the ability of a system, community or society that is exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions (UNISDR 2009). The role of geoheritage in the improvement of resilience through inclusion into risk management and raising awareness through educational activities was addressed by the ‘Shimbara Declaration’ (GGN 2012) and is the subject of several papers (such as GIARDINO ET AL. 2014; NAKADA 2018; GIZZI ET AL. 2019).

Areas of outstanding geoheritage are often exposed to natural hazards, and can be highly vulnerable both through their intrinsic values and through visitors to the area. Human activities such as tourism or exploitation of resources (even in a sustainable manner) are also a hazard to geoheritage areas. The significant potential of risks, through the multiplied factors of hazard and vulnerability (SCAINI ET AL. 2014), call for the integration of risk management into geoconservation strategies.

In Africa, some issues of geodiversity have been covered for key sites of geosciences and for the potential role of geotourism under sustainable development and ecotourism (e.g. SCHNEIDER & SCHNEIDER 2005; CUMBE 2007; ASRAT ET AL. 2012; ERRAMI ET AL. 2013; NGWIRA 2015; THOMAS & ASRAT 2018). Nonetheless, examples of dedicated geoconservation practices in terms of legislation or other effective forms are still limited. As of 2020, only two UNESCO Global Geoparks (UGGp) exist in the continent, the *Ngorongoro Lengai UGGp* in Tanzania and the *M’Goun UGGp* in Morocco (GGN 2020). In terms of natural World Heritage sites, only nine sites are inscribed under criterion (viii) related to Earth’s history and physiographic landforms. A further 25 are inscribed under criterion (vii) of ‘superlative natural phenomena or areas of exceptional natural

beauty and aesthetic importance’, some of them containing sites of geoheritage relevance (WDPA 2020).

Ethiopia has one of the highest numbers of World Heritage Sites in Africa, with nine examples (Fig. 4.1). None of them is directly inscribed under criterion (viii), but *Simien National Park* was partially enlisted for its natural beauty under criterion (vii) (MAUERHOFER ET AL. 2017). Several cultural designations also have an associated geoheritage importance such as the paleontological values for hominids of the *Lower Valley of Awash and the Lower Valley of Omo*, or the heritage stone significance of the Rock-hewn churches of *Lalibela* or *Aksum* (RENZULLI ET AL. 2011; HAGOS ET AL. 2017; MEGERSSA ET AL. 2019). An overview of Ethiopian geodiversity has been given by WILLIAMS (2016) and ASRAT (2018), but no national level geoconservation project or geosite inventorying project has been implemented as yet. So far, the geomorphosite inventory of the *Simien Mountains* (MAUERHOFER ET AL. 2017), the geosite inventory of the *Butajira Volcanic Field* (MEGERSSA ET AL. 2019) and the geo-trekking guide of *Dogu’a Tembien* (NYSEN ET AL. 2019) are the sole examples of dedicated and detailed geoheritage assessment processes in Ethiopia.

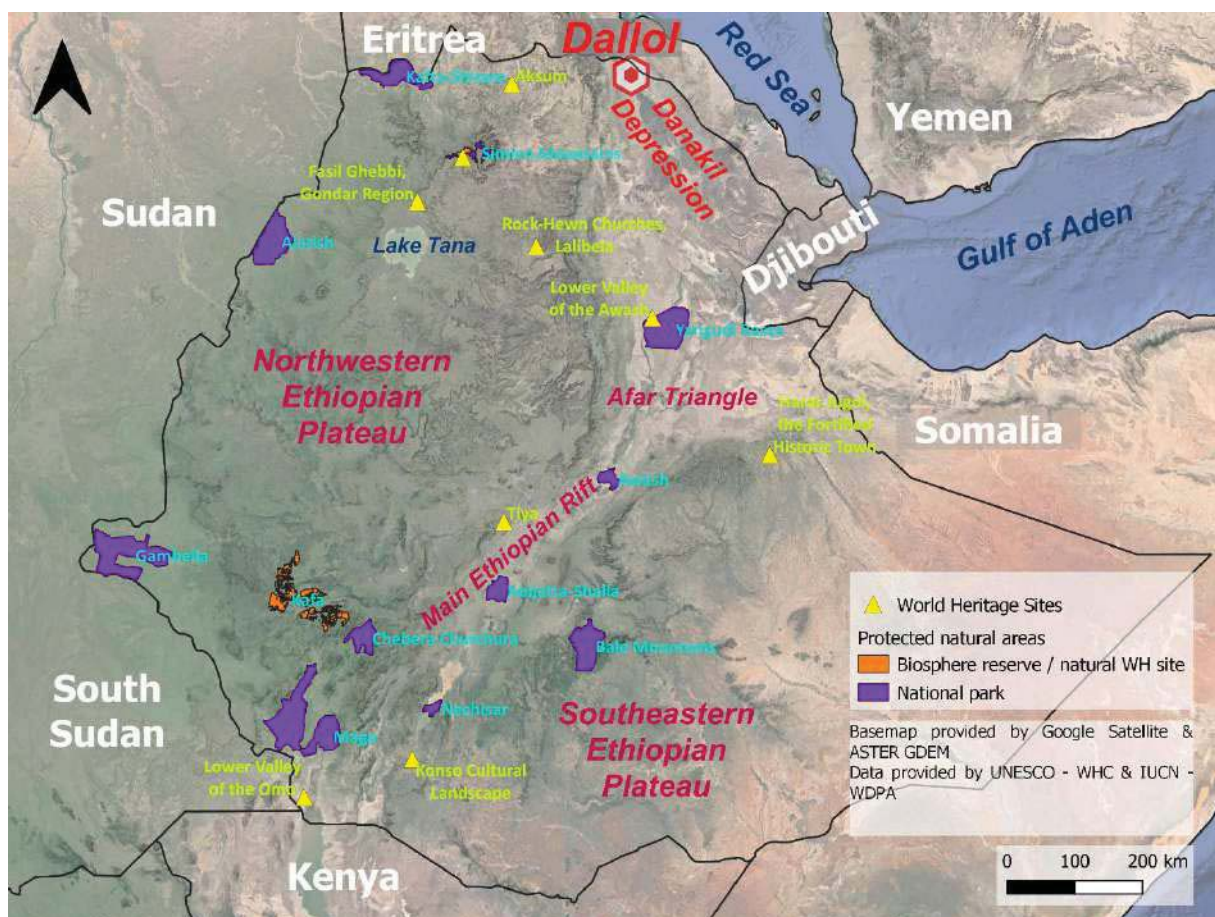


Fig. 4.1 The Ethiopian Protected Area System of national parks and World Heritage sites (Source: WHC, WDPA (2020). Basemap: Google Satellite)

The scientific importance of *Mt. Dallol* and its complex and still not fully understood geothermal system is limited to a handful of studies (e.g. HOLWERDA & HUTCHINSON, WARREN 2015A; FRANZSON ET AL. 2015; CAVALAZZI ET AL. 2019; LÓPEZ-GARCÍA ET AL. 2020), while its aesthetic values attract a growing number of visitors every year (ARCTB 2019, *Fig. 4.2*). The active geothermal manifestations of the area, such as acidic ponds or fumaroles, are probably the most important geological features, and they are a primary interest for (geo)tourism and research despite being highly hazardous phenomena with extreme temperatures and pH. The lack of any protection infrastructure for the geoheritage values and for the visitors results in a low level of resilience. This could potentially lead to dangerous scenarios, where increasing visitor numbers is not accompanied by increased risk awareness and preparation. Hence, the need to identify potential risks alongside the geoheritage and address them through management strategies.

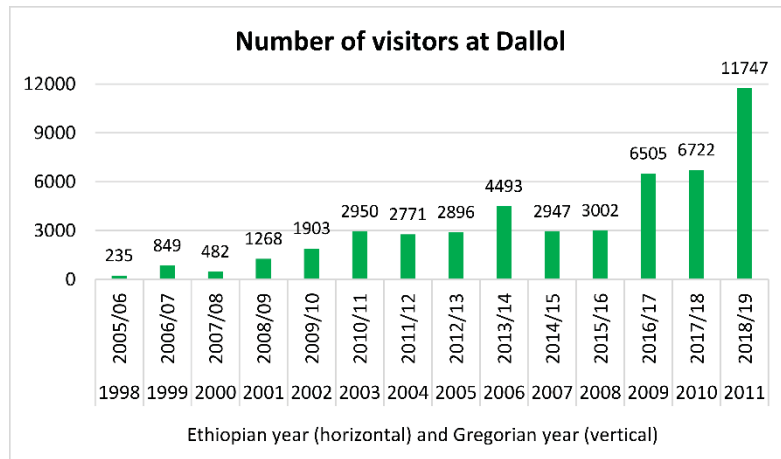


Fig. 4.2 Visitors statistics of Dallol (ARCTB 2019)

IV/A/2 Geology and Geography of the Danakil Depression and Dallol

IV/A/2/a The Danakil Depression

Mount Dallol is situated in the *Danakil Depression*, which is part of the *East African Rift System*, spanning from Mozambique to the *Arabian Peninsula* (ROGERS 2006; DARRAH ET AL. 2013).

The *Afar Depression*, also known as the *Afar Triangle*, is a world-renowned example of continental rifting, and the inception of oceanic crust formation, forming a subaerial triple junction at the intersection of the *Gulf of Aden*, the *Red Sea* and the *Main Ethiopian Rift* (BARBERI ET AL. 1970; TAZIEFF ET AL. 1972; MAKRI & GINZBURG 1987; ROGERS 2006).

The *Danakil Depression* (*Fig. 4.3*) itself could be considered the northern section of the *Afar Depression*, covering a roughly triangular shaped area of 50,000 km², flanked by the *Great Ethiopian Escarpment* (*Balakia Mountains*) to the West, the *Danakil Alps* to the East and *Lake Afrera* to the South (LUPI 2009; NOBILE ET AL. 2012).

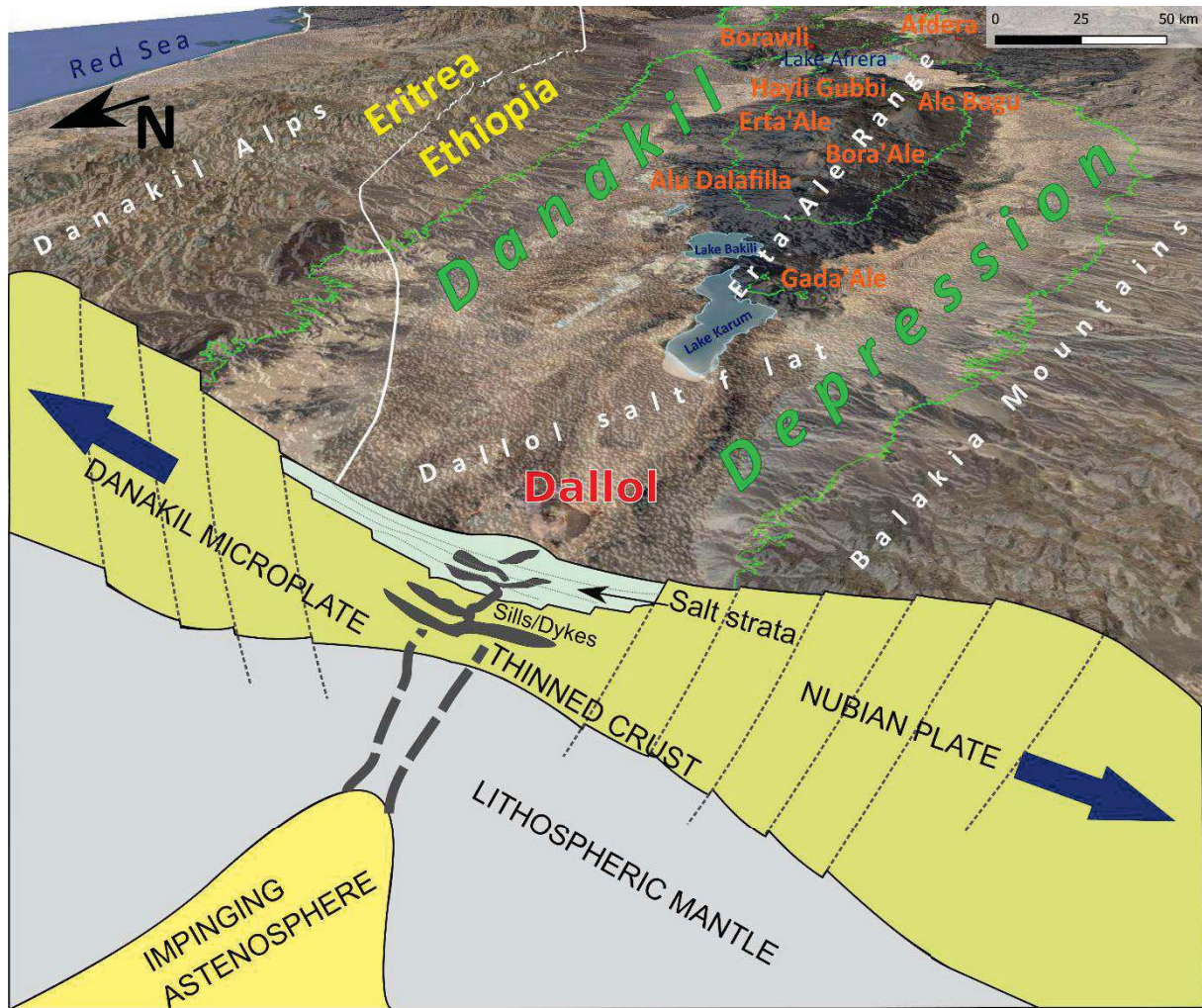


Fig. 4.3 Overview oblique image and simplified tectonic sketch cross section of the Danakil Depression. Vertical extent is distorted and not to scale (Basemap: Google Satellite, DEM: SRTM - de Ferranti)

Rifting in the Afar region started during the Miocene, about 30 Ma, and is ongoing with a spreading rate of 7–20 mm/year (NOBILE ET AL. 2012). Active volcanism and hydrothermal activity take place along a number of NNW-SSE orientated axial volcanic ranges, the most prominent of which is the *Erta Ale Range* (BARBERI ET AL. 1970; NOBILE ET AL. 2012; HAGOS ET AL. 2016). Predominantly basaltic in composition, the range comprises several volcanoes with Holocene activity, such as *Alu-Dalafilla*. The best known of them is the eponymous *Erta Ale*, one of the rare examples of an active lava lake on Earth (Fig. 4.3).

The northern half of the *Danakil Depression* is dominated by a salt pan, also referred to as the *Dallol* salt flat (WARREN 2015A), forming the deepest part of the depression which reaches 120 m below sea level. The basin is infilled with a series of Quaternary evaporites that may underlie the entire depression and is covered by volcanic successions in the southern part (*Erta Ale Range*). Geophysical surveys and drilling have mostly been carried out in the NW section, close to *Mount Dallol*, where economically exploitable potash deposits are located (HOLWERDA & HUTCHINSON 1968). A succession of evaporites of at least 970 m thick is made up of two, thick units of halite,

the *Lower* and *Upper Rock Salt Formation*, separated by the potash-bearing *Houston Formation*, as well as sequences of kainitite, carnallite, bishofite and sylvinite. Their depth ranges from 38 to 190 m near *Dallol* to 683–930 m to the east (WARREN 2015B).

Marine seepage into the current salt flat is prevented by a shallow, volcano-tectonic barrier in the north, but deposition of halite and gypsum still takes place at *Lake Assale* (or *Lake Karum*). Periodical rainfall on the *Western Escarpment* can cause flash floods, running down wadis to flood certain parts of the salt plain (HOLWERDA & HUTCHINSON 1968). The periodic inundation is followed by rapid evaporation, creating a new crust of halite and mud which often shows a typical hexagonal drying-up structure (GOUDIE 1989).

IV/A/2/b Mount Dallol and Black Mountain

Mount Dallol itself is a complex, uplifted, halo-volcanic dome structure (FRANZSON ET AL. 2015; LÓPEZ-GARCÍA ET AL. 2020), rising 60 m above the surrounding salt flat. *Mount Dallol* has been regularly interpreted as a volcano (FRANZSON ET AL. 2015; WARREN 2015A) due to its crater-like central structure, the geothermal activity and the resulting landforms that resemble volcanic features (the latter being interpreted as salt hornitos and maars). Further evidence comes from a positive gravity anomaly and magnetic measurements indicating intrusions, and a phreatic explosion at the nearby *Black Mountain* in 1926. Although a dike intrusion from a magma reservoir from below *Dallol* has been suggested (NOBILE ET AL. 2012), and the updoming of the salt strata and the presence of a heat source of the hydrothermal system imply a connection to dykes or a magma chamber, probably via sills (e.g. HOLWERDA & HUTCHINSON 1968; FRANZSON ET AL. 2015), only scattered presence of volcanic products are reported (HAGOS ET AL. 2016). LÓPEZ-GARCÍA ET AL. (2020) consider *Dallol* as a (proto)volcano, and FRANZSON ET AL. (2015) as a magmatically driven hydrothermal system, but a general consensus about the exact evolution and framework of the *Dallol* dome has not been reached yet.

The focal structure of *Dallol* is a 1.4-km-wide bowl, surrounded by a rim 20 m higher than the deepest part of the bowl. HOLWERDA & HUTCHINSON (1968) interpreted it as a collapse crater, but according to FRANZSON ET AL. (2015), the rims do not show evidence of steep faulting; therefore, the bowl structure might have been formed by the gentle flexing of salt strata, as there is a ring of fractures (FRANZSON ET AL. 2015). The N-NW floor is generally flat, and the salt layers suggest ephemeral lake formation (FRANZSON ET AL. 2015). The central to southern part is dominated by a black dome structure and the iconic, constantly changing structures of geothermal ponds (Fig. 4.4).

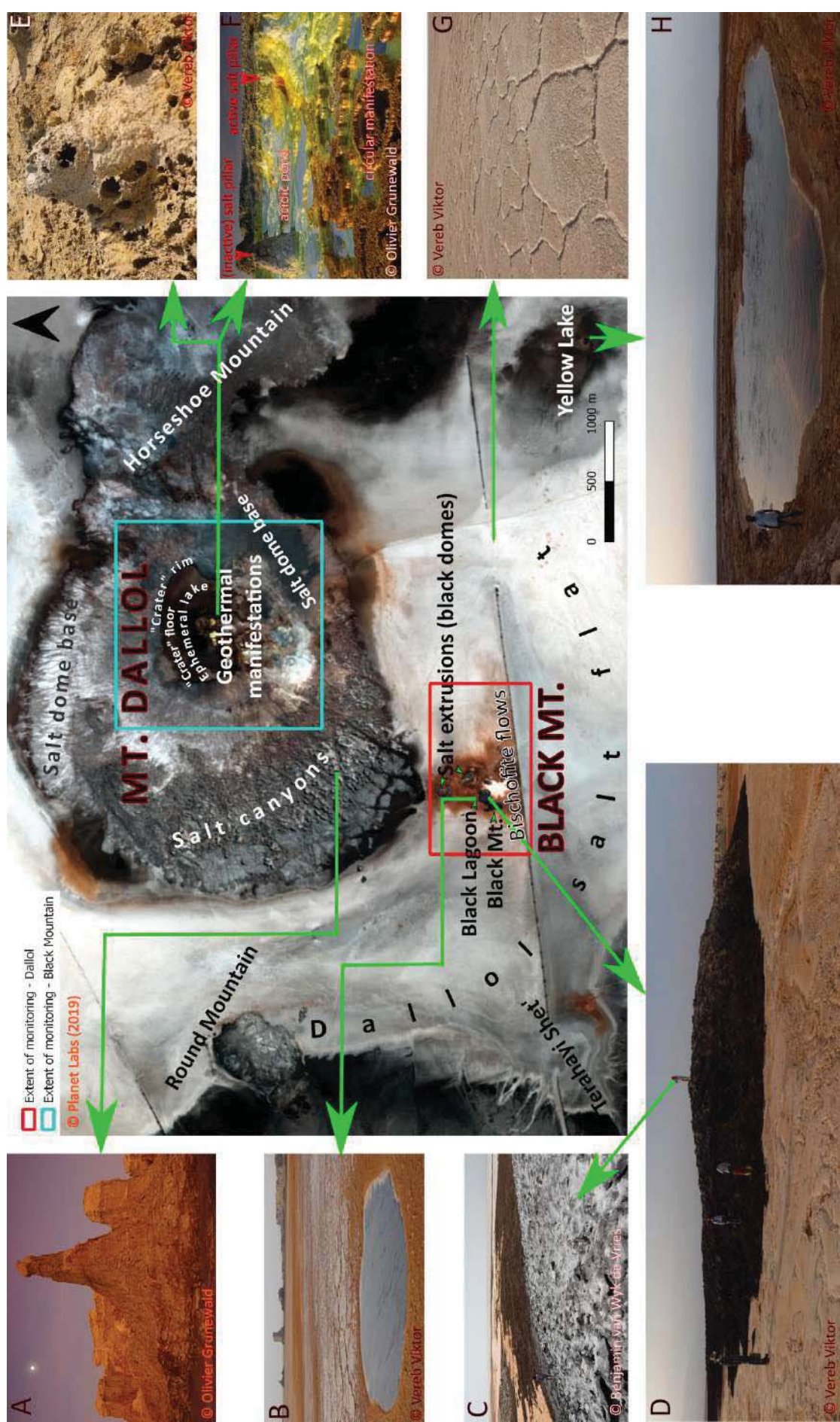


Fig. 4.4 Physiographical features of Dallol. A: Salt pinnacles of the SW of Dallol. B: The super-saline Black Lagoon, site of the 1926 phreatic explosion. C: Blacks of halite-mud mixture on the top of Black Mountain. D: Black Mouniam, the name bearing black dome, surrounded by a surface of bischofite flows. E: Inactive fumarole. F: Principal geothermal features of the central crater area of Dallol: salt pillars, circular manifestations and acidic ponds. G: Hexagonal salt surface near Dallol. H: The brine pool of Yellow Lake

FRANZSON ET AL. (2015), following HOLWERDA & HUTCHINSON (1968), described three typical structures that are present in active or inactive form at *Dallol*: pillars, circular manifestations and acid lakes (Fig. 4.4).

- Pillars can be several metres high and wide, often found in groups, and are most likely generated by boiling upflows, where halide precipitates at the top of the structure.
- Circular manifestations range from several metres to a hundred metres in diameter, also controlled by intense upflows and deposition of halides in circular or semi-circular forms.
- Acid lakes are probably controlled by the mixture of groundwater and geothermal upflows, creating small ponds with extremely low pH (less than 1). Their extent and water level could change frequently, and the drastic colour changes from yellow to green to red might be interpreted as oxidation related to water table changes (FRANZSON ET AL. 2015).

LÓPEZ-GARCÍA ET AL. (2020) suggested an evolutionary pattern of geothermal features, from chimneys and pillars to rounded flat-top geyser fields with lateral terraced ponds (these ponds could be the acid lakes of FRANZSON ET AL. 2015) that finally become inactive with the lowering of the water table level.

The *Black Mountain*, just south-southwest of *Dallol*, is an area of salt extrusions, geothermal manifestations and brine upflows (Fig. 4.4). The feature that gives its name to the site is a black dome, created by highly viscous salt upflows, articulated by hexagonal fractures and degassing pipes. It acquires its black colour from the abundant haematite in the halides (FRANZSON ET AL. 2015). The central elongated black dome is 200 m long and generally 30 m wide. It has smaller vertical extrusions to the north-northeast. Just to the north of the dome is a super-saline, hot (~ 70 °C) lake called the *Black Lagoon* or *Black Pool*, which is interpreted as occupying the site of a 1926 phreatic explosion (HOLWERDA & HUTCHINSON 1968). To the S-SE of the central black dome is a constantly changing area with regular super-saline outflows which precipitate bischofite, a magnesium-chloride mineral (FRANZSON ET AL. 2015; LÓPEZ-GARCÍA ET AL. 2020).

The majority of geothermal features are concentrated at *Dallol* and *Black Mountain*, but there is a third, smaller manifestation at the *Yellow Lake* or *Brine Pool*, 3.5 km SE of *Mount Dallol* (HOLWERDA & HUTCHINSON 1968). The *Terabayi Sbet'*, a 100-m-wide circular crater, was possibly also generated by a geothermal system, and creates saline mudflows of unknown frequency W-SW from *Dallol*, close to the bajadas (FRANZSON ET AL. 2015).

The S-SW segment of *Mount Dallol* and the area N-NE from the central crater are dominated by a labyrinth of salt canyons and a series of erosional pinnacles, showing salt cyclothems of halite,

gypsum and clay (HOLWERDA & HUTCHINSON 1968). Vertically dipping, kilometre-long salt dikes are also observable in the W-SW segment of *Dallol*, forming a series of ridges and depressions, and include rare altered basalts (HOLWERDA & HUTCHINSON 1968). These dykes have been partially mapped by TIBALDI ET AL. (2020) using drone images in Virtual Reality, and show several generations of intrusions. West of the *Dallol* salt canyons, there is a second dome structure called *Round Mountain* and to the east of *Dallol* is *Horseshoe Mountain* (predominantly made up of reddish halite), but these features have not yet been studied in detail (HOLWERDA & HUTCHINSON 1968).

IV/A/3 History of Resource Exploitation and Research

In spite of the extreme climate of the region, where daily temperatures regularly exceed 40 °C and the precipitation remains well below 200 mm per year, the *Danakil Depression* is inhabited, in part due to its economic potential. The annually formed salt layers have been extracted by the local Afari people and the highlander Tigrinyas for centuries by traditional methods: quarrying with sticks and axes, carving the standardised, rectangular tiles of ‘*ganfur*’ and ‘*ghelao*’ (ca. 4 and 8 kg), and transporting them with camels and donkeys to *Berbale* in the *Great Escarpment*, and further west to *Mekel’le*, the regional centre and ancient capital (WARREN 2015A).

From the second half of the nineteenth century, Italy touched on the *Danakil Depression* through a number of mostly unsuccessful expeditions and a colonisation attempts, which only succeeded along the *Red Sea* shoreline and the northern segment of *Danakil*, resulting in the colony of Italian Eritrea. The majority of the depression, including *Dallol*, remained under the dominance of the Empire of Ethiopia, although European economic interest continued. From 1906, the Italian firm of *Compagnia Mineraria Coloniale* started the extraction of potash at *Black Mountain*, first transporting it by camel and then along a newly constructed narrow-gauge railway from *Dallol* to the port of *Mersa Fatma* (HOLWERDA & HUTCHINSON 1968; WARREN 2015A). Following some intense mining during the First World War, potash extraction ceased due to reduced demand and political tensions between Ethiopia and Italian Eritrea. After the Second World War, the railway was dismantled leaving no trace, and the potash concession was handed over to the *Dallol Potash, Magnesium and Sulphur Mines Co.* (HOLWERDA & HUTCHINSON 1968).

After 1954, the *Ralph M. Parsons Company* took over the concession and carried out the first systematic scientific description of the area to prepare for industrial potash extraction. They orchestrated the geological and topographical mapping of the area and the magnetic geophysical surveys, and more than 300 drill holes were drilled. The scientific paper of HOLWERDA & HUTCHINSON (1968), still the most detailed reconnaissance study of the region, was based on the industrial reports of this period. During a 9-year campaign, the *Musley Deposit*, a commercial sylvanite-bearing ore reserve was discovered, and preparations for industrial extraction were

started. But after encountering numerous flooding events in the mine works, the company ceased its operation in 1968, leaving behind their mining camp (Fig. 4.5), which is currently a ghost town and industrial heritage site at *Dallol* (WARREN 2015A).



Fig. 4.5 Remains of the Parsons Mining Camp made from blocks of layered Dallol salt, now slowly falling apart and inclining. Note the straight concrete block building in the background as a contrast

Following the concession period of *Parsons Inc.*, a number of companies were awarded the concession rights (e.g. *Salzdefubrt AG*, *Hydro Agri International*, *BHP Billiton*), but operations were generally restricted to exploration work and re-interpretation of *Parsons'* studies (WARREN 2015A). Industrial-scale extraction of materials at *Dallol*, and more widely in *Danakil*, was also significantly curtailed by socio-economic problems and political turbulence affecting Ethiopia, such as the abolition of the Empire, the rule of the 'Derg' (Provisional Military Government of Socialist Ethiopia), the independence of Eritrea, and the constant clashes between Afari revolutionary movements and the state authorities of Ethiopia and Eritrea. Since 2015, large-scale exploration has returned through the work of *Allana Potash Corp.* and *Yara Dallol Potash Project*, and their data is being used again by scientists (BASTOW ET AL. 2018).

Climatic extremes, political tensions and isolation in terms of infrastructure mean that the *Danakil* remains a seldom visited location. Moreover, despite the importance of geological processes and the economic resources of potash and halite, the number of research studies on *Dallol* and *Danakil* is still limited to a few key articles, e.g. HOLWERDA & HUTCHINSON (1968), BARBERI ET AL. (1970), TAZIEFF ET AL. (1972), CARNIEL ET AL. (2010), GEBRESILASSIE ET AL. (2011), FRANZSON ET AL. (2015), BELILLA ET AL. (2019), CAVALAZZI ET AL. (2019), GÓMEZ ET AL. (2019) AND LÓPEZ-GARCÍA ET AL. (2020).

Permanently installed instruments and facilities for long-term monitoring of seismicity, gas and water chemistry or thermal changes, are completely missing at *Dallol*, and the studies above have relied on limited field excursions and subsidiary reports of economic geological reconnaissance.

IV/B Remote Sensing Monitoring of Geothermal Activity and Landscape Changes

Basic monitoring of the *Dallol* geothermal activity and landscape changes using satellite images was prompted by the fact that in situ monitoring facilities were not available as of 2019, and sporadic field-reconnaissance missions and measurements can only give a partial, extrapolated overview of long-term processes and changes. The growing number of visitors and their potential vulnerability, the economic importance of *Dallol* and the adjacent potash concession zones all call for hazard and risk assessment and monitoring. Therefore, a simple, monthly monitoring process was created, giving a visual overview of changes and hazards for visitors and functioning as an input for further quantitative description of activity patterns of geothermal manifestations and bischofite upflows.

IV/B/1 Monitoring Methodology

Ultra-high-resolution (3 m) RapidEye satellite images were used in order to delineate the distinctive geological and geomorphological features and their areal changes, provided by PLANET LABS INC. (2020). From the 4-band spectral dataset, only visible wavelengths were used. A monthly interval was chosen based on the supposed and observed rate of changes, the availability of ideal coverage and the required processing time. The availability of cloud-free coverage (to avoid similar reflectance values of salt and cloud pixels, and the eclipse of features) and the orbit of the satellite through *Dallol* meant that the intervals used varied slightly, but generally, the first day of each month was used.

A semi-automated workflow was created (*Fig. 4.6*), where manual intervention is restricted to data cleaning and supervision. The workflow was executed separately for *Black Mountain* and the central crater area of *Dallol* in order to minimise coverage of areas with little, slow or no change (e.g. salt flats, salt canyons) outside the geothermal areas. The input satellite images were classified by RGB pixel values with *ENVI*, with the supervised, maximum likelihood classification method of the software. Generally, 7–10 classes were delineated for *Black Mountain* and 10–15 for *Dallol*, with at least 3 training sites per class. The accuracy of pixel classification was generally around 70–80% (classified categories versus the extent of expected classes and features); therefore, purging or rectification of data was required.

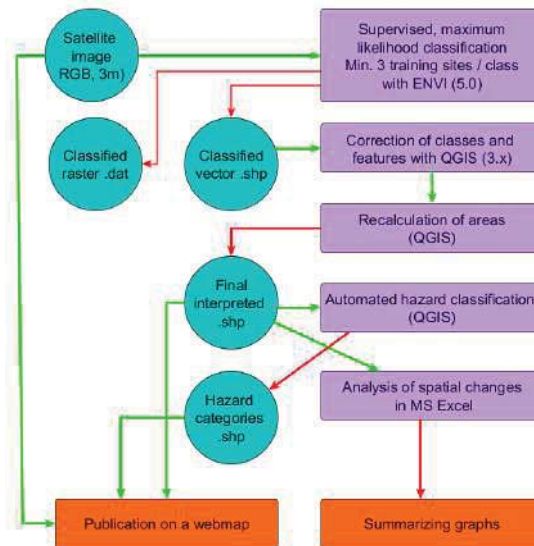


Fig. 4.6 Workflow of the remote sensing monitoring, showing the steps from data to graphical outputs

Further phases of the workflow were carried out in QGIS (QGIS DEVELOPMENT TEAM 2020), using the vector output of classification from ENVI. Cleaning covered the removal of artefacts (purging), the merging or division of classes and adding new features if needed. Final names of geological and geomorphological units (e.g. bischofite flows) were assigned at this point, with the classification using a provisional naming protocol. Areas of each feature were also recalculated, as they could change significantly from the original classification values during the purging. Finally, a new symbology was also applied to each month.

The principal output of the workflow was the interpretation of the extent of geomorphological and geological units (Fig. 4.7). The workflow functions as a visual monitoring tool for areal changes of the geothermal manifestations (active and inactive ponds, bischofite flows) month-by-month, allowing the area of each feature to be compared numerically as well. It also operates as an input for hazard assessment. Based on reports about the units (especially from HOLWERDA & HUTCHINSON 1968 and FRANZSON ET AL. 2015) and our reconnaissance field trips of 2017 and 2019, each feature could be associated with a hazard value according to the stability of its material, the characteristic pH value and temperature as reported by previous studies such as FRANZSON ET AL. (2015). A five-level scale exposure from very low to very high level of hazard was used, and each unit was classified into these categories (Table 4.1). An automated workflow was created in QGIS with the Graphical Modeler to assign the hazard values to each feature. For high and very high (levels 4 and 5) categories, safety buffer zones of 5 and 15 m were also calculated in order to delineate a potential admissible distance for visitors (Fig. 4.7).

Table 4.1 Hazard categories of Mount Dallol and Black Mountain

UNIT	DESCRIPTION	HAZARD VALUE
BLACK MOUNTAIN		
Black Lagoon	Extremely low pH (2-3) and high temperature (71°C) waterbody, with unknown thickness of salt crust around it, possibly overhanging. Danger of scalding, burns, drowning.	5
Vent	Effusive point of the fluidized bischofite, with the unknown thickness of crust around it. Danger of falling through, burns, scalding and eruption.	5
Fumarole	Exhalation of gases of high temperature and various compositions, Danger of burns and lung problems	4
Salt dome with fumaroles	Black (salt) domes, with evidence of fumarolic activity, such as honeycomb crust. Danger of burns, and cuts.	4
Bischofite flows	In its consolidated state, they are relatively safe to be visited, but potentially dangerous during the effusion of new brine material. Often consolidated on weak underlying material. Danger of acid, scalding, falling through crust.	3
Salty marsh	The mixture of the salt strata and the brine emitted at Black Mountain, a slippery, marshy surface around the salt domes. Danger of getting stuck, unknown chemical risk, possible flooding.	2
Salt dome	Relatively safe features of halite blocks, but might contain unknown gas pipes and reactivated fumaroles. Danger from changes, burns, scalds, eruptions	2
Outlier of Dallol clay	A residual feature of clays, traceable at Dallol, a stable and safe feature of Black Mountain region. Danger low.	1
Salt flat	The surface representation of the salt strata of Dallol salt pan, safe and easy to walk. Danger low, possible flooding.	1
DALLOL		
Active geothermal zone	Ponds of acidic and small lakes, active fumaroles and salt pillars. Danger of scalding, burning acid. Cuts on sharp elements, floods and rapid changes.	5
Active/inactive transition	Areas of active and inactive geothermal features, with potential sudden changes, and hidden features underground. Danger of falling through, cuts, Rapid changes possible.	4
Inactive geothermal zone	Geothermal manifestations of ceased or dormant activity, with small chance of reactivation. Danger of reactivation, danger of falling through crust.	3
Salt pillars	Inactive forms of salt pillars, but potential reactivation of geothermal activity beneath	3
Salt canyon	Labyrinth of salt pinnacles and valleys with often unstable blocks, sharp surface of knife like salt remnants. Danger of falling and cuts, getting lost. Possible freak flooding from hydrothermal discharge.	3
Altered honeycomb surface	Rugged, sharp surface of inactive circular manifestations. Danger of falling and cuts	3
Wadi	Ephemeral riverbeds that could be filled very quickly with water during rain events. Danger of flooding.	3
Ephemeral lake coverage	Partially flooded area, otherwise characterized by rugged salt blocks. Danger of flooding, possibly by acid waters.	2
Mining ghost town	The leftover housing and machinery of the Parsons Mining Camp, minor risk of the objects. Danger from anthropogenic material (e.g. broken glass, sharp metal)	2
Dallol salt dome base	The updomed base structure of Dallol, relatively stable salt blocks. Danger of isolation if changes occur around this.	1
Salt plain	The surface representation of the salt strata of Dallol salt pan, safe and easy to walk. Danger low.	1
Salt dome	Safe features of halite blocks (black dome), gas pipes are not significant compared to Black Mountain. Danger low.	1

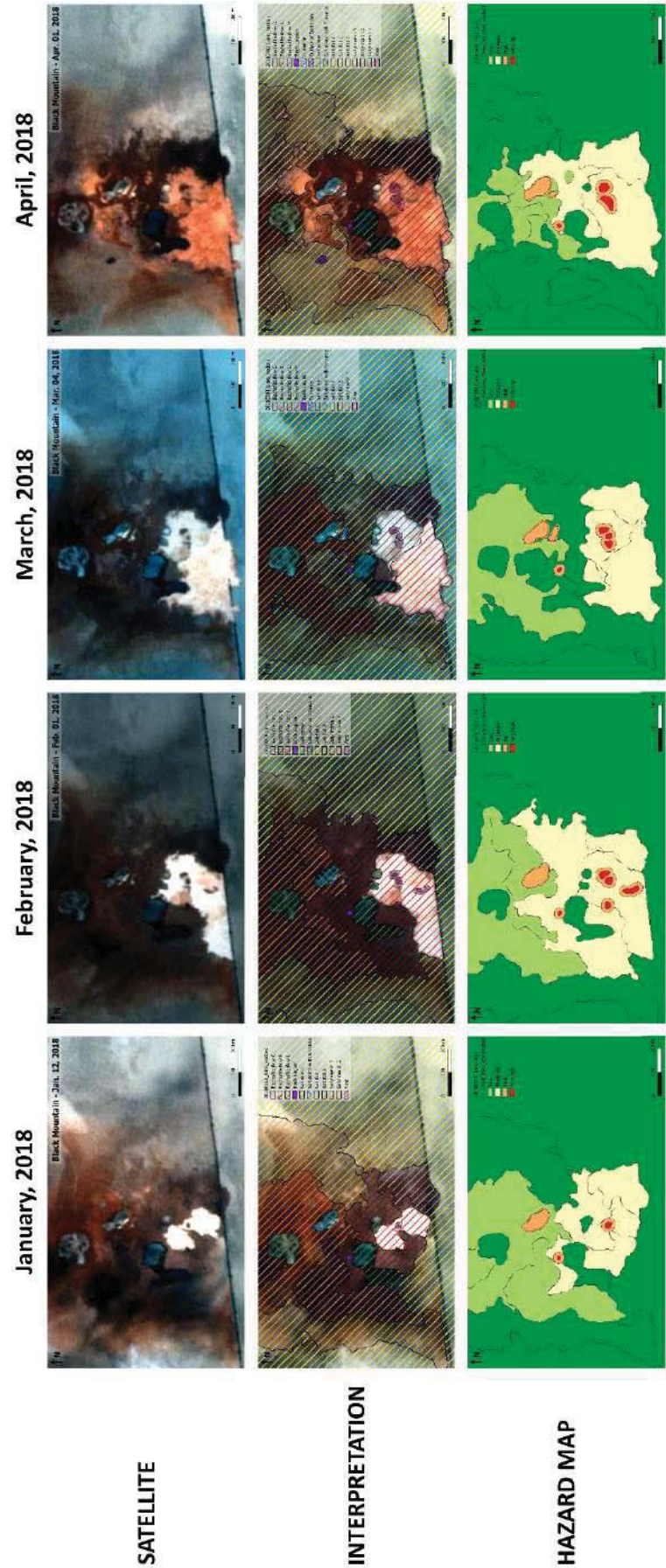


Fig. 4.7 An example from the monitoring dataset at Black Mountain, January–April, 2018. Note the dynamic growth of bischofite flow ‘K’ in January and February, the appearance of a new flow (‘L’) in March, and the alteration of previous ones in April, without the appearance of a new generation. The patterns of salt flats also change slightly month-by-month, according to wind erosion, or even by possible periodic flood

Since the start of monitoring in January 2017, nearly 3 years of dataset have been collected. The extraction of the areal extent of each geothermal feature by month allows a quantitative overview of changes and an initial idea about activity patterns. However, care should be taken extrapolating this, and several more years of consistent monitoring are required for a long-term baseline. These should be validated with regular field observation. It is beyond the scope of this paper to give a detailed overview of processes and landforms, and we focus on I) the description of observations that are visible on the satellite images, II) their interpretation, and III) establishing a framework for further observations.

The accuracy of the automated classification was significantly improved with numerous human validation iterations, but this could not match field observations. For example, features smaller than 0.1 ha were omitted by the classification process, and in case of *Dallol*, several active, but isolated geothermal ponds might not reach this areal extent. This was the primary reason to have broad zones in the classification (e.g. active, inactive, active/inactive transition, where an indeterminable mosaic of small active and inactive features is observable) instead of standalone features of acidic ponds, circular manifestations, etc., so as to reduce information loss during classification and interpretation.

For the bischofite flows, any appearance of a new feature or continuing existence of a previous generation was determined by human supervision, as the genetic link had to be examined month-by-month, comparing possible alteration (resulting in a colour change), further growth of a previous feature or appearance of a new one. The different illumination of the surface by the sun or small quality differences in the monthly datasets might result in a colour (reflectance value) difference between the same type of geological features at different time periods, which underlines the importance of manual rectification.

IV/B/2 Observations - Results

IV/B/2/a Monitoring of Mount Dallol

Changes in activity in the central geothermal zone of *Dallol* are summarised in *Fig. 4.8*. A general decline of the areal extent of active geothermal zones is clearly visible: from the 15–23 ha in the first months of 2017, there is an overall decrease of 1–5 ha. The shrinkage was connected with an increase in inactive areas and accompanied by a smaller growth in transitional zones. Both zones show a significant variability month-by-month, and there might be true changes or possible mismatching with units of similar reflectance. For example, the brownish shade of inactive areas is similar to the reflectance values of the ephemeral lake coverage of the central crater. Also the active

and inactive transitional areas might be classified differently by the automated method from month to month, due to the reflectance value changes in images.

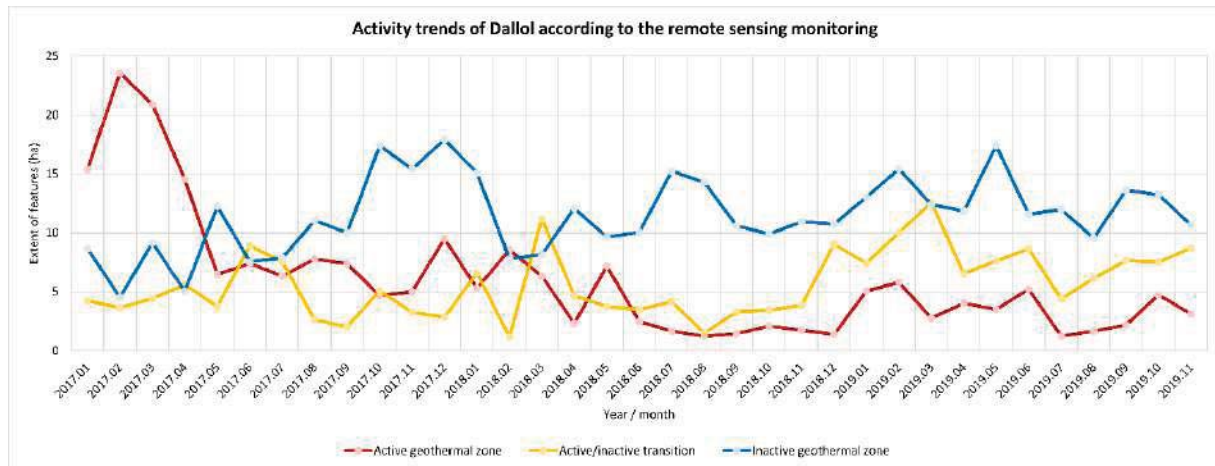


Fig. 4.8 Mount Dallol - changes of the extent of active, semi-active and inactive features between January 2017 and November 2019

Besides the general decline of active features, a slight seasonal pattern is also observable in Fig. 8. Winter and spring months (December to June) show a limited increase in activity (i.e. active, active/inactive transition zones) compared with the values of the summer to autumn period (July–November). This periodicity might be related to the seasonal water supply. Although water is thought to be largely provided by groundwater reservoirs (FRANZSON ET AL. 2015), periodic rain events might help reactivate some acidic ponds through shallow water supply to the hydrothermal system. A longer time series of data along with a comparison with meteorological data is required to confirm this hypothesis.

IV/B/2/b Monitoring of Black Mountain

Monitoring of geothermal activity at *Black Mountain* has focused on the SE area of bischofite flows. The historical continuity of brine upflows is well-known (HOLWERDA & HUTHCHINSON 1968; FRANZSON ET AL. 2015; LÓPEZ-GARCÍA ET AL. 2020), but the volumes and evolution of the geothermal features have not been described. The time span of our monthly monitoring means that some upflow events might be missed, but in general, this interval was suitable to follow the evolution of the features from their appearance through to alteration, and subsequent coverage by new events.

From the start of the measurements, 34 flow events with various durations, magnitudes and surface coverage have been identified (up to November 2019). These are marked with alphabetic characters from *A* to *Z*, and then continuing with *AA*, etc. (Fig. 4.9). Genetic connection of flow features on two subsequent satellite images were identified by the comparison of reflectance values and morphology, taking into consideration possible alteration marked by colour changes. Colour changes can be explained by rainfall and the deliquification of potash-related minerals, such as

cainite or sylvinitite (HOLWERDA & HUTCHINSON 1968). In the field, we actually observed that the surface of bischofite flows was also stripped by the wind.

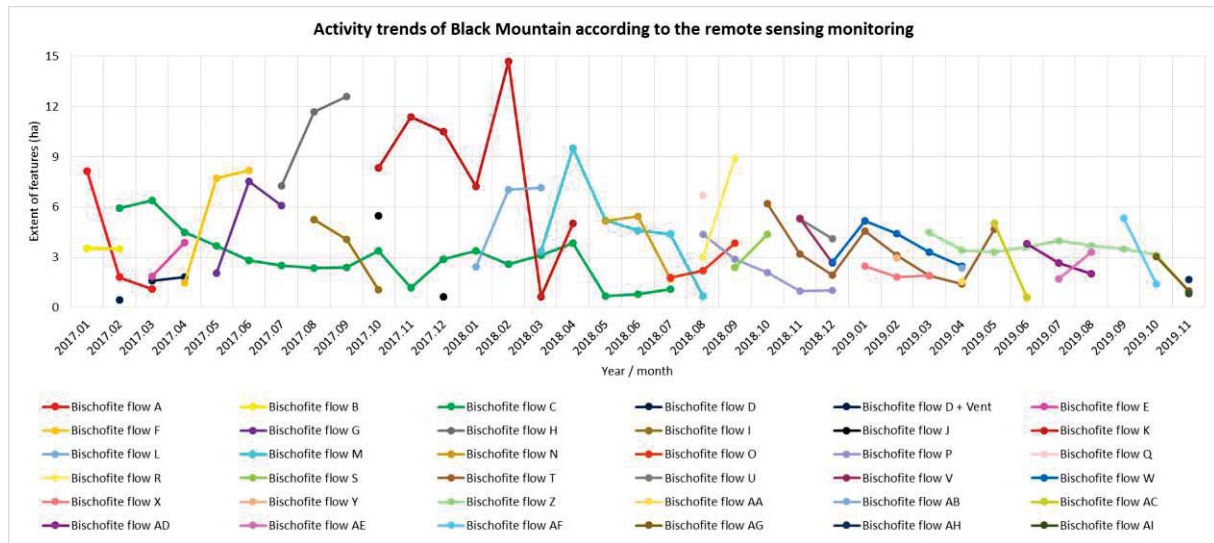


Fig. 4.9 Black Mountain - Changes of the extent of bischofite flows between January 2017 and November 2019

At least one new feature appeared each month, but in several months (e.g. March 2017, August 2018), two separate flows appeared following different paths, and their colours indicated two distinct effusion episodes. There were only 7 months when no new unit appeared (June 2017, September and November 2018, February, April, June, August 2019), but it does not necessarily mean inactivity, only that the pre-existing flows continued to grow (e.g. flow 'K' between October and November 2017).

From this image analysis, we see that a solidified surface exists for 3 months on average (Fig. 4.10); then, it is covered up by a new flow, or its material is altered to brown, dissolved or eroded. One of the rare exceptions was flow 'C' that we were able to follow in a highly altered form for 18 months. Having flowed in a SE direction, spilling through the rampart south of Black Mountain, the final thickness of this flow probably created enough topography to hinder its overflow by other units, or to be flooded.

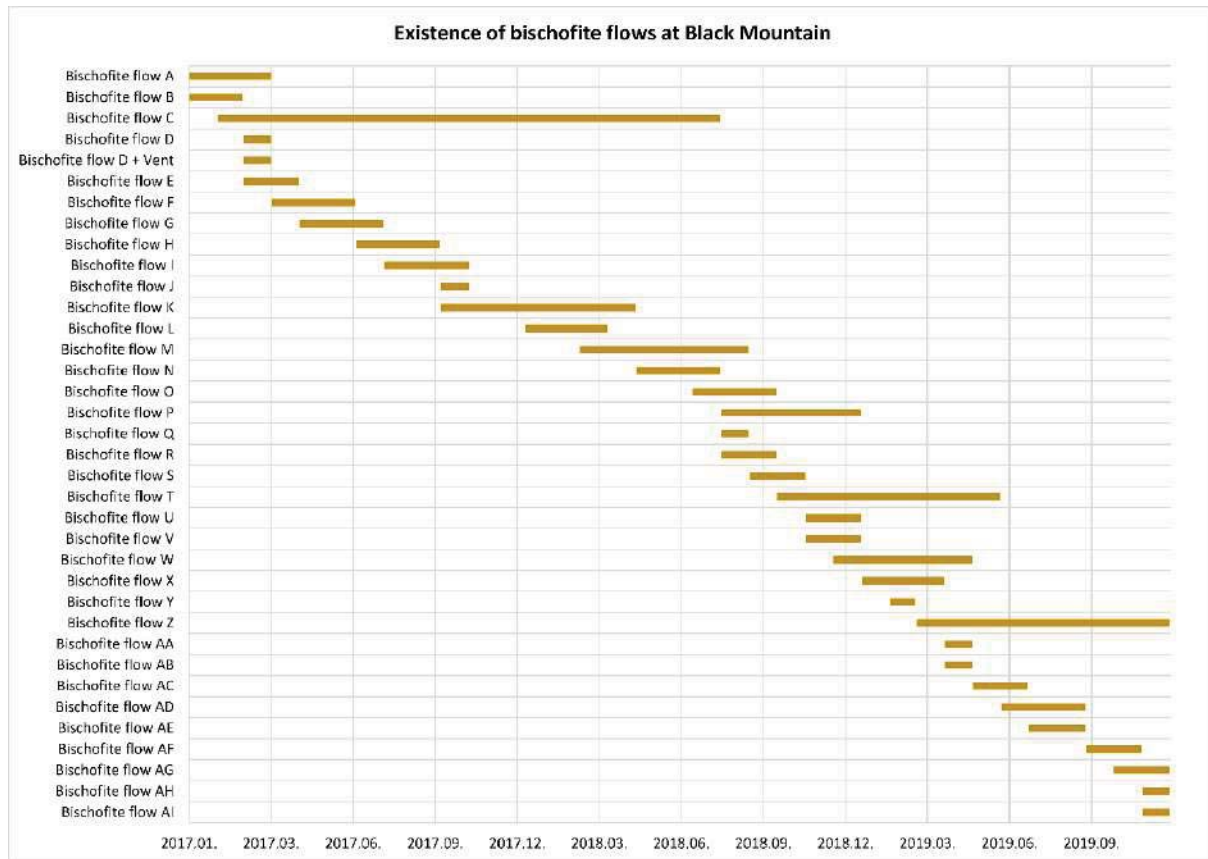


Fig. 4.10 The temporal persistence of bischofite flow generations from January 2017 and November 2019

Neither detailed geodetic survey of slope values nor drone surveys to create a high-resolution DEM have been carried out so far, but according to our field observations in 2017 and 2019, the slope gradient around the central vent is minimal (1–3 degrees). Thus, even small roughness features on the surface could divert the orientation of flows. Information about the intensity of upflows could be deduced indirectly from the values during the first appearance of each month and positive changes on areal extents between two subsequent months. A new flow generally covers less than 5 ha in area. Intensive further growth was observable for some flow generations, such as 'F', 'K' or 'R'.

IV/B/3 Improving Visitor Resilience Through Web Publication

The dataset of the monthly monitoring process obtained in this work, along with general features about visiting the *Danakil Depression* and *Dallol*, is made accessible on a website (<http://dallol.lmv.uca.fr/>). The principal goal of the monitoring and its dissemination is to give a source of information to visitors, including guides, tourists and researchers, about the changing patterns of geothermal activity. The website's monthly mapping acts like a weather forecast, but it also gives a retrospective snapshot of the most recent situation (Fig. 4.11).

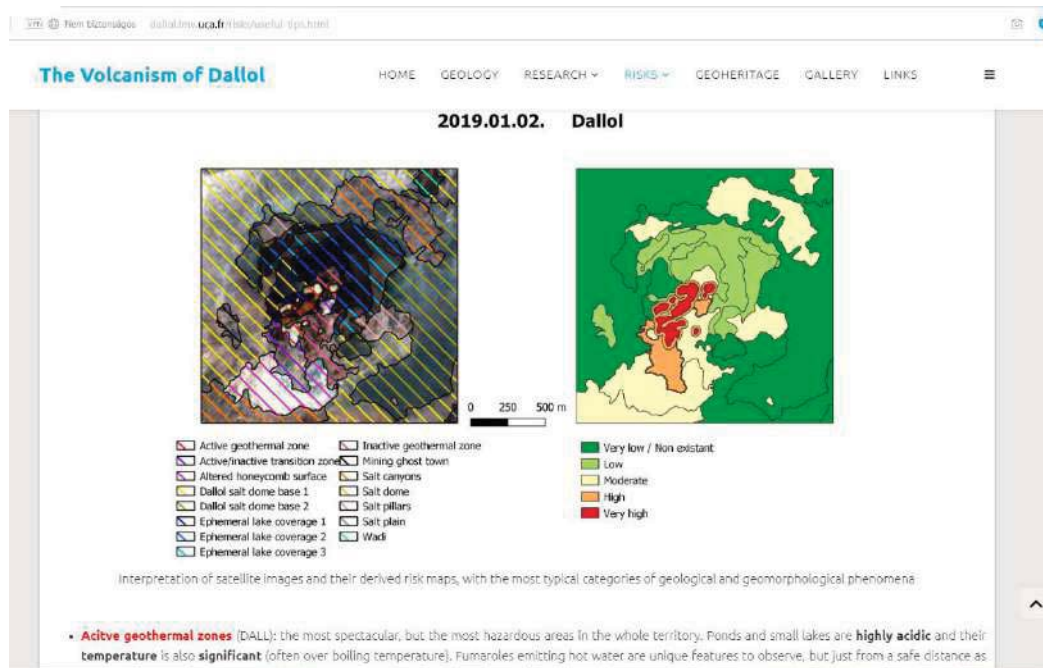


Fig. 4.11 Screenshot from the webpage with the maps of interpreted features and deduced hazard map

The interpretation and the deduced hazard maps are published as downloadable files that could be upgraded in the future to a webmap solution. Slideshows of raw satellite images also help follow up changes at *Mount Dallol* and *Black Mountain*.

The website also provides a basic, easily understandable summary of the geological features, description of the proposed geosites and useful information for visitors about the potential hazards. Moreover, it aims to be a forum for those who plan to visit the *Danakil* for touristic or research purposes.

IV/C The Geosite Inventory of Dallol

This study gives the first preliminary assessment of the geoheritage of *Mount Dallol*, *Black Mountain* and selected sites of *Northern Danakil*. The primary goal, by using a quantitative evaluation, is to determine the geoheritage scientific importance of the *Danakil Depression* that could boost the conservation and protection of the site at a national, and hopefully an international level. Evaluating additional values such as educational or touristic potential could give an overview of their present situation and serve as an input for future recommendations. Finally, the geosite assessment with three different quantitative methods and comparison of the results provides the basis for a discussion about the best combination for Ethiopia, and potentially other countries where no consolidated geoheritage management practices are in place.

IV/C/1 Methodology of Inventorying and Assessment

The selection process for potential geosites was conducted following the proposed workflow of BRILHA (2016) and REYNARD ET AL. (2016). A review of the limited literature and the concentration of present research activity around *Dallol* was an initial limitation in defining the extent of the inventory. Ultra-high spatial resolution satellite images are available for the entire area of the depression (PLANET LABS INC. 2020), but the lack of a correspondingly high-resolution digital elevation model limits the remote identification of potential important geomorphic features. Detailed field work in March 2017 and January 2019 (VEREB ET AL. 2019) was confined to the core area of *Mount Dallol* and *Black Mountain* due to the limited number of fieldwork days and environmental security constraints. Thus, the majority of the evaluated potential geosites are concentrated in these areas, and only a few others were assessed, close to the transport routes from *Dallol* to *Hamed'Ela*, the gateway village to the *Danakil Depression*. However, a list of potential geosites that should be evaluated in the future was also considered for the Ethiopian side of *Northern Danakil*, the territory defined by the Eritrean border to the north, the bajadas of the *Balakia Mountains* in the west, the *Danakil Alps* in the east and the northern perimeter of the *Erta'Ale Range* in the south. It includes potential features like the *Round Mountain* next to *Dallol*, fault-related features in the *Balakia* foothills, selected sites of the bajadas or the salt pan of *Northern Danakil*. This latter is a crucial element of not only geoheritage, but also an area with associated intangible heritage of traditional mining. However, this extension of the inventory and the detailed evaluation of new geosites in the whole depression require further dedicated studies.

The dynamic nature of geologic and geomorphic features was an important consideration in defining the extent of dedicated geosites, which were based on a preliminary literature selection phase, and our fieldwork/monitoring. Representative features of active morphogenetic processes were observed, such as acidic lakes, bischofite flows and active fumaroles. The monitoring of the geothermal activity in section IV/B has shown that these features change rapidly. This means that a feature representing an activity type could change, and a form might become inactive (e.g. fumaroles) or vanish by natural processes (i.e. drying out of acidic lake ponds, erosion and coverage of bischofite flows, collapse of representative salt pinnacles and pillars: JOYCE 2009). Therefore, instead of small, distinctive geosites, larger, summary units are proposed, where each phase of landform evolution can be observed (REYNARD ET AL. 2016).


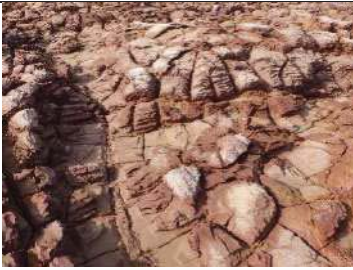

The evaluation methods of VUJIČIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016) were chosen because they use distinct and numerous criteria, allowing a predominantly quantitative assessment of all values, and they offer comparative case studies from different geographical regions (e.g. MOUFTI ET AL. 2015; SZEPESI ET AL. 2017). In particular, the REYNARD ET AL.







(2016) method was used in order to allow future comparison with the first assessment case study of Ethiopia (MAUERHOFER ET AL. 2017). The methodological descriptions, summarising the applied criteria, and the points system for the assessment can be consulted in the respective papers of VUJIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016), and a short summary is given in *chapter I/C*.





IV/C/2 The Preliminary Inventory - Results

Thirteen geosites have been identified and inventoried in three spatial clusters, namely *Dallol* (6 sites), *Black Mountain* (4 sites) and the *Northern Danakil* (3 sites). Several of them are associated with constantly changing, highly active features (especially the geothermal manifestations), and the oldest site, the ancient shoreline (ND-03), is from the Pleistocene high stand, when a branch of the *Red Sea* occupied the area. Apart from one site (DA-06, the *Parsons' Mining Camp*), each site is natural, and human influence on the landscape is minimal. The list of geosites with their main characteristics can be consulted in *Table 4.2*, while their assessment is detailed in section *IV/C/3*.

Table 4.2 Short description of the proposed geosites of Dallol, Black Mountain and Northern Danakil with selected images

CODE	NAME	SHORT DESCRIPTION	SELECTED IMAGE
DALLOL			
DA-01	The geothermal zone of Dallol	Constantly changing area of active, semi-active and inactive geothermal features with salt, pillars, circular manifestations and acidic ponds	
DA-02	The central salt dome of Dallol	Representation of a black extrusive (salt) dome besides Black Mountain, but with higher content of halite and lesser amount of mud with surface representation of hexagonal blocks	
DA-03	Salt canyon areas of Dallol	System of salt pinnacles and gullies, divided to small blocks by hydrothermal salt dykes and faults, and salt karst erosion, representation of halite and mud accumulation cyclotherms	

DA-04	Altered honeycomb surface of Dallol	Region of predominantly circular manifestations, where hot geothermal gas eroded the salt into a delicate and sharp honeycomb			
DA-05	Salt pillars	A cluster of inactive, several m-high, column-like features, created by the vertical solidification of brine-precipitating fumaroles			
DA-06	Mining ghost town of Parsons Co.	A geohistorical geosite with abandoned buildings and machinery of the Ralph Parsons Company which carried out the first detailed reconnaissance study of Danakil. Contains several inactive, salt pillars as well			
BLACK MOUNTAIN					
BM-01	Salt domes of Black Mountain area	A series of small salt extrusions and black domes with a fragmented surface of salt blocks, gas pipes and sometimes active fumaroles. Their darker colour compared to the Dallol central dome represents mixing of halite and muddy layers during deposition			
BM-02	Bischofite flows and their vents	A rapidly and constantly changing area of the extrusion of hot, fluid bischofite, its solidification and alteration and erosion by wind and water			
BM-03	Black Lagoon	An extremely low pH (2-3) and hot (71°C) lake associated with the phreatic explosion of 1926			

BM-04	Outlier of Dallol clay	A residual feature of clay strata observable at Dallol with largely uninterpreted origin, but probably separated by tectonic events and/or erosion	
NORTHERN DANAKIL			
ND-01	Gaet'Ale - Yellow Lake brine pool	A constantly boiling, acidic brine pool south of Horseshoe Mountain, probably associated with the geothermal system of Dallol	
ND-02	Asale – 'Skating rink'	Iconic topographic landmark of the Dallol salt pan, brown to red halite layers forming a ring around a flat salt area. Probably related to a small doming or plug	
ND-03	Ancient sealevel outcrop at Hamed'Ela road	An excellent outcrop of the Pleistocene sea-level, easy to access, containing fossils of Pleistocene flora and fauna such as stromatolites and corals	

IV/C/3 Interpretation of Results - Discussion

A direct comparison of the three methods is not possible due to the different evaluation criteria, the number and categorisation of sub-criteria, and the approaches of summarising and visualising the results. VUJIČIĆ ET AL. (2011) proposed a summary of results through a matrix; REYNARD ET AL. (2016) enlisted numerous possibilities of cartographic visualisation, such as qualitative or multivariate representation of data per geosite; and BRILHA (2016) did not include means of visualisation.

Consequently, in order to give an overview and comparison of the distinctive criteria, two sets of charts were created for each assessment method, described below, and then a possible quantitative comparison is presented.

IV/C/3/a Individual Evaluation of Criteria for each Assessment Method

The values of indicators (VUJIČIĆ ET AL. 2011; REYNARD ET AL. 2016) and the sets of values (BRILHA 2016) were plotted for each proposed geosite. Even with different approaches and a

different number of questions, indicators with similar considerations were marked with a coherent colouring scheme: shades of *blue* for scientific and educational indicators, *red* for vulnerability and protection concerns, *green* for tourism, and *orange* for the aesthetic nature of the site.

Scientific values vary greatly per geosite, but it is clearly visible that in most of the cases, they exceed half of the possible score for this indicator. Applying the methodology of BRILHA (2016) and REYNARD ET AL. (2016) (Figs. 4.13 and 4.14), the *Parsons'* mining camp gets below 50% of the total score, while applying that of VUJIČIĆ ET AL. (2011) (Fig. 4.12), two inactive geothermal manifestations, the altered honeycomb surface and the series of salt pillars scored lower. Although a specific limit was not proposed by BRILHA (2016) as a criterion of geosite based on scientific values, a score of 50% with the relevant evaluation method is a possible threshold for proposed geosites, and for geodiversity sites with moderate or irrelevant scientific importance.

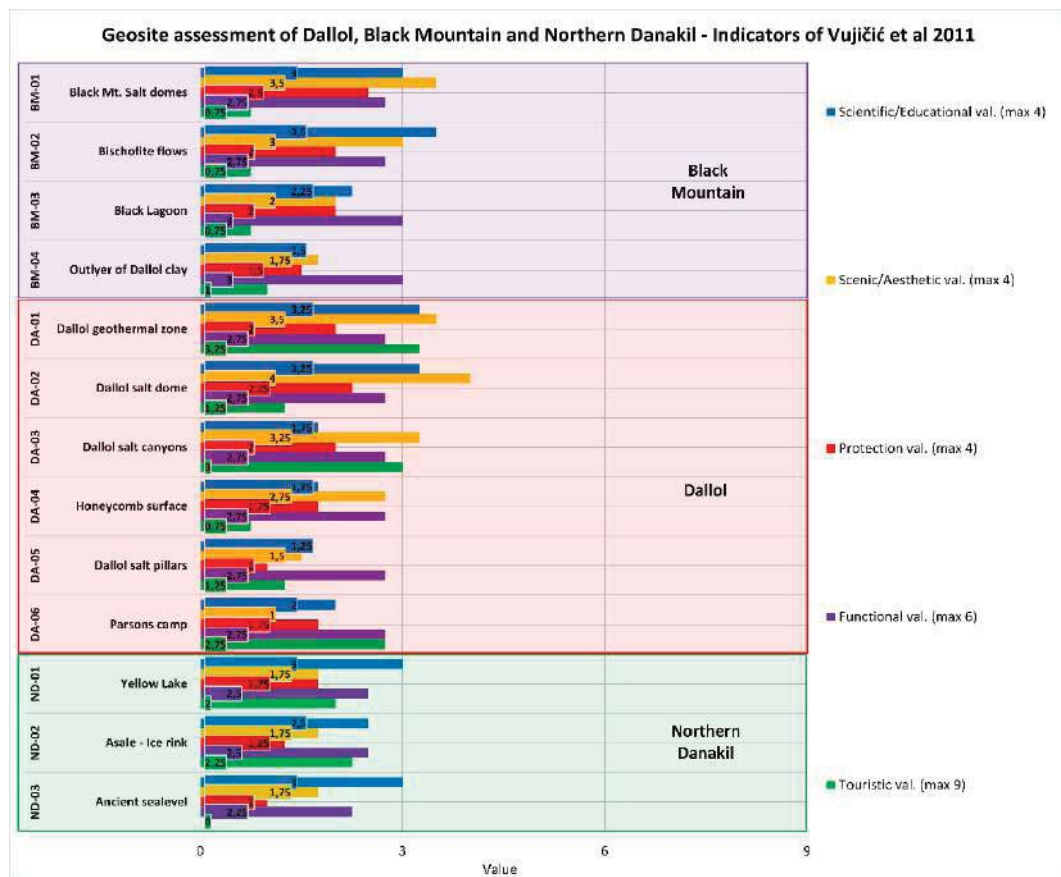


Fig. 4.12 Results of geosite assessment using the VUJIČIĆ ET AL. (2011) method with the individual indicators

Aesthetic or scenic considerations only appear directly in the method of VUJIČIĆ ET AL. (2011) and REYNARD ET AL. (2016). The iconic geosites of the region, such as the geothermal zone of *Dallol* and the spectacular salt canyons that dominate the skyline from the depression, have the highest possible scores for all evaluations (Figs. 4.12 and 4.14).

Touristic values are measured quantitatively only by VUJIČIĆ ET AL. (2011) and BRILHA (2016). It is clearly visible in Figs. 4.12 and 4.13 that touristic values are generally low compared with the

scientific values, indicating that the sites have a high importance for geosciences, but their (geo)touristic use/development is currently very minor. From a methodological viewpoint, it is interesting to note that the touristic values generally score close to the potential educational values when using the BRILHA (2016) method, since these categories share 10 indicators that can be assessed similarly.

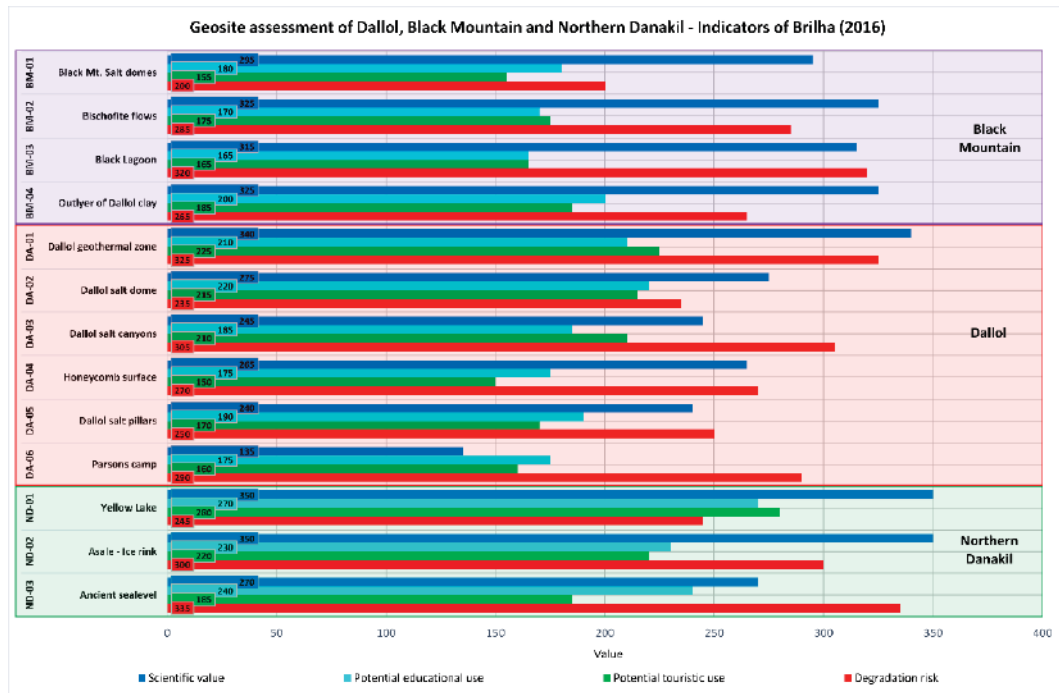


Fig. 4.13 Results of geosite assessment using the BRILHA (2016) method with the individual indicators

In each method, the indicators of current protection and vulnerability of the sites use different considerations; therefore, values are highly variable. High scores are given for most of the sites with BRILHA'S (2016) evaluation, because it measures the potential danger of degradation of the geosites (Fig. 4.13). The outcrops of the Pleistocene seashore that is undergoing constant erosion next to the *Hamed'Elä - Berhale* road, the geothermal manifestation of *Dallol* and the rapidly changing bischofite flows all reached significant values, as they could easily disappear or change irreversibly. The method of VUJIČIĆ ET AL. (2011) measures both the current protection status and the vulnerability of the site, and the obtained scores are generally moderate, indicating the lack of official protection despite the vulnerability of a site (Fig. 4.12). Applying the method of REYNARD ET AL. (2016), the indicator of *Ecological Values* should be considered to be protection-related, but predominantly low scores are connected to this sub-criterion (Fig. 4.14). The *Protected Site* consideration got low scores at almost every site, as it is non-existent. The higher values for *Black Lagoon*, the *Yellow Lake*, and the geothermal ponds of *Dallol*, are related to the other sub-indicator, the *Ecological Impact*, as they function as potential niches for extremophile bacteria (BELILLA ET AL. 2019). During field work, we observed many birds, including crows and swallows, suggesting that

Dallol does provide an important environment, with insects as prey. However, to our knowledge, detailed studies about the assessment of local flora and fauna are still missing.

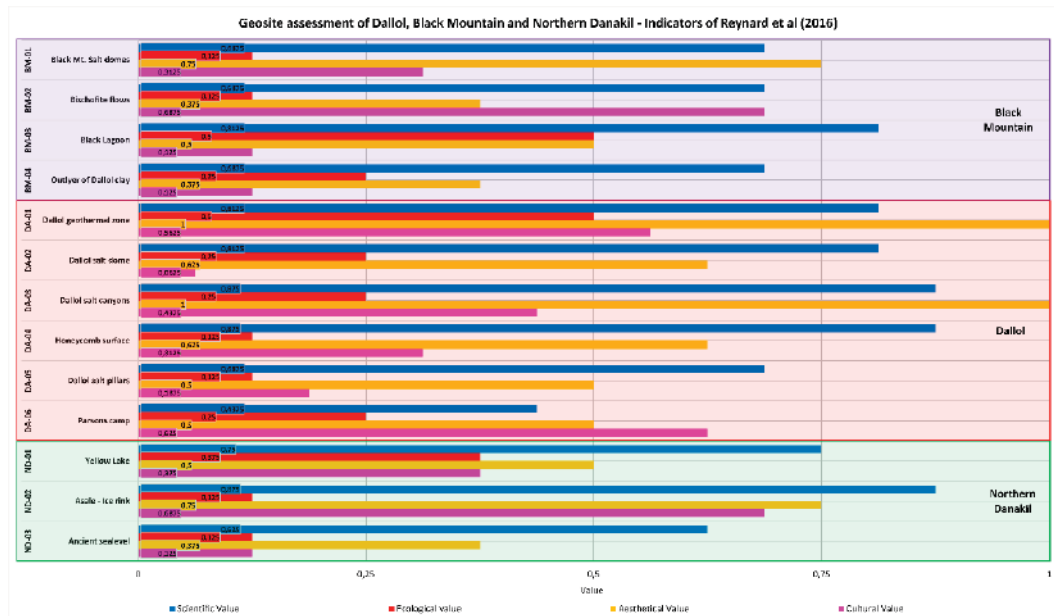


Fig. 4.14 Results of geosite assessment using the method of REYNARD ET AL., (2016) with the individual indicators

Two considerations appear as standalone indicators, which do not function as independent sets of values in other methods, or which are partially absorbed into an evaluation question. The *Functional Values* of VUJIČIĆ ET AL. (2011) are not direct elements of touristic development, such as road infrastructure, but they are an essential framework of it. Differences between the obtained values are minimal, since the (lack of) infrastructure is uniform across all the territory of the *Northern Danakil Depression* (Fig. 4.12).

The other one is the *Cultural Values* of REYNARD ET AL. (2016), also treated as a separate indicator group. Because cultural references are not evaluated in detail, both BRILHA (2016) and VUJIČIĆ ET AL. (2011) restrict cultural values to a single question, *Additional Anthropogenic Values* and *Association with other Values*, respectively. This specific evaluation gives a current overview from the viewpoint of general cultural representation in geoscience literature and personal feedback from local guides, but future consultation with experts on the Afar culture and local people itself could improve the concept about the cultural impact of the geosites. Significant scores are related to sites of geohistorical importance and landmarks for the European explorers and miners, such as the *Black Lagoon* or the mining camp of *Parsons' Co. The Asale - 'Ice rink'* and the geothermal zone of *Dallol* are also important sites for the local population, functioning as a landmark and water source, respectively (Fig. 4.14).

IV/C/3/b Visualisation by Scatter Plots and Their Interpretation

The second type of visualisation was proposed by VUJIČIĆ ET AL. (2011) in the form of a scatter chart (Fig. 4.15). The *Main Value* of the site, calculated by the sum of *Scientific/Educational*, *Scenic/Aesthetic* and *Protection* values, is plotted against the *Additional Values* made up of *Functional* and *Touristic* indicators. Although not described by REYNARD ET AL. (2016), a similar representation can be done for this as well, because the concept of the evaluation is similar. In this case, *Scientific Value* is the *Central Value* that could be plotted against the *Additional Values* made up of *Ecological*, *Aesthetic* and *Cultural* indicators (Fig. 4.16). BRILHA's (2016) method is different, as it does not create a final ranking based on a summation of the sets of values, but rather treats each of them separately, as seen on Fig. 4.13. However, apart from the *Degradation Risk* which is not considered as a value (BRILHA 2016), the three sets of values (*Scientific*, *Potential Educational* and *Touristic*) can also be visualised, but preferably on a 3D scatter plot where each indicator set has its own axis (Fig. 4.17).

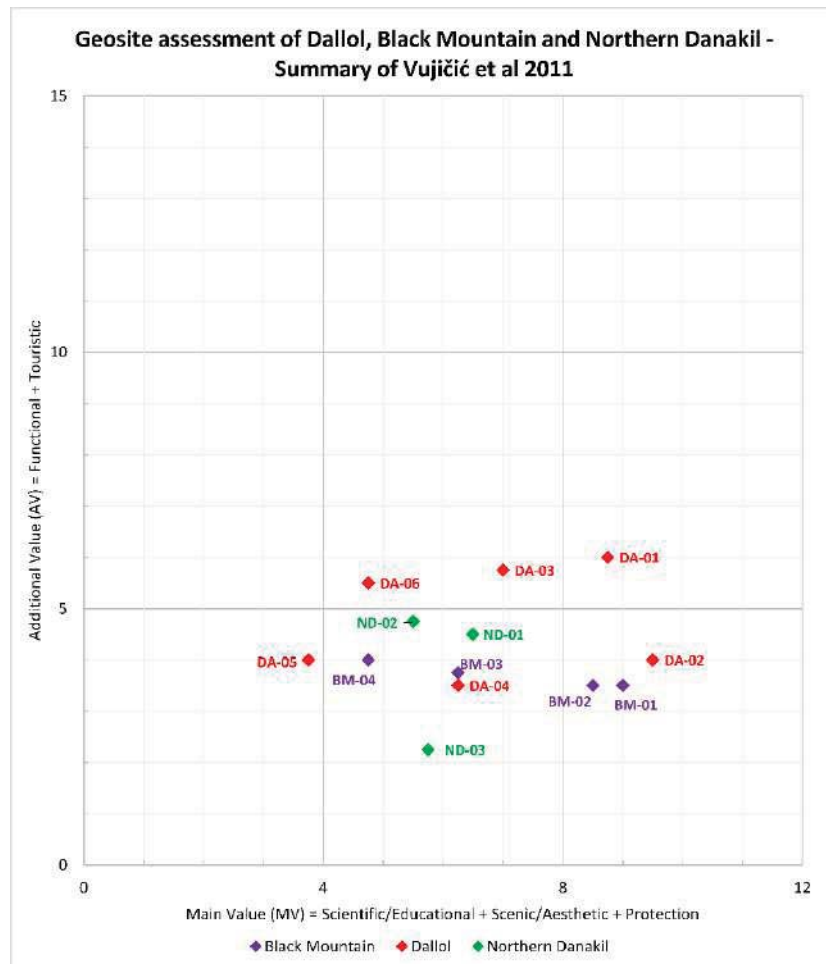


Fig. 4.15 The GAM matrix, the scatter of plot of the results using the method of VUJIČIĆ ET AL. (2011)

In comparing the positions of geosites in the scatter charts for each method (Figs. 4.15, 4.16 and 4.17), significant differences can be seen relating to the disparate number of sub-indicators included

on the axes. Aesthetics are treated as a *Main Value* by VUJIČIĆ ET AL. (2011) (Fig. 4.15), while REYNARD ET AL. (2016) included it in the *Additional Values* (Fig. 4.16). Aesthetics obtain high scores generally with both methods as described earlier; however, the different summation methods strongly affect the position of the geosites in the chart. The higher number of criteria for *Scientific Values* for BRILHA (2016) and the numerous sets of values for *Main Values* by VUJIČIĆ ET AL. (2011) give a more dispersed array on this axis in both cases, while the *Central/Scientific Value* of REYNARD ET AL. (2016) only depends on the 4 sub-criteria; therefore, values of geosites in this respect tend to be close to each other (Fig. 4.16).

In all cases, the scientific indicator group has moderate to high scores, marking the scientific importance of the selected sites, and indicating that they should be validated as geosites. The only exception is the *Parsons' Mining Camp* (DA-06): applying both the BRILHA (2016) and REYNARD ET AL. (2016) method, it gets lower scores, because the geohistorical importance of the site is significant, but the intrinsic value of the geological features observable here, such as the highly eroded salt pillars, is moderate or low. In the case of the method of VUJIČIĆ ET AL. (2011), the salt pillars of *Dallol* (DA-05) get the lowest *Main Value*, related to their moderate aesthetic value and vulnerability (Fig. 4.16).

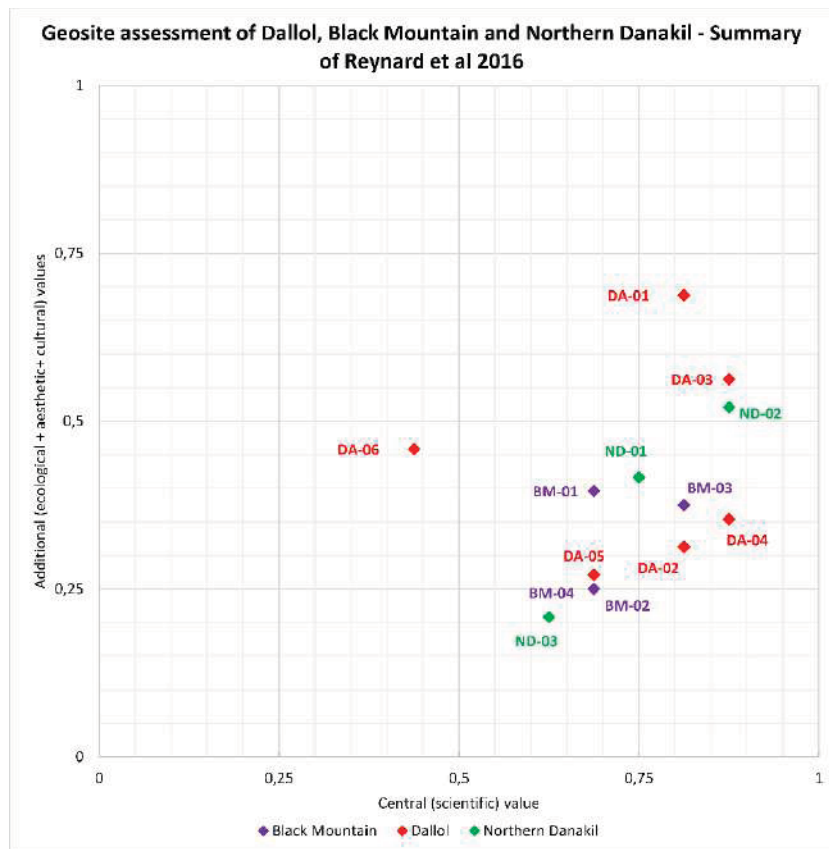


Fig. 4.16 Scatter plot of the results using the method of Reynard et al. (2016) and applying the visualisation of VUJIČIĆ ET AL. (2011)

Additional values are more concordant, with differences connected to the divergent input criteria. Both in the case of the method of VUJIČIĆ ET AL. (2011) and REYNARD ET AL. (2016), these values are moderate to low (Figs. 4.15 and 4.16). Sites already visited by tourists score higher; therefore, their present touristic potential is already higher: for instance, the geothermal zone of *Dallol* (DA-01), the *Yellow Lake* (ND-01), the *Asale – ‘Ice rink’* (ND-02) or the salt canyons of *Dallol* (DA-03). The same pattern is observable with the *Potential Touristic Value* of BRILHA (2016) (Fig. 4.16). However, even these cases barely score 50% of possible values, indicating that they are not yet exploited sufficiently from the perspective of tourism. However, these results should be looked at within the context of each site, including aspects of their management. For example, geotouristic development of the outcrop of the Pleistocene sea level is not possible without reducing the vulnerability of the site (degradation of the roadcut outcrop), indicated by BRILHA’S (2016) evaluation method (Fig. 4.13).

Geosite assessment of Dallol, Black Mountain and Northern Danakil - Summary of Brilha (2016)

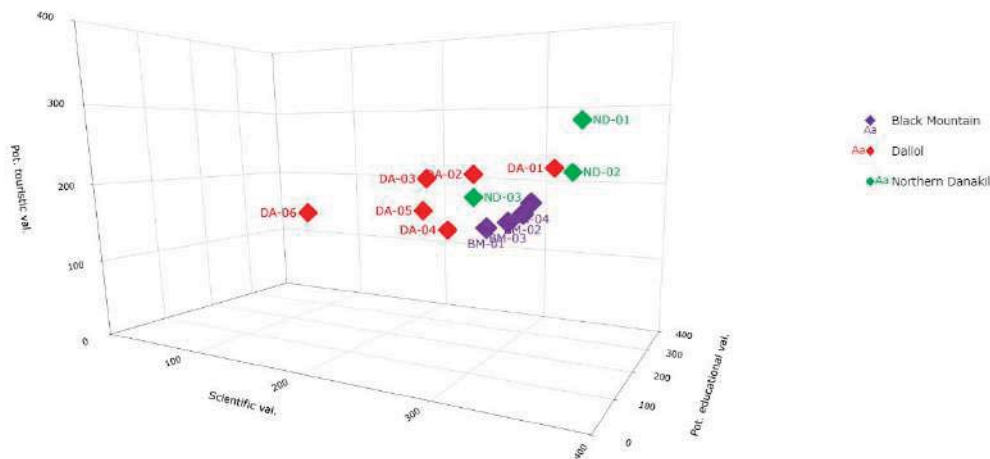


Fig. 4.17 3D Scatter of plot of the results using the method of BRILHA (2016) without the Degradation Risk

IV/C/3/c Quantitative Comparison of the Assessment Methods

For the quantitative comparison of different assessment methods, the primary indicators applied in them were grouped as follows.

- Scientific and educational indicators such as *Scientific Value* (SV) by both BRILHA (2016) and REYNARD ET AL. (2016) and *Scientific/Educational Value* (VSE) by VUJIČIĆ ET AL. (2011). The *Potential Educational Value* (PEU) of BRILHA (2016) was also placed in this group (see below).
- Touristic indicators (*Touristic Value* (VTr) of VUJIČIĆ ET AL. (2011) and *Potential Touristic Value* (PTU) of BRILHA (2016);

- Aesthetics indicators (*Scenic/Aesthetic Value* (VSA) of VUJIČIĆ ET AL. (2011) and *Aesthetic Value* (AEST) of REYNARD ET AL. (2016);
- Protection and vulnerability indicators (*Protection Values* (VPr) of VUJIČIĆ ET AL. (2011), *Degradation Risk* (DR) of BRILHA (2016) and *Ecological Value* (ECOL) of REYNARD ET AL. (2016).

Functional Value (VF_n) is a fundamental factor for VTr, but it is not directly connected to touristic values according to VUJIČIĆ ET AL. (2011); therefore, it was not included in any of the groups, in the same way as *Cultural Values* (CULT) of REYNARD ET AL. (2016).

The assessment methods use different scoring systems, 0–1 in VUJIČIĆ ET AL. (2011) and REYNARD ET AL. (2016), and 0–400 (with a weighting) in BRILHA (2016). In order to compare the results, each value was recalculated as a percentage of the maximum score. For each group of indicators, minimum, maximum, average and standard deviation values were calculated and plotted on charts with the percentage values of each assessment method (Figs. 4.18, 4.19, 4.20, 4.21, 4.22).

Scientific values are assessed with four sub-indicators using the method of VUJIČIĆ ET AL. (2011) and REYNARD ET AL. (2016), contrary to BRILHA's (2016) seven sub-indicators for the same. Comparing the obtained values and patterns (Fig. 4.18), the percentages of VUJIČIĆ ET AL. (2011) represent one of the extremities (minimum or maximum) in all 13 cases, while the same applies to the method of REYNARD ET AL. (2016) in 11 cases (except the Outlier of *Dallol* clay and the *Parsons'* Mining Camp). In seven cases, they are at the opposite side of the range, while at 3 geosites (DA-01, the geothermal zone of *Dallol*; DA-02, the central salt dome of *Dallol*; and ND-01, the *Yellow Lake* in Northern *Danakil*), they both score the maximum or minimum values.

These 3 sites were amongst those with the lowest range of values and the lowest standard deviation. The similarity of scores for these geosites obtained by all methods underlines that their scientific significance is well-established, either low (DA-06, *Parsons'* Camp) or relatively high (BM-01, DA-01, DA-02, ND-01, ND-03).

The values achieved from BRILHA's (2016) method highlighted two sites: they are the lowest values for DA-02 and DA-06. For 6 out of 13 cases, they range between the values obtained by the other two methods. This could be related to the higher number of criteria in BRILHA's (2016) method, as well as the different question content for each method. VUJIČIĆ ET AL. (2011) and BRILHA (2016) used well-defined scoring for every criterion (e.g. ranges for the number of publications about the area), while the method of REYNARD ET AL. (2016) is more flexible, with considerations for evaluation defined rather than distinct values.

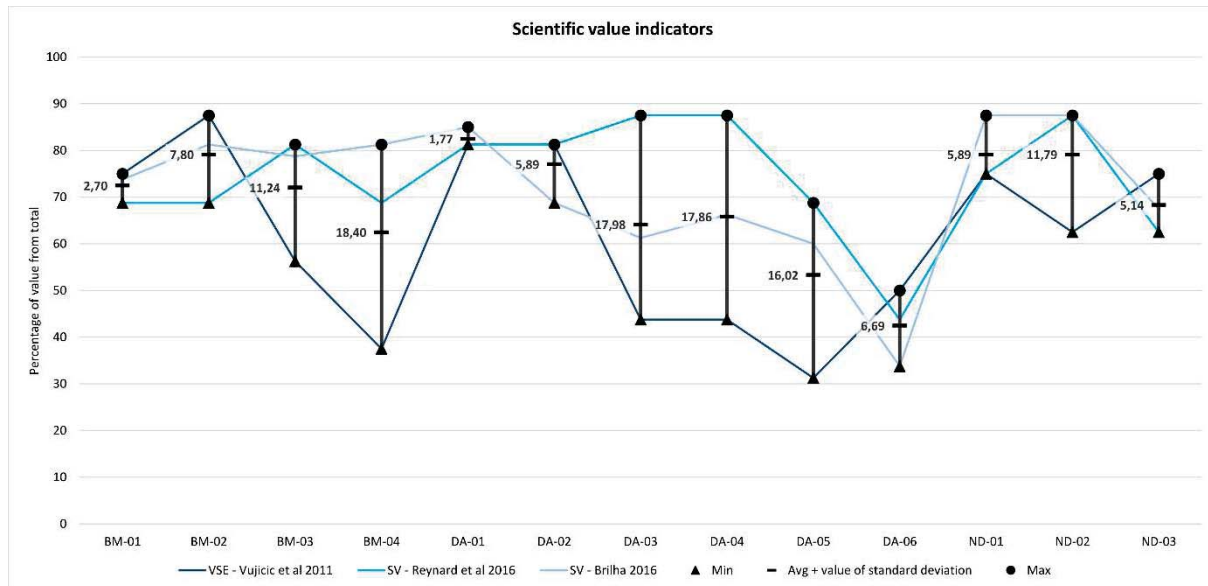


Fig. 4.18 Scientific value percentages per indicators using the method of VUJIČIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016)

According to BRILHA (2016), the *Potential Educational Values* (PEU) of geosites should not be summed with the other sets of values. However, in order to include this indicator in the comparison, we merged it with the *Scientific Value* by their arithmetical mean, based on the similar concept of *Scientific/Educational Value* in VUJIČIĆ ET AL. (2011). This approximate summing generally decreased the scores of BRILHA (2016) due to the limited educational potential of the area (Fig. 4.18). Even so, highest values were reached for 6 sites compared with 13 for VUJIČIĆ ET AL. (2011) and 11 for REYNARD ET AL. (2016).

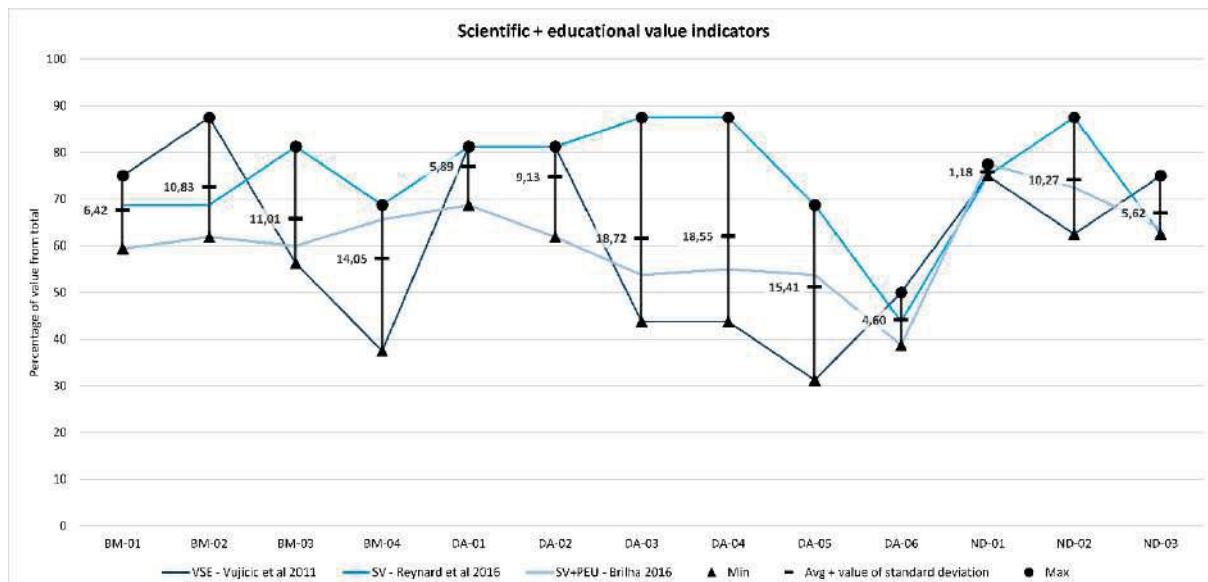


Fig. 4.19 Scientific value percentages including the potential educational value of BRILHA (2016) per indicators using the method of VUJIČIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016)

Indicators concerning the protection and the vulnerability of sites are included in all methods (Fig. 4.20). Following the BRILHA (2016) method generally awards the highest scores as it focuses

on the potential degradation of the geosites, which was considered generally high due to the active geologic (geothermal manifestations) and geomorphic processes (erosion of salt formations, vulnerability of sites next to roads). In contrast, REYNARD ET AL. (2016) evaluate the lack of legal and practical protection of geosites with low scores as these features are within the scope of *Ecological Value* (ECOL). VUJIČIĆ ET AL. (2011) give intermediate scores, since both the current protection level current condition, and the vulnerability of the site are included.

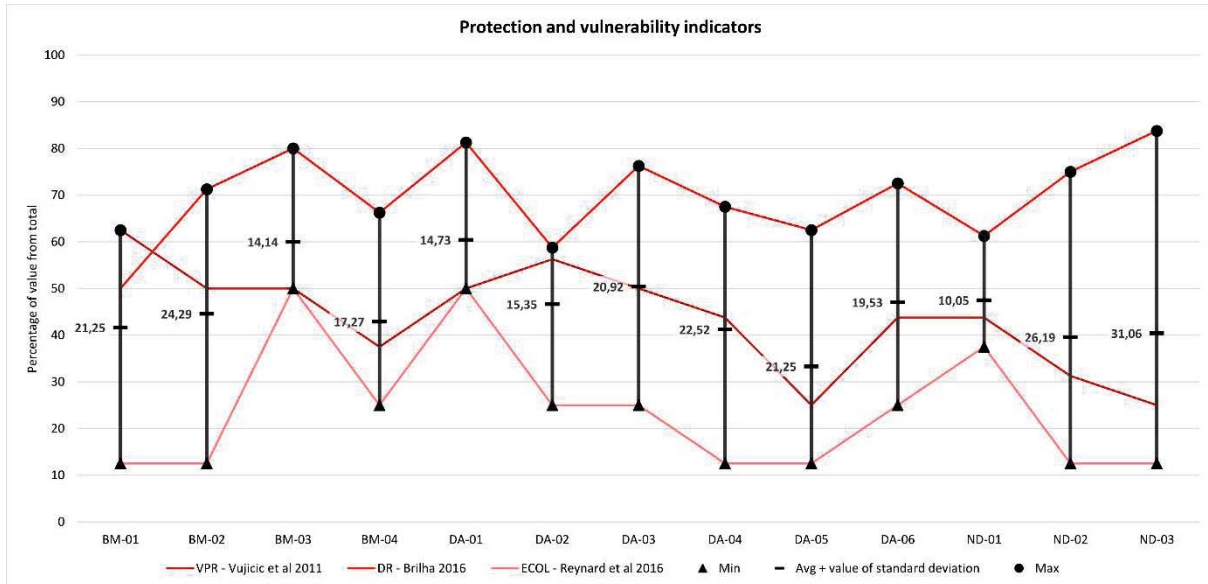


Fig. 4.20 Protection and vulnerability value percentages per indicators using the method of VUJIČIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016)

The prominent difference of touristic scores between the evaluation of *Potential Touristic Value* (BRILHA 2016) and *Touristic Value* (VUJIČIĆ ET AL. 2011) is related partially to the number of criteria used for the evaluation (Fig. 4.21). The former uses 13 criteria in total, while the latter is restricted to 9. The structure of these questions also follows a different approach. VUJIČIĆ ET AL. (2011) measure the existence of touristic facilities (e.g. interpretation centres, restaurants) directly, in contrast to the more generalised sub-indicators of logistics of BRILHA (2016). The lack of infrastructure resulted in minimum values for the GAM.

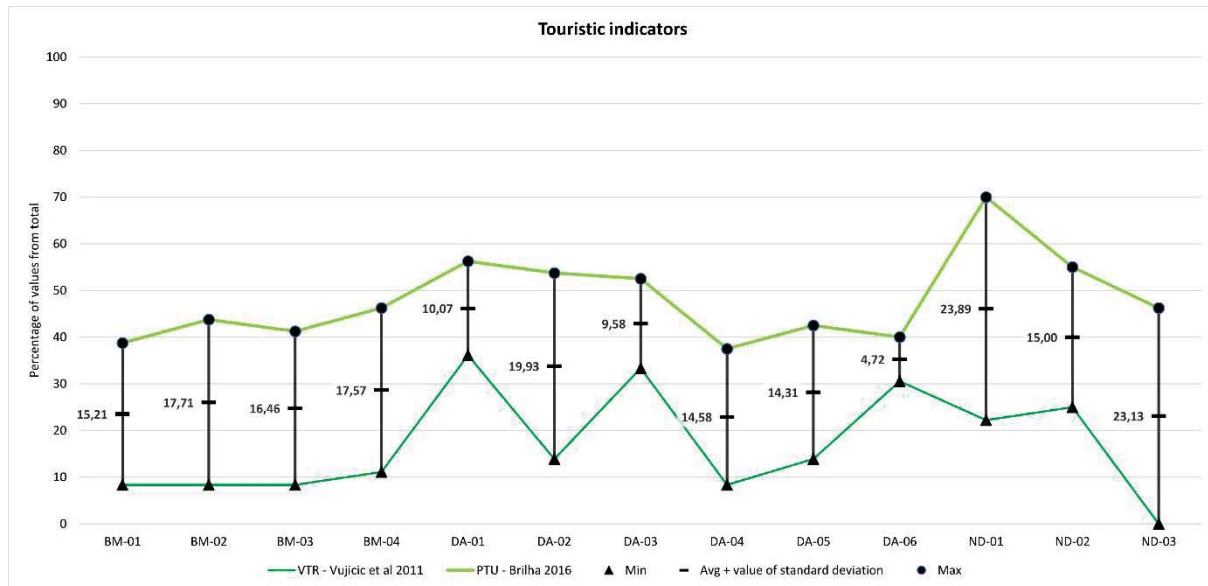


Fig. 4.21 Touristic value percentages per indicators using the method of VUJIČIĆ ET AL. (2011) and BRILHA (2016)

Aesthetics as an indicator was only measured by VUJIČIĆ ET AL. (2011) and REYNARD ET AL. (2016). Contrary to the previously described variables, in this case, the dispersion of values is generally low, with no clearly visible trend between the two evaluations (Fig. 4.22), although the constraints in VUJIČIĆ ET AL. (2011) are more restrictive than the basic guidelines of REYNARD ET AL. (2016). It might be connected with the subjective nature of aesthetics, compared with the more objective indicators of scientific relevance, tourism, etc.

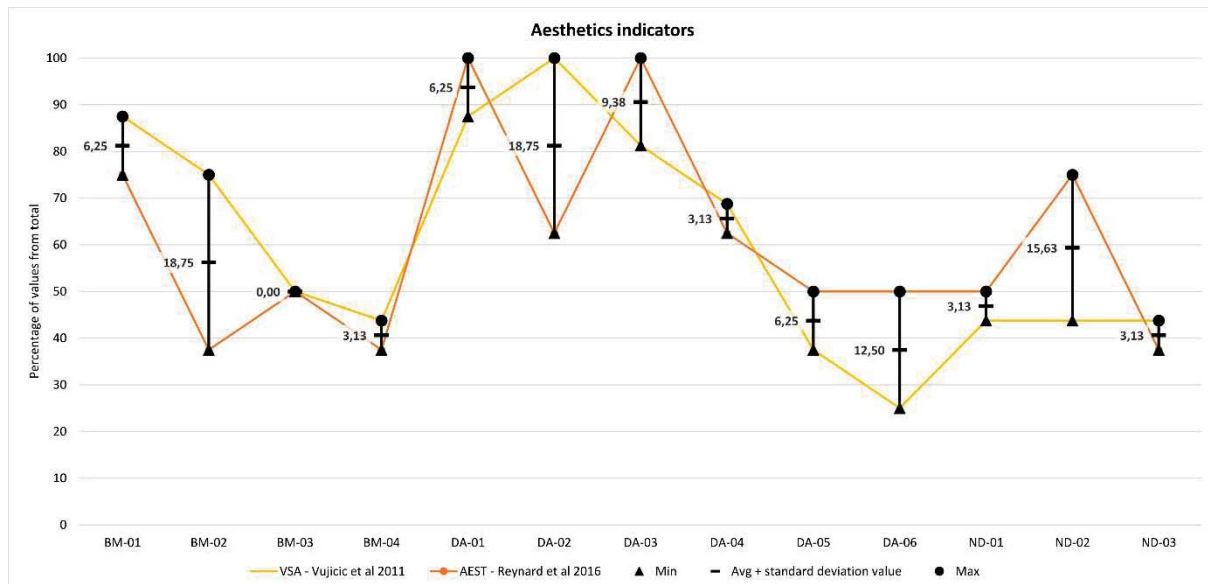


Fig. 4.22 Aesthetic value percentages per indicators using the method of VUJIČIĆ ET AL. (2011) and REYNARD ET AL. (2016)

IV/C/3/d Comparison of Assessment Methods at Dallol

Although the chosen geosite assessment methods of VUJIČIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016) have different structures and considerations (therefore, they may be

used effectively for different purposes in the broad domain of geoheritage), their quantitative results indicate a similar status for *Dallol*, *Black Mountain* and the selected sites of *Northern Danakil*.

The scientific value of the geosites is significant in almost all cases, and the quantitative evaluation has confirmed the conclusions of HOLWERDA & HUTCHINSON (1968), GEBRESILASSIE ET AL. (2011) and FRANZSON ET AL. (2015) about the globally outstanding geological features of the *Danakil Depression*. However, their legislative and effective protection is insufficient (or non-existent), while their vulnerability is significant due to the highly active and rapidly changing natural processes.

All these conditions call for a dedicated plan for geoheritage management. Any management strategy should include considerations for geotourism. The results of the three evaluation methods clearly show that the current geotouristic potential of the geosites of *Dallol* is low, due to the lack of infrastructure, the long-term vision of management, the extreme climate and the regularly strained socio-political conditions. Therefore, significant efforts should be made to improve basic accessibility and interpretation of the area for tourists, while preserving the scientific values and paying attention to the potential hazards, such as vulnerability due to natural and anthropogenic factors.

Each assessment method has proven to be successful in giving a complex overview of the geoheritage of *Dallol*, but they highlight different aspects. For geotouristic development studies, we think that the method of VUJIČIĆ ET AL. (2011) gives the most comprehensive overview, with the directly tourism-focused questions and the related functional and aesthetics considerations, although the method of BRILHA (2016) contains a higher number of dedicated criteria under *Potential Touristic Value*.

Assessment of the educational potential of geosites/geodiversity sites was not the primary goal of this study due to the geographical and economic issues of possible school visits to the sites and the complexity of interpreting features. However, the large number of indicators of *Potential Educational Value* in the method of BRILHA (2016) gave relatively low scores, showing that with a room for development, the area should be a key example for higher education in the long term. It might also be included in the curriculum of local Afari pupils, and it could become a global example using virtual or remote methods, thus minimising the need for visits, which cause risk problems for the site and the visitors.

From the viewpoint of geoconservation and geohazards, the vulnerability and protection indicators are crucial. BRILHA's (2016) *Degradation Risk* gives the clearest interpretation of the vulnerability of sites, especially for the constantly changing geothermal features, while the methods

of REYNARD ET AL. (2016) and VUJIČIĆ ET AL. (2011) put emphasis on the lack of protection, therefore the need for legal and effective protection of the sites.

Finally, in terms of the scientific values, which should be considered the primary goal of any geosite assessment (BRILHA 2018A), all of the methods indicated a significant importance, despite their different evaluation criteria.

From the viewpoint of the evaluator, every method used shows advantages, while in other aspects, they perform less well compared with the others. The clear workflow or road map from the selection of sites to their assessment and synthesis in REYNARD ET AL. (2016) and BRILHA (2016) could be used not only for these quantitative and qualitative assessments, but could also function as a standard for geosite assessments globally.

The well-defined scoring system of VUJIČIĆ ET AL. (2011) and BRILHA (2016), with constraints on each value, reduces the subjectivity of evaluators, and makes it possible to compare the results with similar assessments of other areas. However, the given constraints are not scale-dependent; therefore, they might result in lower or higher scores, if adjustments to local conditions were not made. REYNARD ET AL. (2016) is more flexible in this way, offering guidelines for each criteria rather than constraints, but this might be more subjective.

In terms of visualisation of results (important for decision-makers), VUJIČIĆ ET AL. (2011) proposed a clear, easy-to-understand method with the GAM matrix and REYNARD ET AL. (2016) presented numerous ways of cartographic representation, while BRILHA (2016) did not provide any suggestions on creating visuals. Considering the representation on charts, we have pointed out that the scatter plot visualisation of VUJIČIĆ ET AL. (2011) is also applicable to REYNARD ET AL. (2016) and BRILHA (2016) (in the form of a 3D scatter chart for the latter). It is also important to note that each indicator should be looked at independently (BRILHA 2016), because summation or creation of a final ranking might hide conceptual details that can only be interpreted through the raw scores.

We are convinced that while each method has some benefits, the parallel use and comparison of multiple assessment methods would provide the most robust way of I) characterising geoheritage values and II) raising appropriate questions required for development. Parallel application of a national, locally used method and an international one, or comparison of a number of international methods such as in the present paper are equally advantageous. There is no question that the application of the well-defined international quantitative methods, even though they require extra time, is worthwhile due to the more diverse overview of characteristics they give.

IV/C/3/e Geohazards Resilience in Geoconservation and Geosite Assessment

The methods presented here, as well as other ones, focus on the evaluation and protection of geoheritage, and tend to minimise or ignore the risks posed to visitors. In a hazardous environment, such as *Dallol* or other highly changeable areas, this is a serious shortcoming, which should be improved in the future by adding independent criteria assessing the hazards of the area, vulnerability of visitors, and thus the overall risk of the sites. The impacts of a hazardous event or a simple tourist accident could also be taken into account. The resilience of the local system depends on the number of visitors, the preventive education and preparation, and the mitigation in place (e.g. rescue or treatment facilities). At present, we would say that the level of resilience is low at *Dallol*, while the risk is significant, due to the geothermal and potential volcanic hazards, and the high vulnerability of tourists given the lack of prevention infrastructure and measures.

Our monitoring mission, the deduced hazard values and maps along with the safety proposals take an initial step in this direction. We suggest that the next steps should be the inclusion of hazard, vulnerability and risk assessment methods (e.g. RANKE 2016) in geoheritage studies, and the elaboration of special hazard/vulnerability indicators for geosite assessment methods and geodiversity management practices. It should be integrated into a holistic approach, where the often separately conducted studies on the elements of natural and cultural diversity, the assessment of risks and their mitigation are put together into a complex heritage management plan (*Fig. 4.23*).

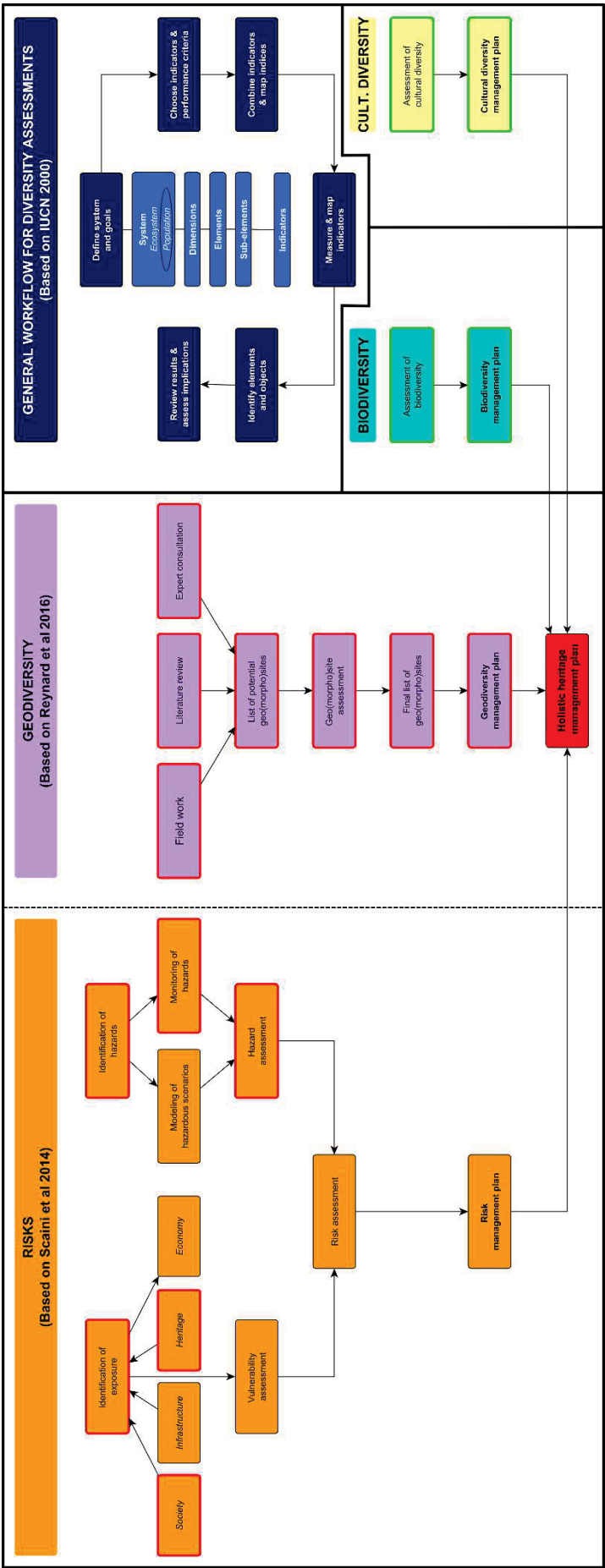


Fig. 4.23 A schematic proposal for a holistic heritage assessment and management approach. Red outlines indicate the steps carried out in the current research at Dallol, while green ones indicate steps carried out by Yara Inc. (ERM 2015)

IV/D A Preliminary Management Plan Proposal for Geoconservation and Geohazard Resilience - Synthesis

A set of geoconservation and geohazard management guidelines were created based on the considerations of local geology, our preliminary satellite monitoring and comparative geosite assessment, as well as discussions with local stakeholders (experts from the *University of Mekelle*, local guides and Afari people).

We also took into account geoheritage aspects of other rift environments (such as the *Chaîne des Puys - Limagne Fault*, and *Lake Malawi*), and expanded the existing geomorphological heritage management proposal for the *Simien Mountains* in Ethiopia (MAUERHOFER ET AL. 2017).

While our proposal does not function as a fully-fledged management plan, it is a compilation of recommendations and ideas, which could be used for discussion on the implementation of conservation and development plans related to the geoheritage of *Dallol* and *Northern Danakil* (VEREB ET AL. 2019).

IV/D/1 In Situ Monitoring of Geothermal Activity at Dallol

The simple monitoring method, presented in this paper, provides a monthly overview of the extent of active and inactive geothermal areas, in particular the changes to bischofite flows, through satellite image interpretation. This can be expanded to include thermal images from satellites like *Pléiades* or *ASTER*. In order to gain deeper insight into the geothermal system, including changes in gas flux, fluid composition and temperature, an in situ monitoring system should also be installed. Investigation of the central crater of *Dallol* with the geothermal manifestations, the *Black Lagoon*, and the bischofite flow area at *Black Mountain* requires the installation of at least a simple webcamera, but preferably thermal cameras as well (MCNUTT 1996, SPARKS ET AL. 2012). A long-term campaign aiming at the regular sampling of gas emissions and hydrothermal ponds is also needed, to expand present knowledge on chemical composition (DARRAH ET AL. 2013).

IV/D/2 Designation of Visitor Routes with Respect to Geohazard Mitigation and Resilience

At the time of writing (2019), visitors to the area do not follow a well-established trail, but rather a simple ascent through salt blocks from the ‘parking lot’. In the geothermal zone, they can wander around freely under the rough supervision of tour guides, and it is easy to ignore potential hazards. Based on the almost 3-year-long dataset of activity patterns, and the level 4 or 5 hazard category areas, a safe visitor circuit was designated in the central area of *Dallol* and around the *Black Mountain* (Fig. 4.24). It does not mean that the spectacular, constantly changing landforms and geological features should not be visited, but the circuit suggests the safest possible route. The visitors should

be informed of what to do (by their guides, an interpretative panel, a website or application), especially in the case of a crisis event. Paving the trail or installing any infrastructure is not proposed, mostly in order to preserve the original state of the landscape, and also because of the potential change to the trail location depending on future changes in geothermal activity. Installation of small signposts is recommended at constant distances (e.g. every 200–500 m) to clearly indicate the path and restrict walking off the trail.

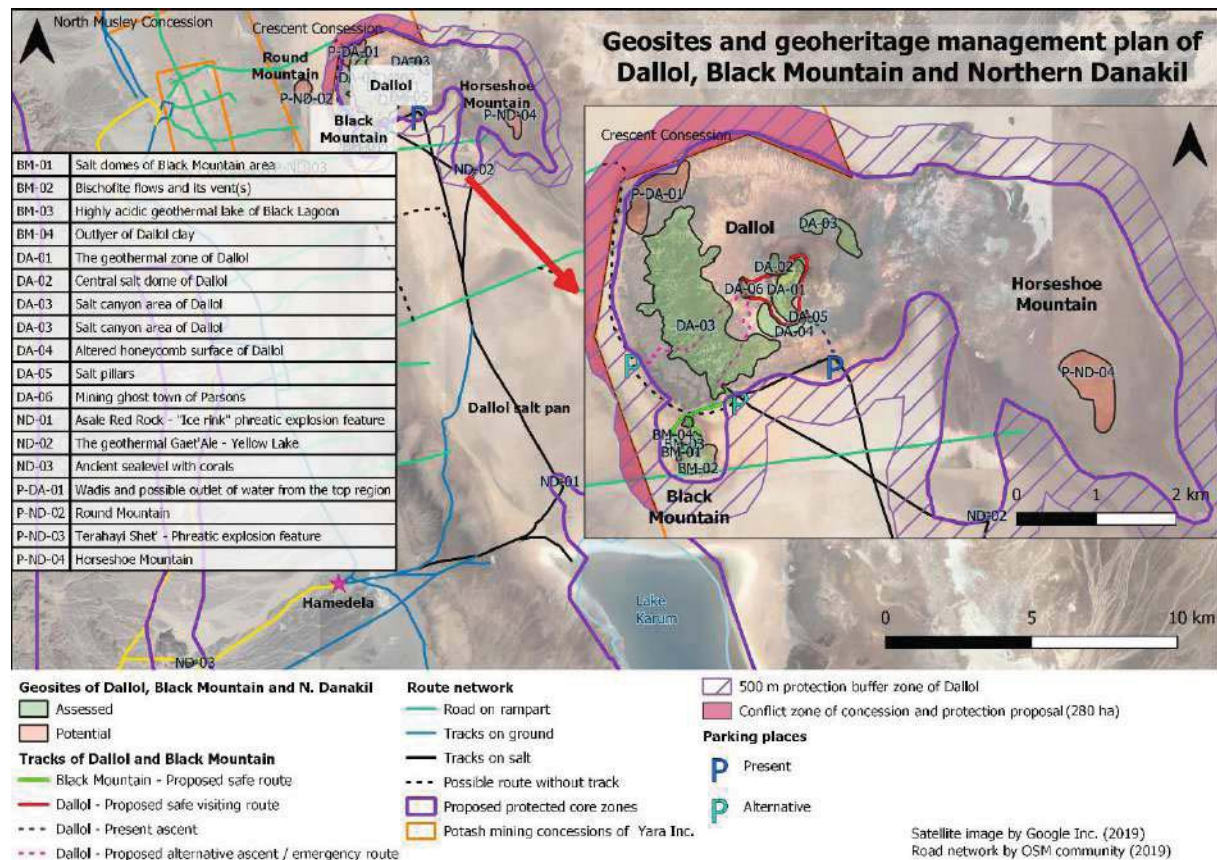


Fig. 4.24 Preliminary geoberitage management plan of Dallol and the Northern Danakil Depression

IV/D/3 Alternative Ascent to Dallol, Inclusion of Less-Visited Geosites in Tour Packages

The majority of visitors reach the area of *Dallol* from the south through the *Berbale - Hamed' Ela* paved road and then cross the salt pan of *Dallol*, starting their ascent to the central area from the closest 'parking lot'. To reduce the impact of linear pressure on the closest trail to the central 'crater', we propose alternative ascent routes (Fig. 4.24). Access by vehicles crossing south of the closest rampart of *Dallol*, or between the salt pinnacles and the *Black Mountain*, could also be possible.

A designated trail should run through the valleys of the salt canyon area through the *Parsons'* Mining Camp to the central 'crater'. A second alternative is to establish a starting point at the meeting of the salt canyons and the *Black Mountain*, from where a trail could lead through the valleys

between the pinnacles to the mining camp, and the circuit to the *Black Mountain* (Fig. 4.24). The latter is a partially existing route and regularly visited by tour groups. Each trail could be designated after consultation with tour guides and local Afari people, and the infrastructure requires basic signposting as well.

On the other hand, a preliminary investigation of increased visitor pressure on the hydrothermal system and the local ecosystem should be carried out before developing any trail. Alternative trails would not only reduce the pressure of present ascent routes but they could also function as evacuation routes in the event of hazardous natural events or accidents.

The majority of the tourist groups focus on the central area of *Dallol*, and some of them visit the southern salt canyon area, or *Black Mountain*. The *Asale- Ice rink* phreatic landform and the geothermal pond of *Yellow Lake* are also popular stops. In addition, new sites could be added to the present tour packages, or new geotours could be created following assessment of other potential, but presently poorly known sites (where even a general geological and geomorphological description is lacking), such as the *Horseshoe Mountain* area, and important outcrops of fluvial fans and bajadas of the *Balakia* foothills (Fig. 4.24).

IV/D/4 Interpretative Facilities

Currently, self-guided tours are not allowed in the *Danakil* and *Afar Depressions*: the area can only be visited in small groups with local Afari permission and armed escort. Therefore, infrastructure and methods for independent tours that work well in similar tourist destinations worldwide, such as geosites in geoparks, natural parks or World Heritage sites, are not applicable here, or only with modifications. However, certain measures could be taken in order to improve and supplement the personal interpretation of local guides. Installation of interpretation panels is not recommended due to the inexistence of self-guided tours, the general tendency of spending only a short time on geological explanations (MACADAM 2018), the exposure of information material to extreme conditions, and the need for maintenance and renewal. However, synthetic panels should be placed at the present and future starting points of walking tours and ascents to the trails (Fig. 4.23), where important information about the geological background of *Dallol* and *Danakil*, potential hazards and their mitigation, should be included. A long-term development might include a more extensive network of interpretative facilities, such as an optimised website or application, thanks to the constant improvement of mobile data coverage in the area.

A partial reconstruction of a building of the old *Parsons'* Mining Camp or installation of a traditional Afari-style hut at a safe distance might serve as a basic interpretation centre, illustrating the history of potash exploitation and the geothermal system of *Dallol* on some panels. It might also provide shelter and protection to tourists from the heat and unexpected events. An Afari-style

stick construction would not protect against hydrothermal explosions, but the salt brick one could offer a basic, temporary refuge.

IV/D/5 Training for Tour Guides

A significant number of tour operators provide guided tours of the *Danakil Depression* and *Erta Ale* (ETOA 2020). Although it is not stated explicitly in their tour packages, their activity is an indirect representation of geotourism, as the focal point of the visits here is the unique geoheritage of the area. Special courses for tour operators, background material and textbooks for tour guides about the geological phenomena could be implemented ensuring a scientifically correct, but understandable level of presentation. In the mid-term, a dedicated geotour service with qualified tour leaders should be established, with visits focusing specifically on local geoheritage (MAUERHOFER ET AL. 2017). Although a detailed study is not available on the composition of tour groups, the majority of the visitors are from outside Ethiopia; therefore, language courses for the guides are also crucial. Tour operators are generally located outside the *Afar Region*, especially in the *Tigray Region* and *Addis-Ababa*, with groups led by predominantly non-Afari people. In order to increase the involvement of the local population to boost the local economy, a higher number of Afari people could be included in the guided tours, who can contribute not just as escorts but also as guides, benefiting from their local knowledge of the environment.

IV/D/6 Geodiversity Management Plan on Potential Zones of Conflict of Interests

In order to exploit one of the most significant potash deposits on Earth (HOLWERDA & HUTCHINSON 1968), several concession zones have been designated. The so-called *Crescent Zone* is a 35.3 km² area exploration zone, awarded to *Yara Dallol Potash Project*, which surrounds *Mount Dallol* and the *Black Mountain* in a semi-circle from north to west. Originally, the area of *Dallol* itself was included in the concession zone, but it was relinquished by the ‘Ethiopian Mining Laws’ (ERM 2015). However, the exploration area is still directly adjacent to the outer perimeter of *Dallol*, and it includes potential geosites as well, such as the *Round Mountain* or the *Terabayi Sbet* phreatic explosion feature (Fig. 4.23).

The current ‘Environmental and Social Impact Assessment’ of the concession zone neither includes any reference to the geoheritage of the area nor does it provide a geodiversity management plan, in contrast to the biodiversity and cultural heritage management (ERM 2015). Moreover, the national legislative framework in Ethiopia does not make direct reference to geodiversity and management procedures and regulations (ASRAT 2018). However, as a temporary solution, ‘voluntary’ measurements are proposed for the concession companies (namely the *Yara Inc.*), in order to prevent possible disturbance of landforms and geological processes in the contact zones

of the concession and *Mt. Dallol*. In detail, we propose I) to add an at least 500-m-wide buffer zone to the concession contract, where exploration/exploitation activities would be limited, and II) to ensure the protection of important geological features and the hydrothermal system inside the concession zone as well (Fig. 4.23).

The exploration companies could also be included in the geoconservation and geotouristic development investments, as part of the social responsibility expectations of the project (e.g. sponsorship of geotour-guide formation, implementation of basic tourist infrastructure). They could also benefit from such work, because natural hazards could impact mining operations, and management of tourism could reduce disturbance to the resource operations.

IV/D/7 Legislative Framework for the Protection of Geoheritage in the Danakil Depression

Besides a small segment in the *Awash National Park*, the entire area of the *Afar rift*, including the *Danakil Depression*, lacks legislative protection both at a national and international level. The present study was restricted to the area of *Dallol* and selected parts of *Northern Danakil*, but the management and protection of the whole area should be considered, including sites and elements of the entire rift environment. Therefore, we propose that besides the ensemble of *Dallol*, and *Black Mountain*, further selected sites in the *Northern Danakil*, such as the salt pan of *Dallol* or *Lake Assale*, the surrounding *Balakia Mountains* and *Danakil Alps*, and the entire area of the *Erta Ale Range*, should be protected.

In line with the present Ethiopian legislative framework and regarding the importance of the area (PROCLAMATION 541-2007), a national park might be proposed, namely the *Afar Rift National Park* or the *Afar-Danakil National Park* (VREUGDENHIL ET AL. 2012), with a focus on the geoheritage of the area. However, it must be noted that certain studies such as TESSEMA ET AL. (2010) and ABEBE & BEKELE (2018) raised significant concerns about the relationship of local communities to Ethiopian national parks, especially considering their management structure and regulations, which prohibit or interfere with traditional activities such as grazing.

The broadest inclusion of Afari people, especially the recognition of the intangible heritage of traditional salt mining at the *Dallol* salt pan, would be crucial in the study area. This activity has strongly reduced in recent years due to the challenge from industrial salt extraction and livelihood discrepancies between traditional activities and better paying sectors, such as recent road construction or even the booming tourism. Therefore, any conservation plan should ensure a balance between different present-day economic activities of the area, namely tourism, traditional and industrial mining and nomadic lifestyles.

A considerable alternative national legislative framework is the establishment of community (wildlife) conservation areas (COUNCIL OF MINISTERS REGULATIONS 163-2008). Although this designation is dedicated primarily for the community management of wildlife areas, its goals with supporting the inclusion of local communities from management to even revenues could work well in the *Afari Region* too. While it may need customisation for geoconservation, even preservation of local, extremophile elements of flora and fauna should justify such form of protection.

In the mid- to long-term, the global importance of the site as a primary example of active rifting processes potentially merits an international designation. Well-selected areas of national legislative protection should be considered for one of the two UNESCO designations for the protection of geoheritage:

- The World Heritage Convention through criterion (viii) *‘to be outstanding examples representing major stages of earth’s history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features’* (UNESCO-WHC 2017)
- The International Geosciences and Geoparks Programme, the mechanism of international cooperation by which *‘areas of geological heritage of international value, through a bottom-up approach to conserving that heritage, support each other to engage with local communities to promote awareness of that heritage and adopt a sustainable approach to the development of the area’* (UNESCO-IGGP 2015).

The international significance of geoheritage is given for both designations, but for a definite choice between the two labels, several aspects have to be carefully considered. For example, the broadest inclusion of *Afari* people would tie in with the Geopark bottom-up approach. On the other hand, due to the unique geological ensemble of the area, the outstanding universal value for a World Heritage application would be justifiable, especially considering the fact that geoheritage is still under-represented on this list (DINGWALL ET AL. 2005). Even the precursory establishment of a national protection framework in the area, which is a prerequisite for all UNESCO designations, may affect this choice. The national park title supposes a stronger federal role in decision-making, which might be more easily transformed to a World Heritage site application, while community conservation areas or other regional, decentralised frameworks might back better the Geopark concept. The authors of this study do not wish to indicate which of the approaches would be best (this is a matter for the Ethiopian authorities, amongst others), but they recommend a feasibility study for both the national level protection, and international designations.

Evaluating the reality of the proposed geoheritage management plan, we should consider that the *Dallol* area is both of industrial and tourist importance, so the potential damage and benefits of

both areas should be integrated and weighed up. While it has been perceived that unconstrained mining might seriously damage the site, the impact of unconstrained tourism is potentially even more damaging. In addition, tourism and mining may both be affected by natural and socio-economical events, which can overlap, as illustrated recently (2013) when the *Yara* potash activities were affected by the formation of a large crater not far from the tourist routes (FRANZSON ET AL. 2015).

IV/E Conclusion

In this paper, we have addressed the problem of developing a geoheritage strategy for a poorly known and hazardous area, which is undergoing a tourist boom. Recent tourist deaths at volcanic and hydrothermal areas, such as at *White Island* (2019), *Stromboli* (2019), *Pozzuoli* (2016), and *Ontake* (2014), illustrate that there is a need to manage such geoheritage and tourist sites.

A holistic study of geohazards and geoheritage was presented on the globally outstanding, complex halo-volcanic dome structure of *Dallol* and the adjacent *Black Mountain*. Observations of ongoing remote sensing monitoring and a geosite inventory with multiple aspects were used to set out some important management principles for the area, a baseline for a geoconservation plan that takes into account resilience to geohazards, and anticipates potential problems of the present tourist boom.

First, the monthly variability of the main geothermal features has been studied from 2017 to the present (October 2019). This has shown an overall decrease in geothermal activity in the central zone of *Dallol*, for example in the reduction of acid ponds. For *Black Mountain*, the monthly monitoring confirmed that the surface of bischofite flow areas is renewed frequently; a new flow is generally traceable for only 3 months, followed by its erosion or disappearance below a new flow feature.

Each geological-geomorphological unit was associated with a hazard value according to observations from satellite images and field work validation, which served as input to a monthly, five-scale hazard map, published on a website (DALLOL 2020, <http://dallol.lmv.uca.fr>). It serves as a repository to follow up the rapid changes, and an advance information source for visitors.

In the second part of the study, a preliminary geosite inventory of *Dallol*, the *Black Mountain* and selected sites of *Northern Danakil* was made. Using parallel and comparative analysis of three quantitative methods of VUJIČIĆ ET AL. (2011), BRILHA (2016) and REYNARD ET AL. (2016), we were able to recognise the following

- Moderate to high scientific importance for the 13 geosites, some of which, such as ‘The Geothermal zone of *Dallol*’ (DA-01), suggests a global geoheritage importance.

- The current (geo)touristic values are limited due to the lack of dedicated infrastructure and no comprehensive management strategy; thus, there is a great potential for future development, an aspect also confirmed by the significant aesthetic values.
- Although the three methods chosen use different conceptual frameworks, the comparison of their results is possible. This could improve the objectivity of the geosite assessment, as the interpretation of results involves multiple perspectives.
- The assessment of geohazards is still not or only basically integrated into geosite assessment methods.

Finally, based on the results of our preliminary geoheritage assessment and the monthly monitoring project, a collection of geoheritage management guidelines was created, underlying key areas that could be addressed in detail in future studies:

- mitigation of geohazards in the active hydrothermal areas,
- future prospects for geotourism and education, with particular regard to improving the resilience of visitors through different geological phenomena (e.g. safety in active geothermal areas, effects of sea level changes on the example of the depression),
- considerations of legislative and effective protection: a holistic approach, connecting and cross-referencing detailed studies of disaster risk reduction, geoheritage and other elements natural (biodiversity) and cultural heritage (tangible and intangible).

These guidelines may serve as a basis from which further studies and documents could continue, with the expansion of the inventory to the whole *Danakil Depression* or the *Afar Rift*, and pursuit of the satellite monitoring in the long-term, reinforced by in-situ measurements. A broad collaboration of researchers from different domains, local inhabitants and natural resource exploitation companies is recommended for the valorisation of this globally unique area.

V Synthesis

The three study areas and the research conducted on them were different in many aspects. Although they are all volcanic areas with significant, often of international geoheritage values, the highly different geographical, socio-economical and heritage management practices and prospects called for a different approach at each place, both in the purpose and in the workflow for the geoheritage inventories. Site-specific issues have been already covered in the respective chapters; this final synthesis aims at giving some general, concluding thoughts, based directly on the experience of the study areas, and also thinking further about some of these issues. Some of the main points were already discussed in articles and conference presentations, but this chapter brings all together and further emphasizes the need for dealing with these issues, laying the ground for future discussions.

V/A Comparison and standardization

Chapter I/C showed that there is a plethora of geosite inventorying and assessment methods worldwide due to the different considerations for creating an inventory (such as scale, purpose) and also connected with the young and constantly developing nature of geoheritage as research domain (see *chapter I/B*). MUCIVUNA ET AL. (2019) counted more than 70 inventorying and assessment methods based on literature research, but there are probably more which are not published in English. Many of them were used locally for a specific project or purpose (e.g. during the establishment of a geopark) with no intention to be used in other (international) context, and some can be regarded as development steps towards more thorough methods.

With a strong simplification, geoheritage inventories and assessment methods can be seen as the interpretation of the abiotic values of a certain area, mostly from a geoconservation viewpoint, but often for geotourism as well. Studies on these inventories are ‘interpretations of these interpretations’. Studies which compared several assessment methods (such as KUBALIKOVÁ 2013, ŠTRBA ET AL. 2015) pointed out that each technique emphasized different aspects of a geosite, based on the distinctive values and indicators, used during each survey.

This thesis underlines the **importance and advantages of the parallel, comparative usage of geosite assessments**. Quantitative methods are relatively easy to carry out, therefore multiple iterations can be run for the same geosites in an inventory with different methods and/or carried out by different experts. A single interpretation method can already present the values of geosites, as was demonstrated by the majority of inventorying studies, or even *chapter III* of this work about *Clermont-Ferrand*, where the relative urgency of setting up the inventory was a limiting factor in this direction. However, as in the previously mentioned comparative studies— and *chapters II* and *IV*

inspired by them— pointed out, such parallel applications not only shed light on different aspects of a geosite. Also they can tell a lot about the assessment method itself, for example a need or possibility of adapting it to local conditions, or about any indicators that are missing, over- or underemphasized (also taking into account the original purpose of the method).

Comparative applications can be either carried out using a (future) global vs. national method, a national vs. internationally widely used one, or choosing methods with different purposes (geoconservation vs. geotourism emphasis). Parallel assessments would be welcome not only for research studies, but also for existing inventories and future applications, where the scientific publication of the results is not necessarily intended.

Currently (in 2020), there is no operational global geoheritage inventory (see *chapter I/C*), and there is no standardized, widely-used global method for international geoconservation projects. Research projects, aspiring geoparks therefore apply one of the methods from the plethora of available ones with or without modifications, or new techniques are compiled, incorporating previous ones or proposing significantly different workflows. The choice of a preferred method is often biased by the experts of the project, the amount of time and effort taken to read through previous literature, connection with other experts of the geoscientific community, or even institutional recommendations or requirements (e.g. student projects often tend to use and potentially develop methods of their supervisors).

Three of the methods used in this thesis (VUJIČIĆ ET AL. 2011, REYNARD ET AL. 2016, BRILHA 2016) are increasingly used in projects globally, but none of them has become standardized as a global recommendation. Studies of research groups with a synthesizing approach of previous methods (e.g. BRILHA 2016), or pioneering attempts of new proposals, are important steps for creating more sensitive and globally usable geosite assessment techniques. But, without a dedicated commitment of geoconservation organizations, the “market” of assessment methods will continue to expand, and the comparison of different protected areas and research projects will continue to be increasingly difficult. A primary commitment of this thesis was to add more insights into the discussion of methods with the interpretation of results, instead of creating new method(s).

Therefore, a second idea that the present work aims to emphasize is the **need for standardized and globally acclaimed geosite assessment method(s)**, under the auspices of relevant international organizations such as IUGS and/or IGGP. Such work should rely on the broadest collaboration of the international geoheritage community that might start from existing or planned research projects on inventorying; however, it has to be tested thoroughly globally, and has to incorporate the feedbacks of a broad number of research groups, geoheritage management bodies, etc. Some potential scenarios of global methodology are the following:

- A highly flexible, globally usable assessment technique, *I)* which incorporates the broadest circle of indicators (from scientific to additional values), *II)* could be rationally adapted to local conditions (e.g. values or percentages better following a territorial context, instead of fixed, global values for some indicators), *III)* or it could be even modular (not all components have to be assessed for a project). Such a method is not optimized for all territories or purposes globally (e.g. geotouristic development of an area), but gives a satisfactory description, and results that could be more easily put into a global context.
- An assessment method specifically for the geosites of international relevance that have been either selected by national / administrative unit-based geosite inventories, or by groups of experts. This technique could be also preferentially context-free, therefore not optimized for example for Asian vs. European sites, or karstic vs. paleontological frameworks and so on. It means that results might be different compared to a previously carried out national / territorial assessments, but the global comparability would be ensured. This initiative can be considered as the revival of the *Global Geosites* initiatives, as discussed in *chapter I/C*.
- The modular structure of an assessment method mentioned in the first scenario can be achieved also as separate techniques, optimized for different purposes. It means that there should be a recommended method optimized for geoparks or World Heritage sites for a fundamental scientific value estimation, a principally geotouristic approach, an ex-situ geoheritage method, etc.

It is important to note at this point that these scenarios should not lead to the neglect of existing methods, especially national frameworks. A global recommendation could be very helpful for protection frameworks under formation (e.g. geopark plans) or new geoconservation initiatives (e.g. new national / regional inventories) to prefer the choice of an assessment method, but the possibility would be still open for benefitting from other techniques. It should be stressed that the use of multiple methods is desirable.

V/B Considerations on the scale and purpose of inventories for site-specific management

From the four key requirements of geosite inventories proposed by LIMA ET AL. (2010), namely *the topic, the values, the scale and the purpose*, the latter two were especially emphasized by this thesis. Each study area was examined on a different scale with a different purpose, while their topics were highly overlapping, such as a general inventory of geoheritage, as well as the values, defined by the comparative usage of assessment methods, discussed in the synthesis *sections of V/A and V/C*. The

scale-dependency of the purpose of geosite inventories could be best illustrated through *chapters II and III*, the *Chaîne des Puys – Limagne Fault*, including both the World Heritage site and the adjacent city of *Clermont-Ferrand*, which shares the same geological background.

The currently (2020) inactive *Global Geosites* programme (see *chapter I/C*) does not contain any reference to this area, but the World Heritage title and its justification on the Outstanding Universal Value gives a strong testimony on the global importance of the site, just as the collective national geosite ‘AUV0122 – *Chaîne des Puys*’ (ARA DREAL 2020), where an international rarity is indicated. Should it be inscribed on such an inventory, it should cover *I*) the ensemble of geological phenomena, following the World Heritage limits (the monogenetic volcanoes, the associated fault line and the inverted relief of *Montagne de la Serre*), *II*) the more restrictive national geosite ‘AUV0122’ confined to the volcanic chain, *III*) or an even different area, including more (e.g. *Plateau of Gergovie*) or less elements, without territorial management considerations. Such **global geosite aims at showing the global geoheritage importance** of a site, with a sufficiently chosen – sometimes significant – territorial extent.

Geosites **in the national inventory** of France are collected on a regional base, and their **aim is to give the best examples of the geodiversity from certain geological frameworks on a national scale** (DE WEWER ET AL. 2006, 2014, 2015). It means that according to the geological process and the landform, the size of a geosites could be highly variable in order to comply with the scientific integrity. There are several examples in the *Chaîne des Puys*, where the integrity of a national geosite calls for the inclusion of the source (i.e. a scoria cone) to the complete territory of products (i.e. lava flows, the ‘*cheires*’), resulting in complex, often large features extending through various municipalities and land use types (e.g. AUV0021 - *Puy Laschamp*, AUV0027 *Puy de Côme*, AUV0088 – *Puy de Grave Noire*, AUV0100 – *Puy Louchadière*). In other cases, a compact, often small site, like AUV0094 - *Puy de la Poix*, mostly surrounded by a relatively homogenous environment, could include all elements of the selected geological phenomena in a small area.

Effective geoconservation is carried out through direct or indirect measures of site management: land use-restrictions, physical protection of the geosite with slope-stabilization or protective structures, interpretation and geotouristic ‘exploitation’ with simple facilities like trails or panels, or complex educational buildings and exhibitions. For compact sites with a limited territorial extent, often similar ownership-structure, physical and socio-economical challenges and possibilities, it is easier to compose an effective geoconservation strategy that could be more easily put into practice (like *Puy de la Poix* mentioned before). Complex geosites (often geomorphosites) – selected on a national or regional level – are definitely verified by their scientific integrity, but they can be hard to manage with effective geoconservation due to highly different conditions within

the site. Using the national geosite examples of scoria cones and lava flows from the previous paragraph:

- The scoria cones themselves almost all have steep, forested slopes, intersected only by occasional open-field crater (*Puy de Côme*, *Puy de la Nugère*), or by flank quarries (*Puy de Grave Noire*, *Puy de Louchadière*), and a limited road- or trail network. Forestry ownership might be highly fragmented, but the land use is generally homogenous, therefore they are well-interpretable elements of a dedicated geosite-management strategy, ensuring a balance between slope stabilization, preservation and interpretation of micro-forms, forestry and pastoral activities.
- The lava flow fields (locally called *cheires*) spreading into significant lobes or channelled into narrow sections comprise hundreds of microforms (pressure ridges, tumuli, levées, outcrops at frontal sections). These features all stretch over numerous municipalities and their land-use is highly variable from an almost complete forest-canopy (*Cheire de Puy de Côme*) through mostly mixed agricultural-forestry land usage (*Cheire de Puy de Louchadière*) to the almost completely urbanized *Puy de Grave Noire* lava flow. The unity of these features are important from a scientific viewpoint, and their holistic importance as water reservoirs and conduits calls for at least a policy level, cross-municipality treatment. However, from an effective geoconservation viewpoint, ownership and land-use considerations, and possibilities of interpretation, the large national geosites should be divided to smaller units, focusing on key, understandable microlandforms of a larger, holistic unit (e.g. quarries, direct outcrops, significant clusters of pressure ridges).

This was the principal consideration during *chapters II* and *III* in order to create **a more detailed and dense inventory** for the two study areas (the World Heritage site and the city), since a network **of geosites with compact, well interpretable extent could help with creating a management strategy for each site**. Importantly, such detailed inventories allowed also the inclusion of important sites, that have significant scientific or additional values and could be included in geoconservation strategies, although it was not sufficient enough for the inclusion on a national level.

The detail of subdivision depends on the purpose of an inventory and the context of geological elements. In the *Chaîne des Puys – Limagne Fault* example, the delineation of larger sites was possible because of: *I*) the more homogenous land-use, *II*) the limited relevance of ownership problems due to the strong protection frameworks, and *III*) the less significant disturbance by anthropogenic effects (urbanization, road-network). For example, scoria cones, series of important outcrops at a road section, and clusters of microforms on lava flows, could be treated as geosite

units, while there are small, compact point like features as well (springs, isolated microforms or outcrops).

In contrast, in the *Clermont-Ferrand* example, the extreme fragmentation – spatially and proprietary – of the holistic landforms (the *Grave Noire* lava flow, the sedimentary features of the northern neighbourhoods) called for a more fine-scale geosite selection. Geodiversity is almost suppressed to the remaining niches of individual outcrops and underground cavities. They could be more easily be adapted to a geodiversity action plan (DUNLOP ET AL. 2018) with a similar division strategy, as a separate management plan should be created for each site regarding geoconservation issues (e.g. slope stabilization) or potential of interpretation. Where the urban context allowed, larger units (geomorphosites) were also selected, such as *Creux de l'Enfer* (CF1217) or *Puy de Crouël* (CF1101).

An even more fine-scale description of the geodiversity and delineation of geosites is possible, as suggested by VAN WYK DE VRIES (2017), where the *Puy de Chaumont* scoria cone, which is a well interpretable, homogenous unit for an effective geoconservation strategy, was subdivided to several, small geosites, like fault lines, ravines and pyroclastic-flow deposit features. Such “micro-inventory” of geodiversity can be considered, like studies on the detailed interpretation of geomorphological landforms or thorough description of outcrops. They are valuable inputs for geoscientific research, and their results can be essential to the management of a specific site by delineating microforms to be preserved, or specially interpreted.

Finally, it is important to note that **geosite inventories**, created with the aim of **helping the effective geoconservation** of administrative units of protection frameworks, **should also treat geoscientific integrity as priority**. Selected geosites have to be a well-defined element of a geological framework and have to show an important and complete segment of a feature, to be standalone, or be clearly a part of a larger feature. Management considerations only mean that they are divided into units so that they can be handled effectively by the responsible stakeholders. For large units, where the high variety of the geological phenomena itself, the different land-use types, ownership problems, fragmentation or partial destruction by human influence do not allow an integrated management strategy, a holistic strategy should be still preferred, for example with cross-municipality policies, reinforced by national, regional or departmental units.

Finally, scale-considerations can be put into context with an example from cultural heritage. The castles of the *Loire Valley* are globally outstanding heritage of mankind. It comprises hundreds of castles (*châteaux*) extending from *Sully-sur-Loire* to *Chalonnes*, but on a global scale, it is one, complex area, acknowledged as one World Heritage site. The castles can be clustered into smaller groups by art historical considerations (royal vs. noble-built, early – late renaissance, etc.) or even by

geographical position (*Orléans-Blois* section, castles around the *Cher* river, etc.). The effective management is taking place castle-wise, because although they are connected by their historical context, each property requires a different management strategy due to building structure or ownership. A whole property is nominated generally as Historical Monument, such as *Villandry* with the castle itself, the gardens, and the interior furniture and relics included. However, an even more fine-scale register can be compiled, recording the principal plant or animal species in the gardens, the complete register of the interior equipment of rooms, etc. These special inventories can be both used for their scientific description, but could be well-integrated to the property management strategy as well.

V/C Interdisciplinary approach to geosite assessment methods and geosite management

The domain of geoheritage was born in an era, when interdisciplinary approaches had become more and more widespread, as global challenges called for cooperation between different fields of science. This was especially true for natural sciences, where environmental issues and in particular global climate change had called for joint efforts. Geoheritage inventories have the principal goal of recording the geoscience importance of the elements of geodiversity (BRILHA 2016), but additional values on biodiversity, cultural values or historical importance (either human history in general or the history of science) are already included in many of the commonly used methods (see selected examples of *chapter I/C*). It is a highly important approach, something which is also followed by the geopark concept, where the focus of conservation and interpretation is geology, but cultural and biological values are also emphasized (UNESCO-IGGP 2015). However, considerations of geosciences are generally underrepresented in inventories of biodiversity or cultural heritage, just like geoheritage in general in key international documents or even local decision making protocols.

The thesis examined the relation of geoheritage to resilience to geohazards through study areas of highly different context, also drawing up an initial concept of the most important aspects of this integrated approach (see *chapter I/E*). The geosite assessment methods used all contained indicators in some form for the aspects of resilience. Most of them regarded risks from a geoconservation viewpoint: the vulnerability of the site by natural or anthropogenic processes (e.g. VUJIČIĆ ET AL. 2011, BRILHA 2016), and their effective or legislative protection affecting vulnerability too (VUJIČIĆ ET AL. 2011, DE WEVER ET AL. 2015, REYNARD ET AL. 2016). The interpretive potential of geosites in terms of resilience does not appear directly, but in most of the methods the educational potential could be appropriate for covering these questions, especially in form of textual descriptions.

In terms of resilience to natural hazards, the hazard potential of geosites do not appear in internationally used geosite inventorying and assessment methods, only the vulnerability of the sites by natural or human induced degradation of its intrinsic values. Hazard or risk maps can already be available or can be compiled for an area with geoheritage values (as the thesis demonstrated in *chapter IV*), or site-specific hazards aspects can be interpreted (like some examples with slope stabilization in *chapter III*) or even formed into a strategy, but they are not integrated to the workflow of assessment methods. Therefore, this thesis would like to **call for including considerations on hazards into geosite inventories at a fundamental level**. It should be noted that in areas, where detailed risk assessment is not available, a geoheritage inventory could function as a basic approach, helping with the management of risks.

Geoheritage inventories are mostly carried out by geoscientists. Many studies and research projects focus on the connection of geoheritage with other aspects, such as resilience in this work, cultural heritage (e.g. FEPULEAI ET AL. 2017, SCARLETT & RIEDE 2019) or biodiversity (such as ŚWIERKOSZ ET AL. 2017). However, even with the broadest-scale of interest of geoscientist experts in other aspects of natural and cultural heritage, associated values of a geosite might not be interpreted and understood in such complexity, as by specific experts (e.g. on art history, taxonomy).

A recommendation of this work is that **the role of additional values in geosite inventories** should be emphasized besides fundamental scientific values. Assessment methods, especially with an aim of global utility, should include the broadest field of additional value indicators from biodiversity to culture, and from disaster risk reduction to tourism infrastructure or economic considerations. With a flexible, modular approach, the possibility would be open at any geosite to assess all these issues, but a partial or multi-stage evaluation of additional value would be also feasible.

For more effective heritage conservation strategies with a holistic approach, which help fostering geoheritage as one of its elements, the **interconnection with documentation, inventories and experts of other domains**, like cultural heritage management, territorial planning or tourism experts, should be developed. That means that during the compilation of geoheritage inventories, their opinion or results should be integrated in a way into the assessment process. It could be either a link to key documents, papers, or specific inventories (e.g. for biodiversity), or including a section, where their evaluation about geoheritage-related associated values (such as territorial management plans of the area, risk assessment results) should be included together with the evaluation of the same indicator by a geoscientist / geoheritage expert. On the other hand, the same interdisciplinary approach would be desirable in the related fields as well about geological

information, therefore including these considerations in cultural heritage or biodiversity inventories and reports, or territorial planning.

V/D Final remarks

Geoheritage has emerged rapidly in the last three decades, fulfilling more and more professionally and thoroughly the demand of this highly important, yet somewhat neglected aspect of natural diversity that surrounds us. Theoretical studies developed the framework of geoconservation, geoeducation and geotourism, and put into practice as usable inventorying methods, geoparks, protected or managed geosites, innovative educational programs of geosciences and outreach to the greater public by ‘geo-focused’ touristic initiatives and programmes. The domain of geoheritage has spread now globally, in some countries it already reached a remarkable success with a network of geoparks, well-established inventories, while in other places, the work has just started or should be initiated. Even in countries with advanced geoheritage practices, there is a room to improve, especially in terms of integrating results offered by studies on practice and policies.

The geosite inventories and their interpretation presented in this thesis hopefully function as inputs for further initiatives, strategies and policies, that help improving the resilience of local communities to natural hazards, either through lessened risks, or improved adaptivity to it through using the interpretative potential of geosites.

The work was supportive, where geoconservation has already reached significant results (*chapter II*), reactive, where extreme vulnerability and ongoing destruction of some sites called for action (*chapter III*), and proactive, where the global importance justified a study addressing some present and future challenges and questions of geoheritage (*chapter IV*).

These small mosaics could contribute to the larger picture of geoconservation in practice in the three study areas, and the even more extended field of geoheritage studies, and add the important element of risk and resilience to geoheritage.

ANNEXES

VI ACKNOWLEDGEMENTS

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^ **chapter I/B** (*The domain of geoberitage*)

> **chapter I/C** (*Inventorying geoberitage*)

∨ **chapter I/D** (*Disaster risk reduction and resilience*)

< **chapter I/E** (*The connection of geoberitage and resilience*)

□□ **chapter II** (*A detailed geosite inventory of the Chaîne des Puys – Limagne Fault World Heritage site*)

△△ **chapter III** (*The urban geoberitage of Clermont-Ferrand: from inventory to management*)

○○ **chapter IV** (*Geoberitage and Resilience of Dallol and the Northern Danakil Depression in Ethiopia*)

⊙ **chapter V** (*Synthesis*)

○○● example of a 'mixed' type of reference; an item, cited in **chapter IV** (see its symbol above),
chapter I/C and **I/E** (2nd and 4th in the 'quartile')

□△ example of a 'mixed' type of reference; an item cited in **chapter II** and **III**

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VIII APPENDIX

The appendix of the thesis contains those supplementary materials that could not be placed into the core of dissertation due to length constraints.

Contents

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Notes

The tables of the geosite inventories, containing the scoring of each indicators use abbreviations. For the method of REYNARD ET AL. (2016), these abbreviations can be consulted in *Table 1.2* in *chapter I*. For the methods of VUJIČIĆ ET AL. (2011) and BRILHA (2016), the decoding can be consulted in the following two tables.

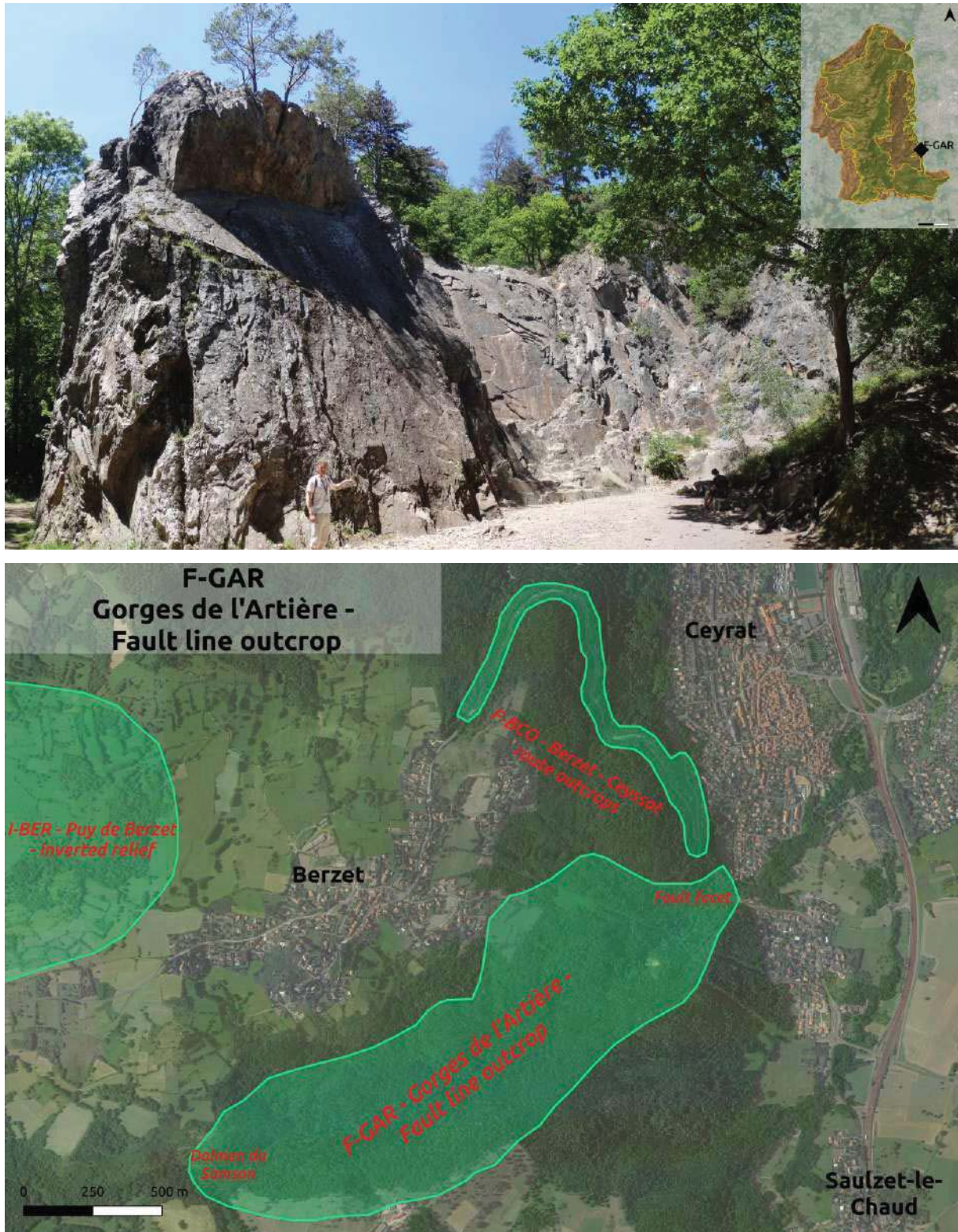
Table 8.1 Abbreviations for the method of VUJIĆ ET AL. (2011)

MAIN VALUES (MV)			ADDITIONAL VALUES (AV)	
Scientific/Educational (VSE)	Scenic/Aesthetic (VSA)	Protection (VPr)	Functional (VFfn)	Touristic (VTr)
Rarity (VSE_RAR)	Viewpoints (VSA_VP)	Current condition (VPR_CC)	Accessibility (VFfn_AC)	Promotion (VTR_PROM)
Representativeness (VSE_REP)	Surface (VSA_SF)	Protection level (VPR_PL)	Additional natural values (VFfn_ANV)	Organized visits (VTR_OV)
Knowledge on geoscientific issues (VSE_KGI)	Surrounding landscape (VSA_SLN)	Vulnerability (VPR_VU)	Additional anthropogenic values (VFfn_AAV)	Vicinity of visitors center (VTR_VVC)
Level of interpretation (VSE_LI)	Environmental fitting of sites (VSA_EFS)	Suitable number of visitors (VPR_SNV)	Vicinity of emissive centers (VFfn_VEC)	Interpretative panels (VTR_IP)
			Vicinity of important road network (VFfn_VIRN)	Number of visitors (VTR_NV)
			Additional functional values (VFfn_AFV)	Tourism infrastructure (VTR_TI)
				Tour guide service (VTR_TGS)
				Hostelry service (VTR_HS)
				Restaurant service (VTR_RS)

Table 8.2 Abbreviations for the method of Brilba (2016)

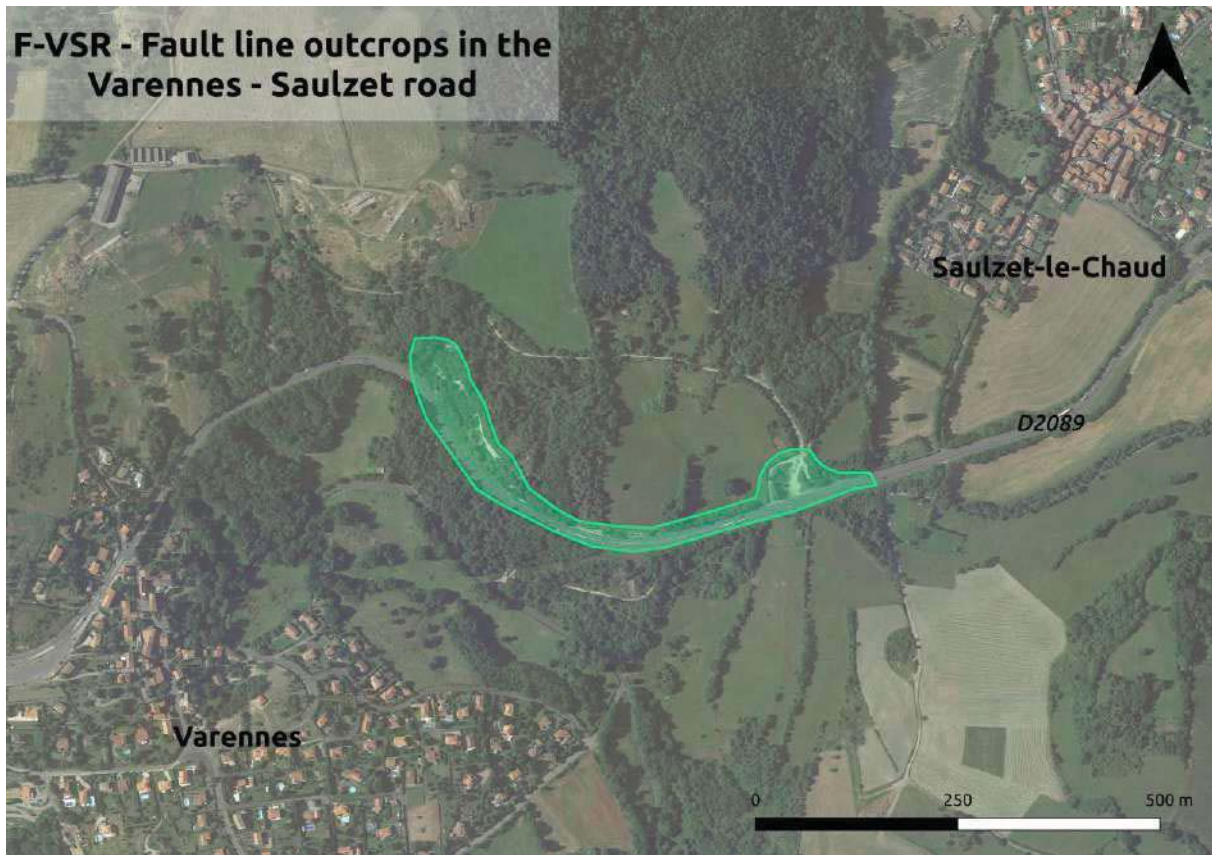
SCIENTIFIC VALUES (SV)	POTENTIAL EDUCA- TIONAL VALUE (PEU)	POTENTIAL TOURISTIC VALUE (PTU)	DEGRADATION RISK DR)
A. Representativeness (SV_A_Repr)	A. Vulnerability (PEU_A_Vuln)		A. Deterioration of geological elements (DR_A_DGE)
	B. Accessibility (PEU_B_Acc)		
B. Key locality (SV_B_KL)	C. Use limitations (PEU_C_UL)		B. Proximity to areas/activities with potential to cause degradation (DR_B_PAPCD)
C. Scientific knowledge (SV_C_SL)	D. Safety (PEU_D_Safe)		
	E. Logistics (PEU_E_Log)		
D. Integrity (SV_D_Int)	F. Density of population (PEU_F_DP)		C. Legal protection (DR_C_LP)
E. Geological diversity (SV_E_GD)	G. Association with other values (PEU_G_AOV)		
	H. Scenery (PEU_H_Sce)		
F. Rarity (SV_F_Rar)	I. Uniqueness (PEU_I_Uni)		D. Accessibility (DR_D_A)
G. Use limitations (SV_G_UL)	J. Observation conditions (PEU_J_OC)		E. Density of population (DR_E_DP)
	K. Didactic potential (PEU_K_DiP)	K. Interpretative potential (PTU_K_IP)	
	L. Geological diversity (PEU_L_GD)	L. Economic level (PTU_L_EL)	
		M. Proximity of recreational areas (PTU_M_PRA)	

VIII/A/1 Gorges de l'Artière - Fault facet and the tectonically influenced valley – F-GAR



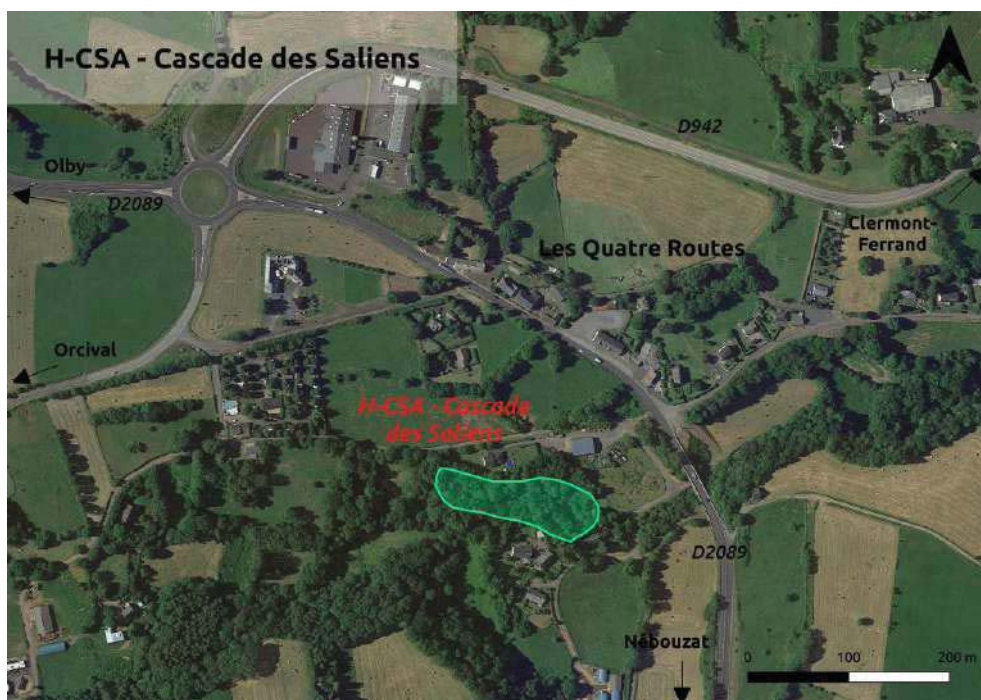
Fault facet of the Limagne Fault at Gorges de l'Artière, next to Ceyrat. Frequently used by rock climbers, the surface of the rock is cleaned from vegetation, but climbing might accelerate erosion at certain points

VIII/A/2 Varennes - Saulzet route- fault line outcrop series road – F-VSR



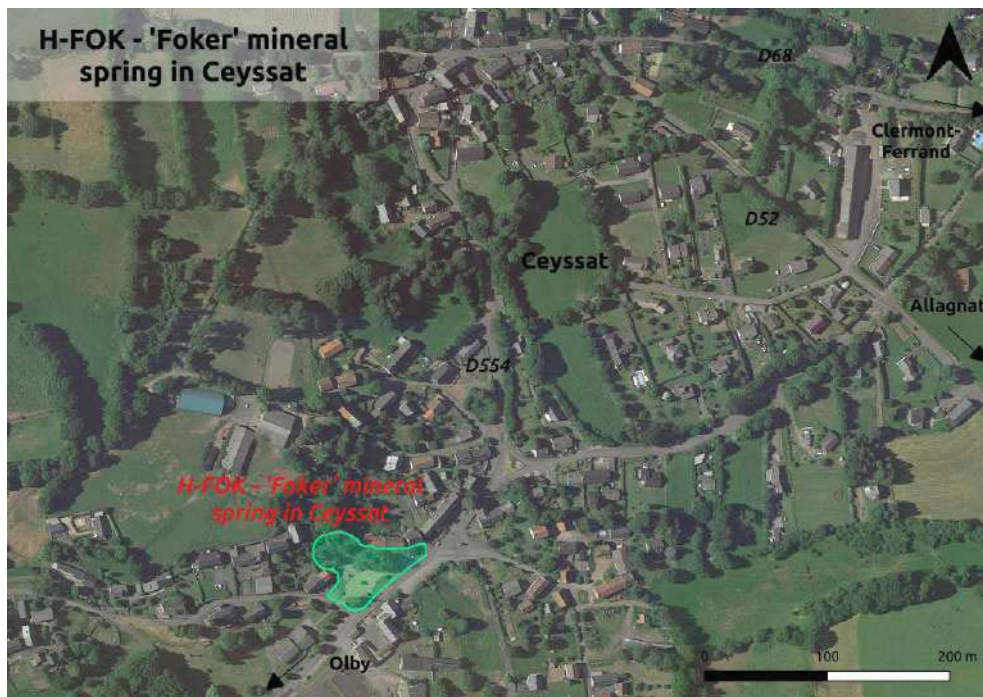
A constantly eroding section of the Limagne Fault, next to road between Varennes and Saulzet-le-Chaud. The granite with large phenocrysts is crossed by a dike

VIII/A/3 Cascade des Saliens – H-CSA



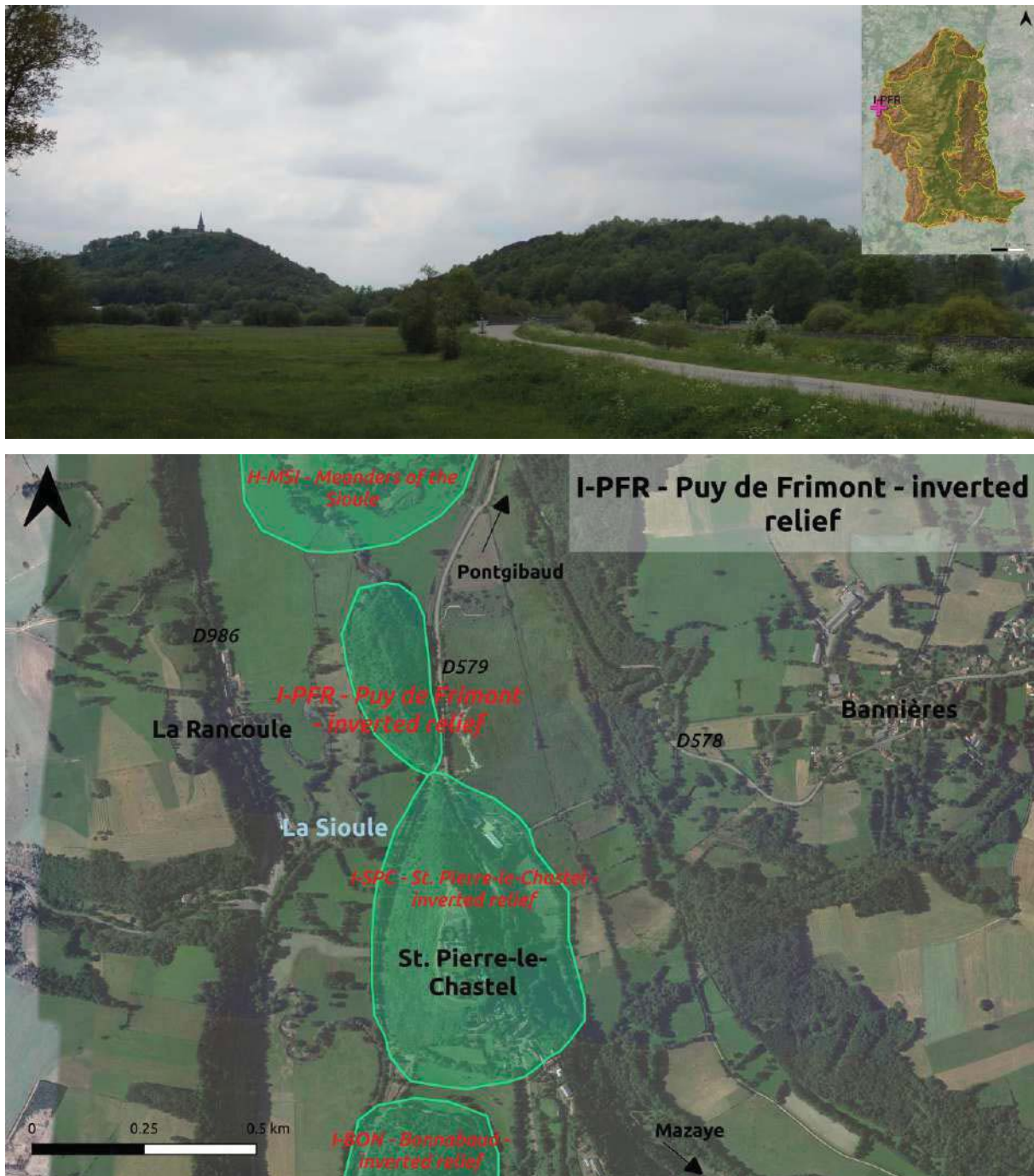
The Cascade des Saliens, a series of two waterfalls on Quaternary lava flow layers. Although developed with a small path and protective fences, the site is still relatively unknown and untouched, compared to other, popular geosites of the World Heritage property

VIII/A/4 'Foker' mineral spring at Ceyssat – H-FOK



The 'Foker' mineral spring, rich in absorbed carbon-dioxide and minerals (sulphates, calcium), creating a travertine-like precipitation of minerals around the source socket

VIII/A/5 Puy de Frimont - inverted relief – I-PFR



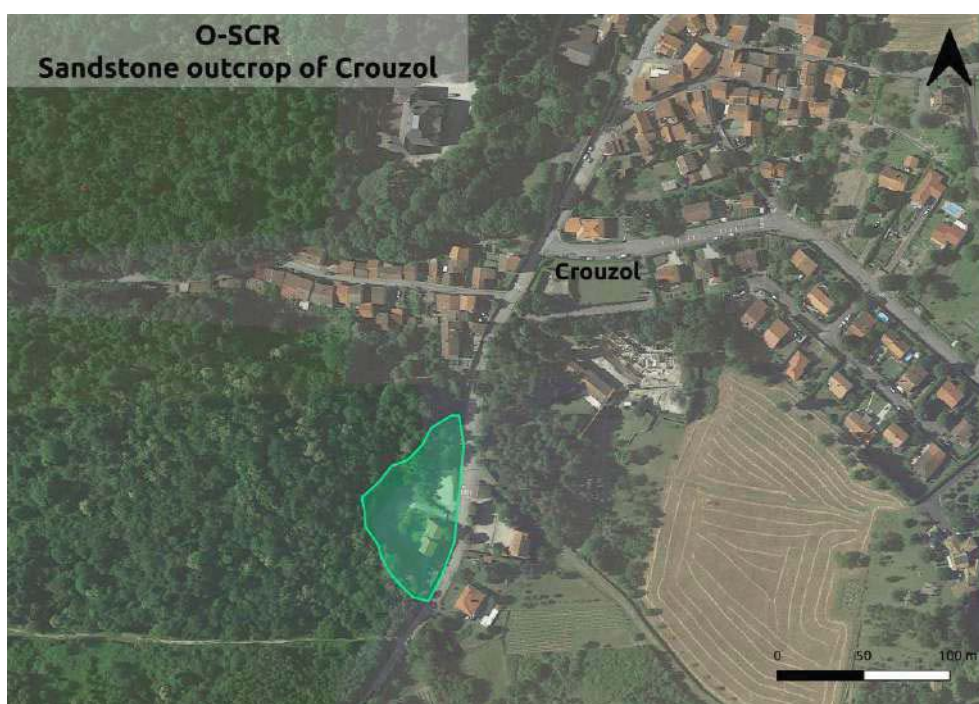
Puy de Frimont (on the right) and the village of St. Pierre-le-Chastel (on the left), relief inversion features of a lava flow, probably descended from the Massif du Saunçy.

VIII/A/6 Front ending of the Montagne de la Serre at Le Crest – I-LCR



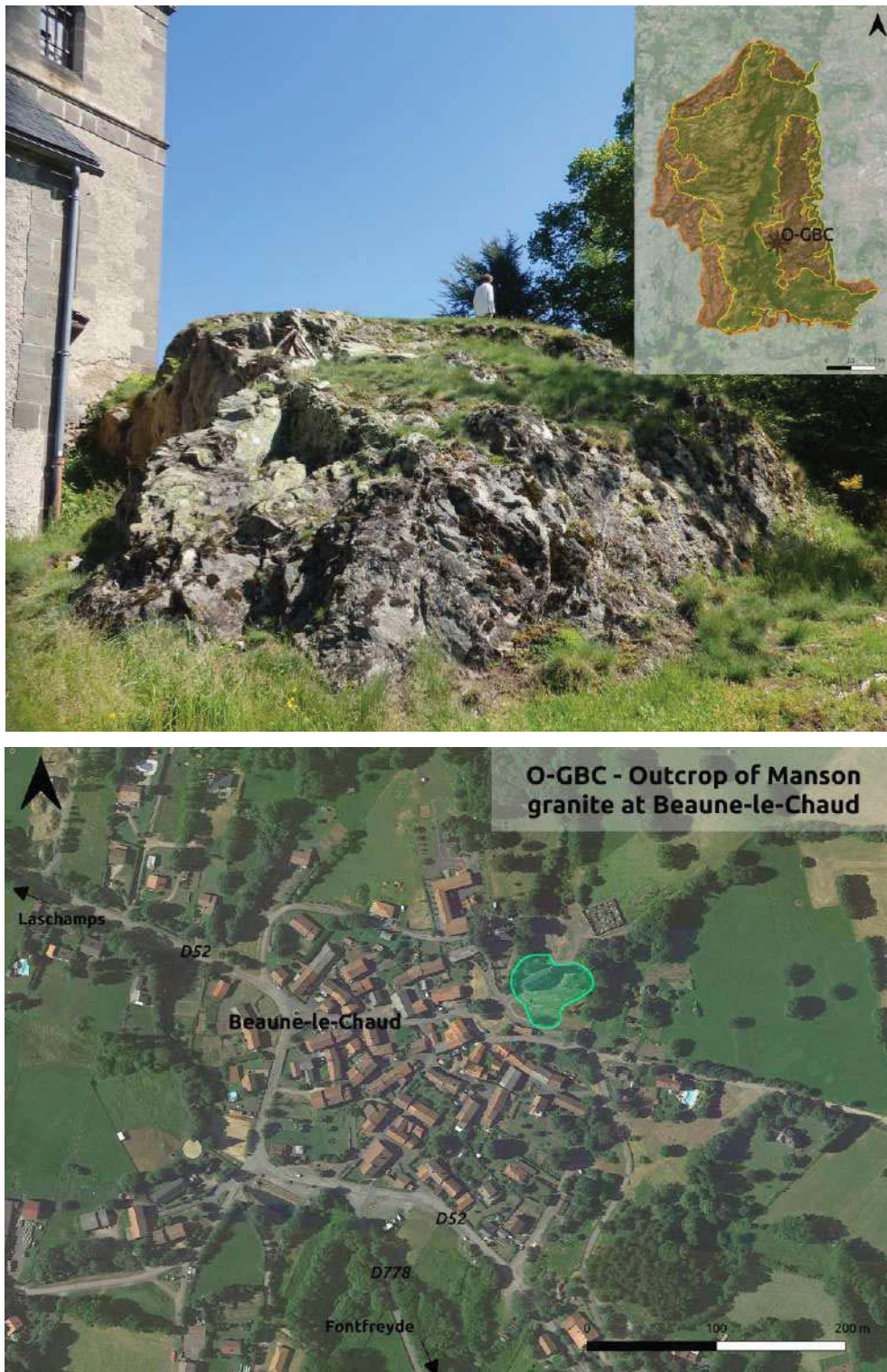
The 'endpoint' of Montagne de la Serre at Le Crest. The village is situated around the basaltic lava flow capping, which shows some outcrops in the ancient castle area

VIII/A/7 Sandstone outcrop at Crouzol – O-SCR



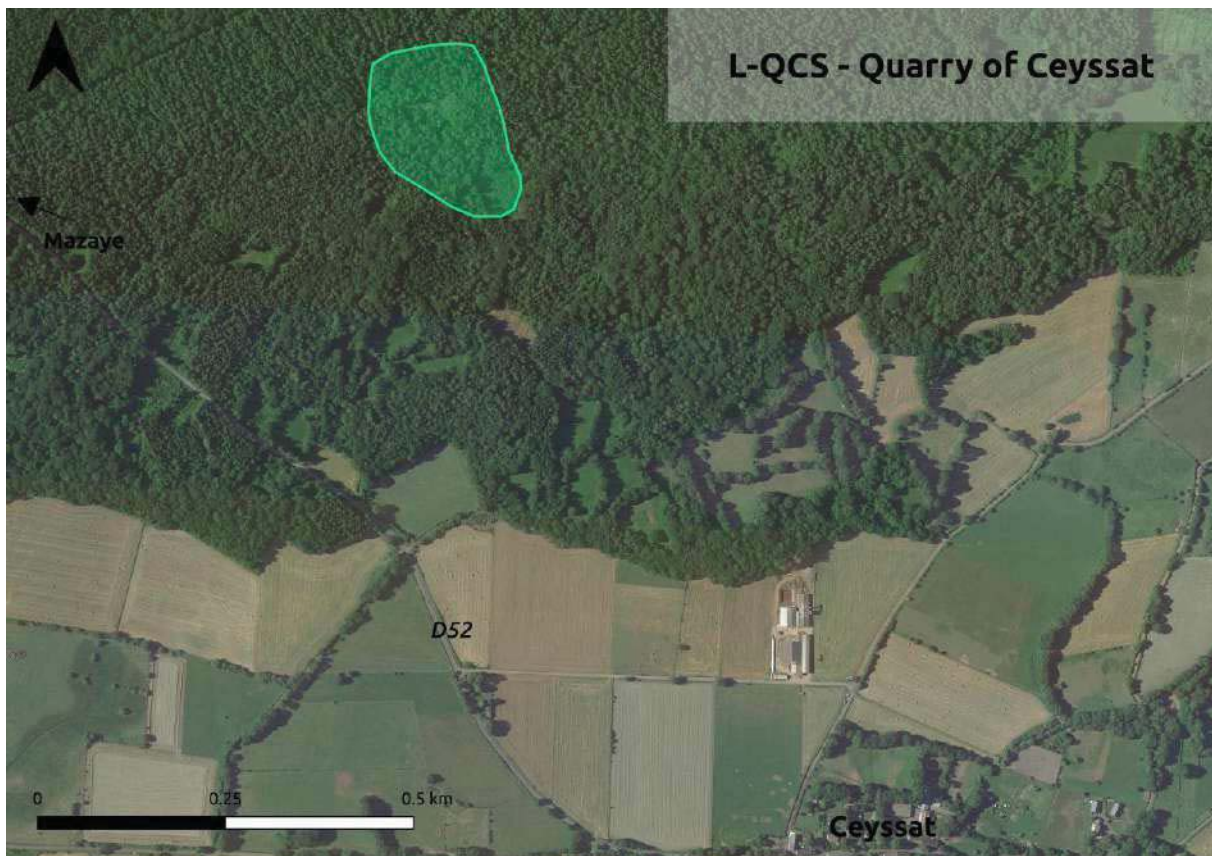
Testimony of the Oligocene syn-rift sedimentation, a sandstone outcrop close to Crouzol, threatened by disappearance due to over-vegetation and easily erodible slopes.

VIII/A/8 Outcrop of Manson granite at Beaune-le-Chaud – O-GBC



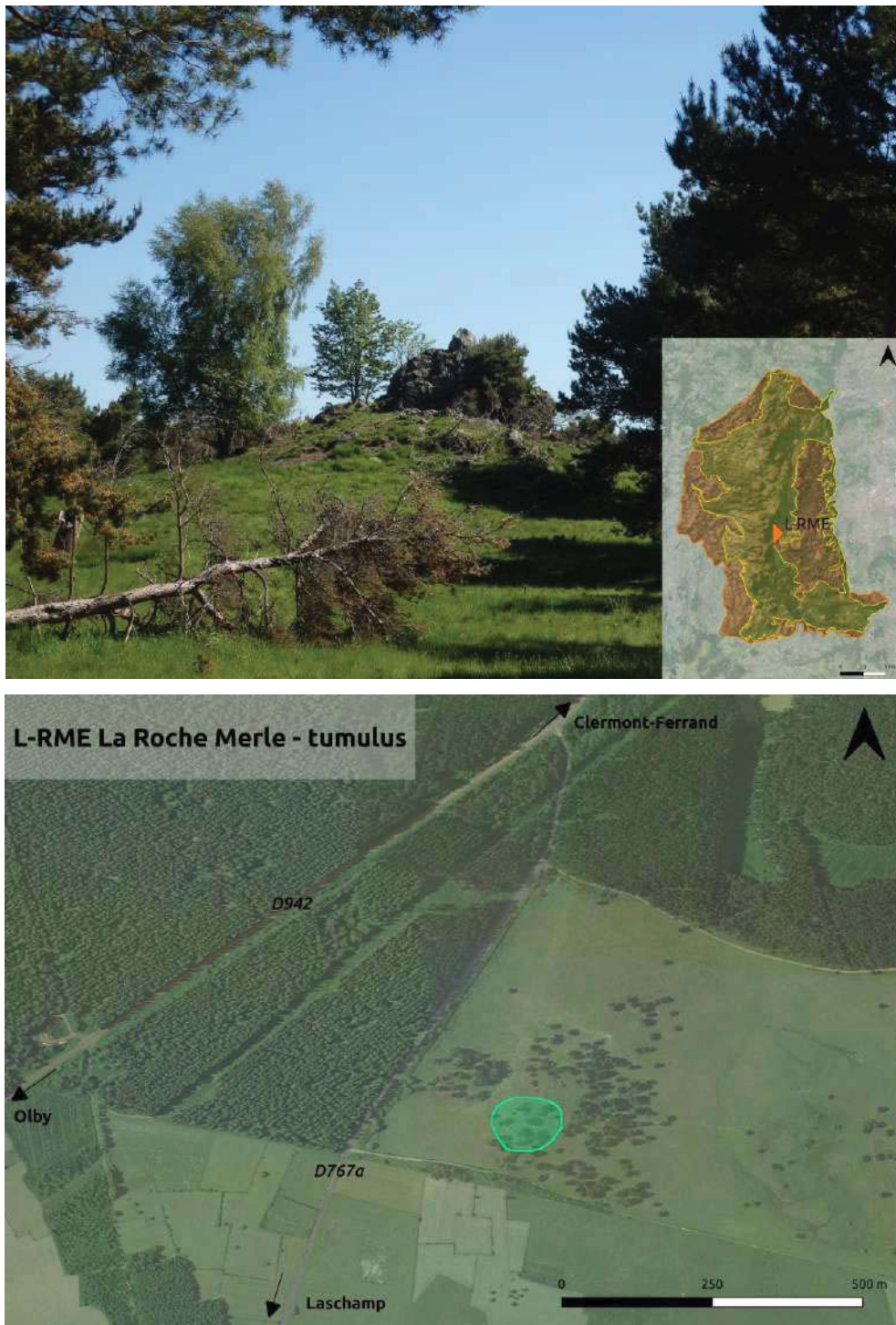
One of the relatively rare outcrops of the Hercynian basement, the Plateau des Dômes, located next to the church of Beaune-le-Chaude.

VIII/A/9 Quarry of Ceyssat – L-QCS



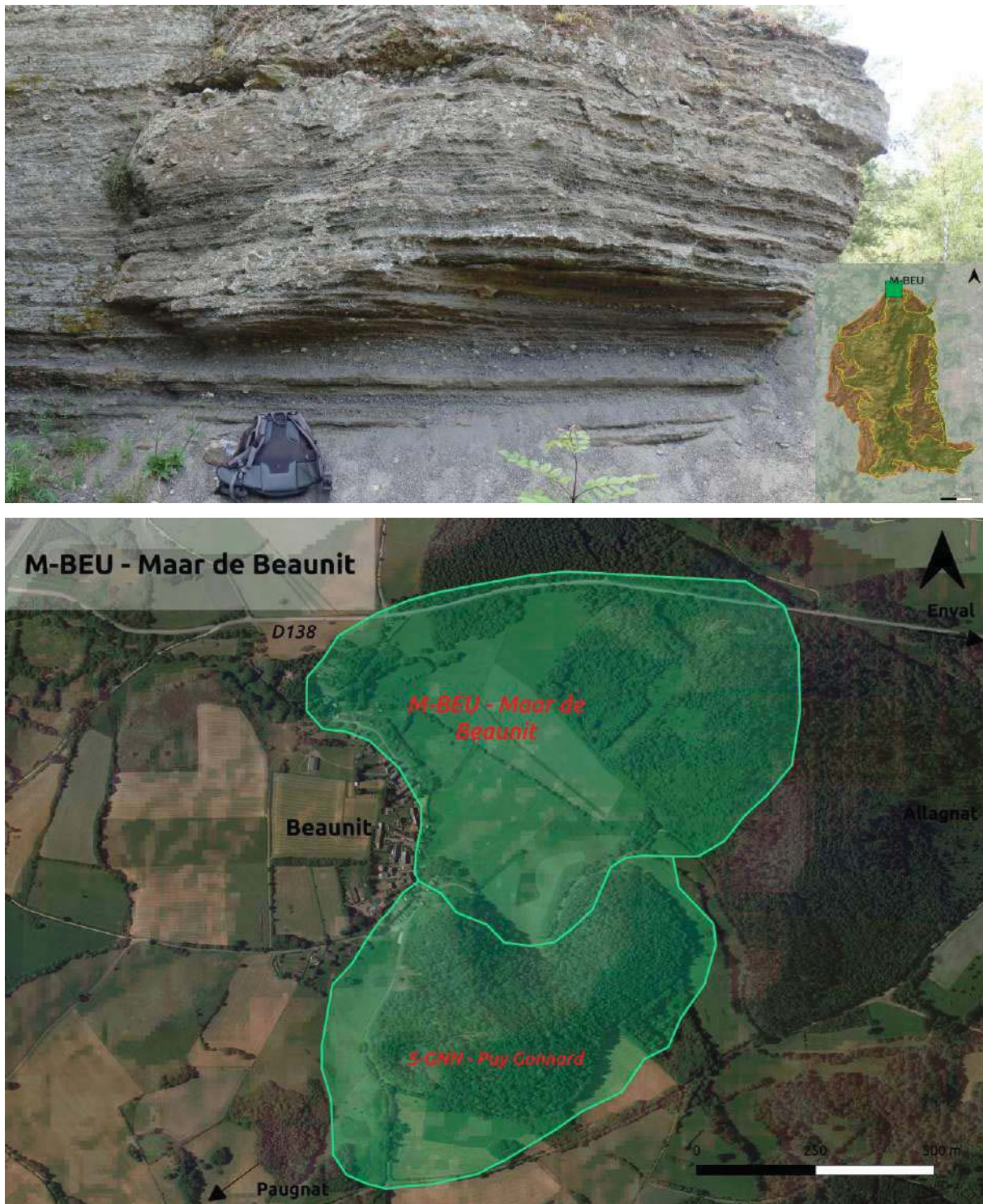
The abandoned quarry, close to Ceyssat, featuring a relatively rare, well-visible outcrop of a 'cheire', the widely spreading lava flows of the Western side of the Chaîne des Puys

VIII/A/10 Roche Merle – tumulus – L-RME



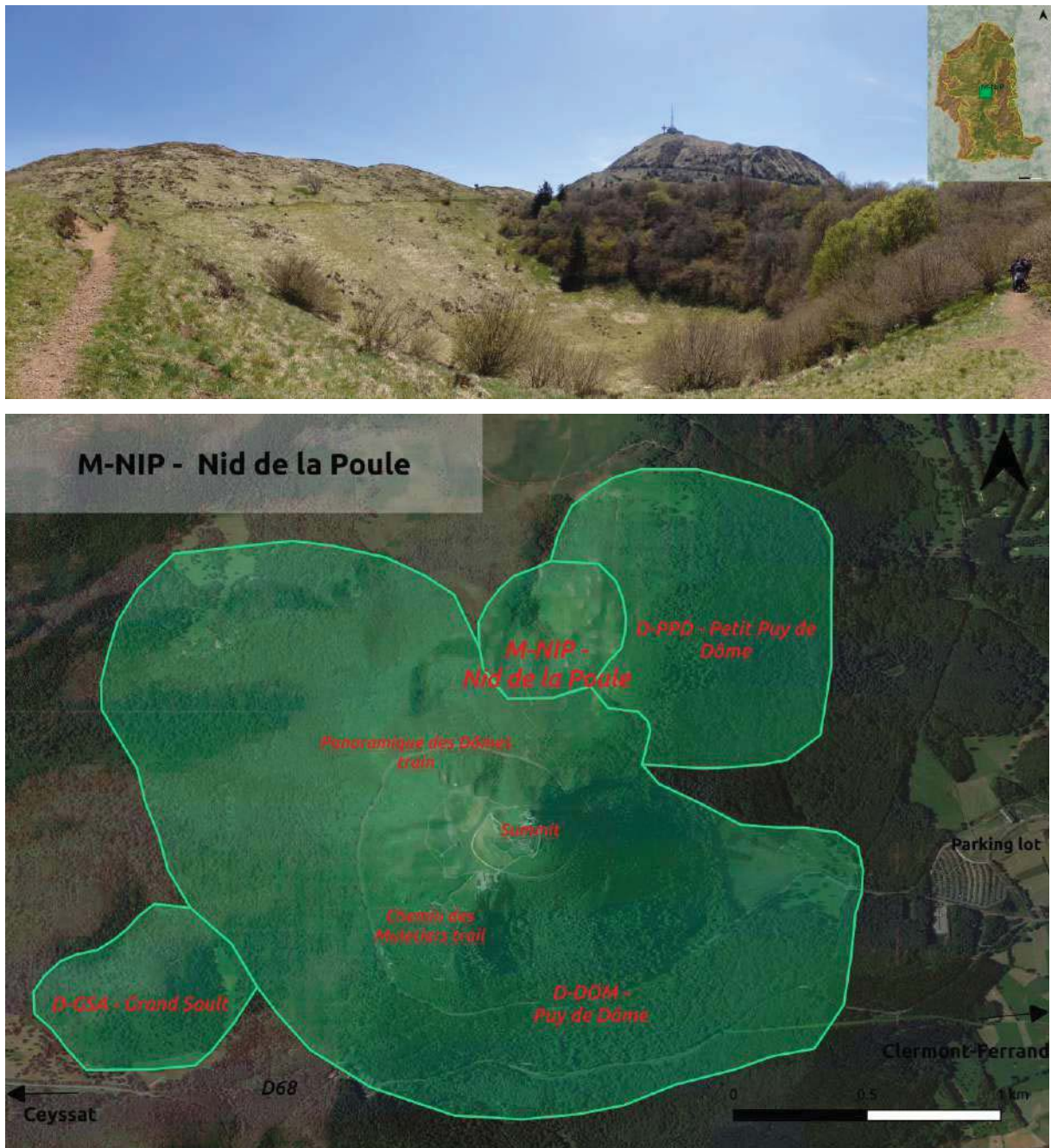
The tumulus of Roche Merle. Currently unavailable directly on a touristic trail. it has a low level of vulnerability, also due to exclusion from economic (agricultural and forestry) activities.

VIII/A/11 Maar de Beaunit – M-BEU



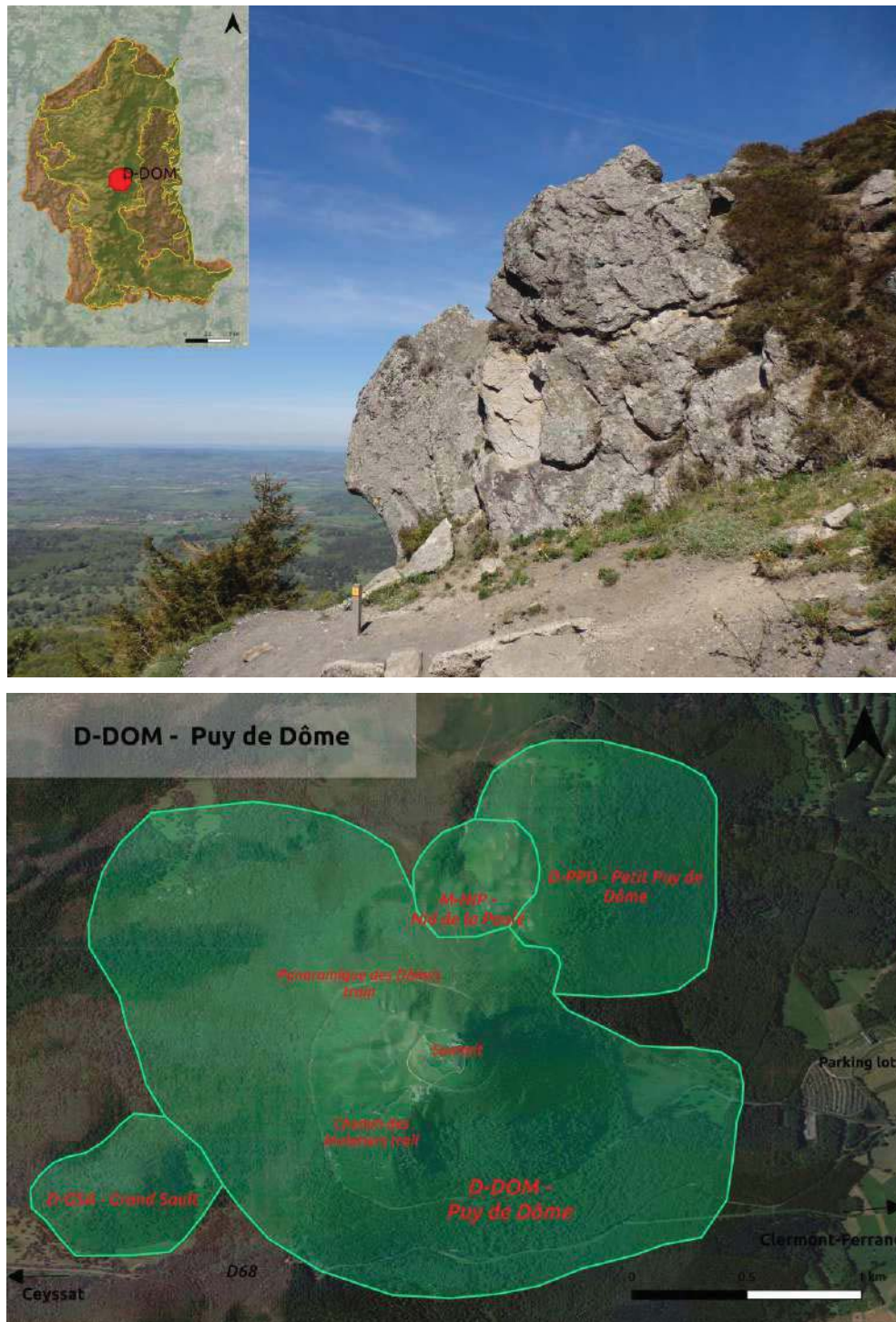
The phreatomagmatic sequence of Maar de Beaunit. The ancient quarry features a small interpretative panel as well

VIII/A/12 Nid de la Poule – M-NIP



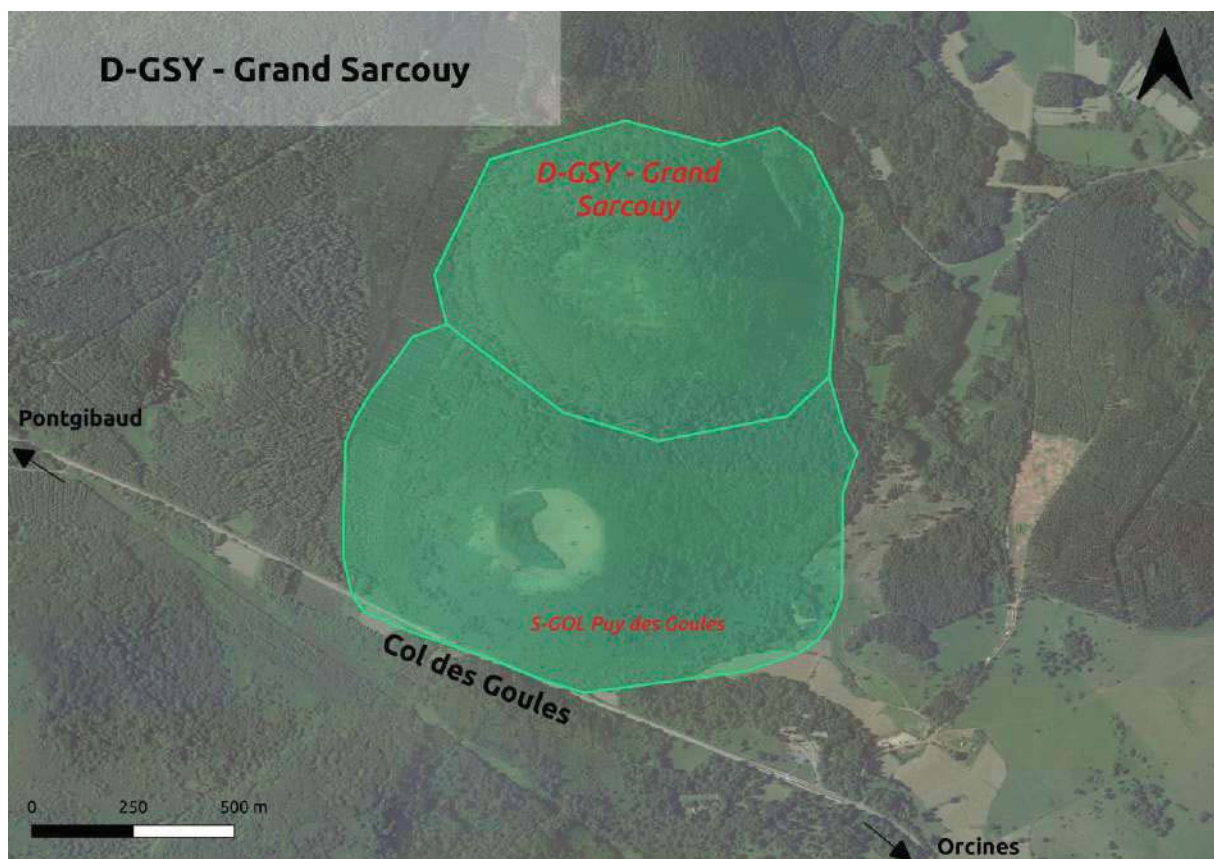
The maar of Nid de la Poule with the Petit Puy de Dôme (left) and the Puy de Dôme (middle) in the background. The site is a popular destination, yet without dedicated interpretative facilities, panels.

VIII/A/13 Puy de Dôme – D-DOM



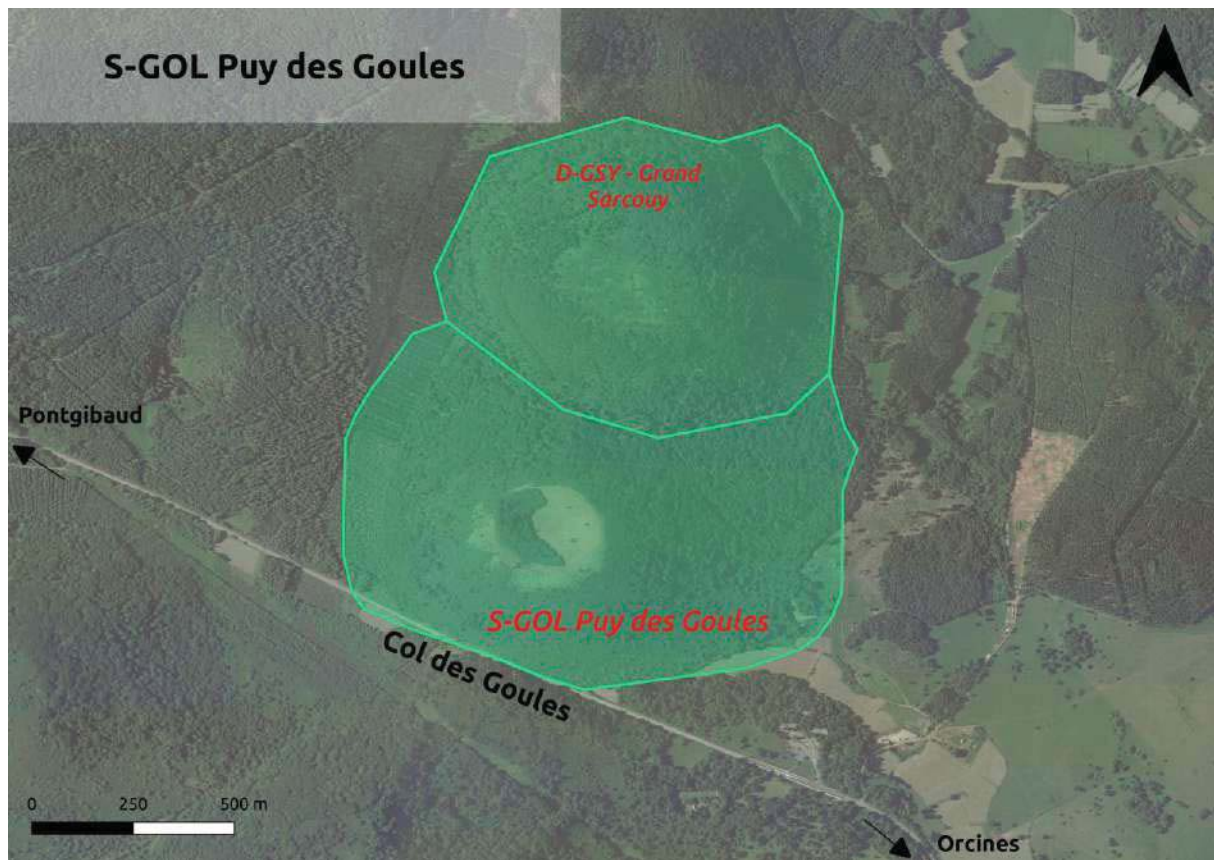
Trachytic outcrop close to the summit of Puy de Dôme, on the southern side at the Chemin des Muletiers. VAN WYK DE VRIES ET AL. (2019) raised the attention on the ongoing (2020) non-respective bolting and stabilization works, threatening the geoheritage values.

VIII/A/14 Grand Sarcouy – P-GSY



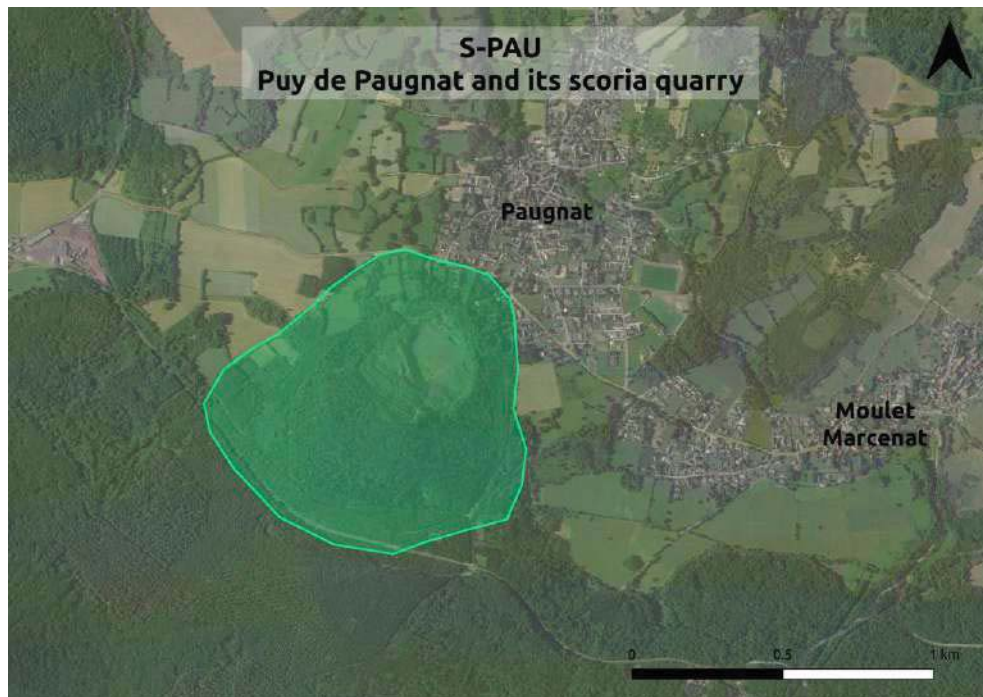
Trachytic outcrop and cave close to the top of the Grand Sarcouy lava dome. Behind the protective fencing, the cave is semi-artificial, as the rock was quarried for the use of Roman sarcophagi.

VIII/A/15 Puy des Goules – S-GOL



View to the crater of Puy des Goules, with monogenetic volcanoes in the background (from the left: Puy de Dôme, Puy de Paugnat, Le Clersou, Puy de Côme). The crater is kept open from the vegetation with sustainable grazing of sheep.

VIII/A/16 Puy de Paugnat and its scoria quarry – S-PAU



*The abandoned and only partially recultivated quarry of Puy de Paugnat, and the remains of the cone in the background.
The cliff in the middle of the image is a viewpoint with a basic protective fencing*

VIII/B Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site - assessment with the method of de Wever et al. (2015)

Code	Category	Geosite	Prim. Geol. Int.	Secon. Geol. Int.	Edu. Int.	Rarety	Geohist. Imp.	Pres. State	Geohist. Int. Score	Heritage Stars'	Eff. Prot	Nat. Vuln.	Anthr. Threat	Prot.&Yuln.
F-BCO	Fault line	Berzet - Ceyssat route - fault line outcrop series	2	1	1	1	0	2	20	1	2	2	3	8
F-CCR	Fault line	Chemin de Crête - fault line outcrop series	2	2	3	1	1	2	31	2	2	2	1	7
F-GAR	Fault line	Gorges de l'Artière - Fault facet, Dolmen de Samson and the tectonically influenced valley	3	3	3	3	2	3	46	3	2	3	1	9
F-GEV	Fault line	Gorges d'Enval - Fault facet and the tectonically influenced valley	3	3	3	3	2	3	46	3	1	1	2	7
F-MPE	Fault line	La Montagne Percée - fault line outcrop and viewpoint	3	2	3	2	2	3	41	3	1	2	1	7
F-PCH	Fault line	Puy Charmont - Fault line outcrops	2	1	1	2	1	2	24	2	1	2	1	6
F-PCX	Fault line	Puy de Chateix - Fault line outcrops	2	2	1	2	1	3	29	2	1	2	1	6
F-RSA	Fault line	Rocher de Salut - fault line outcrop and viewpoint	2	2	2	1	2	2	30	2	1	1	1	5
F-VRN	Fault line	Route de la Nugère at Volvic - Fault line outcrops	3	3	1	2	0	2	32	3	2	2	3	10
F-VSR	Fault line	Varennes - Saulzet route- fault line outcrop series	2	1	1	2	0	2	22	2	2	2	2	8
F-VVO	Fault line	Vierge de Volvic - fault line outcrop and viewpoint	2	1	3	1	1	1	26	2	2	2	1	7
H-CSA	Hydrology	Cascade des Saliens	2	2	2	1	1	3	30	2	1	2	1	6
H-FBC	Hydrology	Fontaine du Bois, Chambois	3	1	1	1	2	3	30	2	0	3	2	7
H-FOK	Hydrology	'Foker' mineral spring at Ceyssat	3	2	3	1	2	3	39	3	0	3	2	8
H-LAY	Hydrology	The lava flow blocked Lac d'Aydat	3	3	3	2	3	3	46	3	0	2	2	7
H-LCA	Hydrology	The lava flow blocked Lac de la Cassière	3	2	3	1	3	3	41	3	0	2	2	7
H-MSI	Hydrology	Meanders of the Sioule	1	1	1	0	0	3	16	1	2	2	1	6
H-SCP	Hydrology	Spring of a paleovalley at 'Chez Pierre'	2	2	2	1	1	3	30	2	1	2	2	7
H-SSO	Hydrology	Source de Louchadière - Saint Ours	3	1	1	1	2	3	30	2	1	3	2	8
H-VOS	Hydrology	The spring of Volvic	3	2	3	3	3	3	45	3	0	3	2	8
I-BER	Inverted relief	Puy de Berzet - inverted relief	1	1	0	1	0	2	13	1	1	0	1	3
I-BON	Inverted relief	Bonnabaud - inverted relief	2	2	2	1	1	3	30	2	1	1	1	5
I-CCG	Inverted relief	Croix Chemagrand - Inverted relief and granite-lava contact	1	1	0	2	0	2	15	1	1	1	1	4
I-LCR	Inverted relief	Front ending of the Montagne de la Serre at Le Crest	2	2	3	3	2	3	39	3	2	2	2	9
I-PCO	Inverted relief	Puy de Cros - inverted relief	1	1	2	1	1	2	21	2	2	1	1	6
I-PFR	Inverted relief	Puy de Frimont - inverted relief	2	2	2	1	1	3	30	2	0	0	0	2
I-QRH	Inverted relief	Quarry of the Montagne de la Serre close to Rouillas-Haut	2	2	2	3	1	2	32	3	2	1	2	8

VIII/B Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site - assessment with the method of de Wever et al. (2015)

Code	Category	Geosite	Prim. Geol. Int.	Secon. Geol. Int.	Edu. Int.	Rarety	Geohist. Imp.	Pres. State	Geoher. Int. Score	Heritage Stars'	Eff. Prot	Nat. Vuln.	Anthr. Threat	Prot.&Yuln.
I-RED	Inverted relief	Mont Redon - inverted relief	2	2	1	2	0	2	25	2	1	1	1	5
I-SPC	Inverted relief	St. Pierre-le-Chastel - inverted relief	2	2	2	1	1	2	28	2	1	1	2	6
D-CHO	Lava dome	Puy Chopine	3	2	2	3	3	3	42	3	1	1	1	6
D-CLI	Lava dome	Le Cliersou	2	2	3	2	3	3	39	3	0	3	2	8
D-DOM	Lava dome	Puy de Dôme	3	3	3	3	3	3	48	3	0	2	2	7
D-GRO	Lava dome	Puy des Grosmanaux	2	2	1	2	3	2	31	2	1	1	1	5
D-GSA	Lava dome	Grand Sault	2	1	0	2	2	2	23	2	0	0	1	3
D-GSU	Lava dome	Grand Suchet	2	2	3	2	2	3	37	3	0	2	1	6
D-GSY	Lava dome	Grand Sarcouy	3	3	2	2	3	3	43	3	0	2	2	7
D-KIL	Lava dome	Cratère Kilian	3	2	1	2	3	3	40	3	1	1	0	5
D-MCR	Lava dome	Puy Montchar	2	1	1	1	2	2	24	2	1	0	1	4
D-PPD	Lava dome	Petit Puy de Dôme	3	2	2	2	3	3	40	3	0	2	0	5
L-ARG	Lava flow	Argnat lava flow outcrop	1	1	1	1	0	2	16	1	2	2	2	7
L-CCP	Lava flow	Gorges de la Sioule and Côme lava flow front at Peschadoire	3	2	2	1	2	3	36	3	1	1	0	5
L-CTG	Lava flow	Trou de Glace - Côme lava flow outcrops	3	2	2	2	2	3	38	3	2	2	1	8
L-GFG	Lava flow	La Fontaine gelée - lava tube	2	1	2	2	1	3	29	2	2	2	1	7
L-GRH	Lava flow	La Grotte de Ribbe Haute - lava levée	2	2	2	2	2	3	34	3	2	2	1	8
L-GRP	Lava flow	La Grotte et Maison de la Pierre	3	2	3	3	3	3	45	3	0	2	1	6
L-LBS	Lava flow	Outcrop of the lava flow basement of Puys de la Vache and Lassolas at Saint-Saturnin	3	3	2	3	2	3	43	3	1	1	1	6
L-LCP	Lava flow	Outcrop of the lava channel of Puys de la Vache and Lassolas at Ponteix	2	2	2	2	1	3	32	3	1	2	1	7
L-LLC	Lava flow	The lava lake of the Côme lava flow	3	3	2	2	1	3	39	3	1	1	0	5
L-LLN	Lava flow	Columnar basalts of the lava lake at Nébouzat	2	2	1	2	1	3	29	2	2	1	2	7
L-OCH	Lava flow	Lava flow outcrop at Chanonat	2	1	1	1	2	2	24	2	2	1	1	6
L-PBR	Lava flow	Les Bramauds- pressure ridges	1	1	1	0	1	2	16	1	1	1	1	4
L-PCY	Lava flow	Ceyssat- pressure ridges	2	1	1	0	1	3	22	2	1	1	1	5
L-PRC	Lava flow	Lava flow of Puy de Combegrasse- pressure ridges	2	1	2	0	2	2	25	2	1	1	1	5
L-PRP	Lava flow	Lava flow of Puy de Poucharet- pressure ridges	3	2	2	0	1	3	32	3	1	1	1	6

VIII/B Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site - assessment with the method of de Wever et al. (2015)

Code	Category	Geosite	Prim. Geol. Int.	Secon. Geol. Int.	Edu. Int.	Rarety	Geohist. Imp.	Pres. State	Geoh. Int. Score	Heritage Stars'	Eff. Prot	Nat. Vuln.	Anthr. Threat	Prot.&Vuln.
L-PVA	Lava flow	Vauriat , lava flow of Louchadière - pressure ridges	1	1	1	0	1	2	16	1	1	2	1	5
L-PVI	Lava flow	Outcrop of the lava flow of Pariou at Villars	2	2	1	1	2	2	27	2	2	1	1	6
L-QCB	Lava flow	Quarry of Chambols	2	2	2	1	1	3	30	2	2	3	2	9
L-QCS	Lava flow	Quarry of Ceysat	2	1	2	1	1	3	27	2	2	2	1	7
L-QGO	Lava flow	The quarries of Volvic stone at Les Goulots	3	1	2	2	3	3	37	3	2	3	2	10
L-QMF	Lava flow	Quarry of the lava flow of Puy de la Mey at Fontfreyde	2	1	2	1	2	3	29	2	2	2	1	7
L-RME	Lava flow	Roche Merle - tumulus	3	2	2	2	2	3	38	3	1	1	1	6
L-SAY	Lava flow	Lava flow outcrop - Sayat	1	1	1	1	0	2	16	1	2	2	2	7
M-ACH	Maar	Maar d'Anchald	2	2	2	0	1	2	26	2	1	1	1	5
M-AMP	Maar	Narse d'Amboix	3	3	2	2	3	3	43	3	0	3	1	7
M-BCL	Maar	Bois de Clerzat	1	1	0	0	2	2	15	1	1	1	1	4
M-BEL	Maar	Maar de Beauloup	1	1	1	0	1	2	16	1	2	1	1	5
M-BEU	Maar	Maar de Beaunit	3	2	3	1	3	3	41	3	1	1	2	7
M-CRM	Maar	Creux Morel	2	1	3	1	2	2	30	2	1	0	1	4
M-ENV	Maar	Maar d'Enval	1	1	1	1	2	2	20	1	2	1	1	5
M-ESP	Maar	Narse de l'Espinasse	2	2	2	2	3	3	36	3	0	1	0	4
M-MCT	Maar	Maar de Monchatre	1	1	1	1	1	2	18	1	2	1	1	5
M-NIP	Maar	Nid de la Poule	2	2	3	2	3	3	39	3	0	2	1	6
M-VIL	Maar	Maar de Villars	2	2	2	1	3	3	34	3	1	2	2	8
O-BCP	Other	Hercynian base outcrop at 'Chez Pierre'	1	1	1	0	1	2	16	1	1	2	1	5
O-GBC	Other	Outcrop of Manson granite at Beaune-le-Chaud	1	1	1	1	1	3	20	1	2	2	2	7
O-PGG	Other	Granite outcrop of Pontgibaud	1	1	0	1	1	2	15	1	1	2	1	5
O-PMQ	Other	Puy de Manson quarry	2	2	1	1	1	3	27	2	2	2	2	8
O-SCR	Other	Sandstone outcrop at Crouzol	2	1	1	3	1	2	26	2	3	3	2	10
S-BAR	Scoria cone	Puy de Barre and its scoria quarry	2	2	2	2	2	3	34	3	1	1	1	6
S-BCH	Scoria cone	Bois de Chantat	2	2	1	2	2	2	29	2	1	1	1	5
S-BES	Scoria cone	Puy Besace	1	1	0	1	2	2	17	1	1	1	1	4
S-BLE	Scoria cone	Puy de Bleymas and its scoria quarry	2	2	2	1	1	2	28	2	1	1	1	5
S-BNE	Scoria cone	Puy de la Bannière	1	1	0	1	1	2	15	1	1	1	1	4
S-BNS	Scoria cone	Puy des Bannières	1	1	0	1	1	2	15	1	1	0	1	3
S-CGR	Scoria cone	Puy de Combrasse	2	2	3	1	3	3	37	3	0	1	1	5
S-CGX	Scoria cone	Chuquet-Genestoux scoriaceous outcrop	1	1	1	2	2	2	22	2	1	0	1	4
S-CHR	Scoria cone	Puy de Charmont	2	2	2	1	2	3	32	3	1	2	1	7

VIII/B Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site - assessment with the method of de Wever et al. (2015)

Code	Category	Geosite	Prim. Geol. Int.	Secon. Geol. Int.	Edu. Int.	Rarety	Geohist. Imp.	Pres. State	Geohist. Int. Score	Heritage Stars'	Eff. Prot	Nat. Vuln.	Anthr. Threat	Prot. & Vuln.
S-CHU	Scoria cone	Puy de Chaumont	2	2	2	2	2	3	34	3	1	1	1	6
S-COM	Scoria cone	Puy de Côme	3	2	3	2	3	3	43	3	0	1	1	5
S-COQ	Scoria cone	Puy de la Coquille	2	2	2	1	3	3	34	3	1	1	1	6
S-ENF	Scoria cone	Puy de l'Enfer and its scoria quarry	2	2	3	2	3	3	39	3	1	2	1	7
S-ESP	Scoria cone	Puy de l'Espinasse and its scoria quarry	2	2	2	2	2	2	32	3	1	1	1	6
S-FIL	Scoria cone	Puy Fillou	1	1	0	1	1	2	15	1	1	0	0	2
S-GLI	Scoria cone	Puy de la Goulie	1	1	0	1	3	2	19	1	1	0	1	3
S-GNN	Scoria cone	Puy Gonnard	2	2	2	2	3	3	36	3	1	1	1	6
S-GOL	Scoria cone	Puy des Goules	2	2	3	2	3	3	39	3	0	2	1	6
S-GOT	Scoria cone	Puy des Gouttes	2	2	3	2	3	3	39	3	1	2	0	6
S-GRN	Scoria cone	Puy de Grave Noire and its scoria quarry	3	2	3	3	3	3	45	3	1	3	2	9
S-JUM	Scoria cone	Puy de Jumes	2	2	3	2	2	3	37	3	0	2	2	7
S-LAC	Scoria cone	Puy de Laschamps	3	2	2	2	3	3	40	3	1	1	1	6
S-LAS	Scoria cone	Puy de Lassolas	3	3	3	2	3	2	44	3	1	2	2	8
S-LEM	Scoria cone	Puy de Lemptégy	3	3	3	3	3	3	48	3	0	1	1	5
S-LOU	Scoria cone	Puy de Louchadiere	2	2	2	2	3	3	36	3	1	1	1	6
S-LOV	Scoria cone	Puy la de Louve scoria quarry of Gare de Volvic	3	3	2	2	3	2	41	3	1	2	2	8
S-MCE	Scoria cone	Puy Montchié	1	1	1	1	2	2	20	1	1	1	0	3
S-MEC	Scoria cone	Puy de Mercoeur	1	1	1	1	2	2	20	1	1	1	1	4
S-MET	Scoria cone	Puy de Monteillet	2	1	1	1	1	3	24	2	1	1	0	4
S-MEY	Scoria cone	Puy de la Mey	2	2	2	1	2	3	32	3	2	2	1	8
S-MGY	Scoria cone	Puy de Montgy	1	1	0	1	1	3	17	1	1	0	0	2
S-MOD	Scoria cone	Puy Monténard	2	2	2	1	2	3	32	3	1	1	2	7
S-MOR	Scoria cone	Puy de la Moreno	1	1	1	1	2	2	20	1	1	1	1	4
S-NAI	Scoria cone	Puy Nain	1	1	1	1	1	1	16	1	1	2	1	5
S-NUG	Scoria cone	Puy de la Nugère	3	2	2	2	3	3	40	3	1	1	1	6
S-PAR	Scoria cone	Puy de Pariou	3	2	3	2	3	3	43	3	0	2	1	6
S-PAU	Scoria cone	Puy de Paugnat and its scoria quarry	2	2	3	1	3	2	35	3	1	1	1	6

Code	Category	Geosite	Prim. Geol. Int.	Secon. Geol. Int.	Edu. Int.	Rarety	Geohist. Imp.	Pres. State	Geoh. Int. Score	Heritage Stars'	Eff. Prot	Nat. Vuln.	Anthr. Threat	Prot.&Vuln.
S-POU	Scoria cone	Puy de Poucharet	3	2	2	2	2	3	38	3	1	1	0	5
S-ROD	Scoria cone	Puy de la Rodde	1	1	0	1	2	2	17	1	1	1	1	4
S-SAL	Scoria cone	Puy de Salomon	1	1	1	1	1	2	18	1	1	1	1	4
S-TEN	Scoria cone	Puy de Ténuzet and its scoria quarry	2	2	2	2	3	1	32	3	3	2	3	11
S-TOU	Scoria cone	Puy de la Toupe	2	2	3	2	2	1	33	3	3	2	3	11
S-TRE	Scoria cone	Puy de Tressous	1	1	0	1	1	2	15	1	1	0	0	2
S-VAC	Scoria cone	Puy de la Vache and its scoria quarry	3	3	3	2	3	3	46	3	0	2	2	7
S-VER	Scoria cone	Puy de Verrières	1	1	0	1	1	2	15	1	1	0	0	2
S-VIC	Scoria cone	Puy de Vichatel	2	2	2	1	3	3	34	3	1	1	0	5

VIII/C Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
assessment with the method of Vujičić et al. (2011)

Code	Category	Geosite	VSE_RAR	VSE_REP	VSE_KGI	VSE_LI	VSA_VP	VSA_SF	VSA_SLN	VSA_EFS	VPR_CC	VPR_PL	VPR_VU	VPR_SNV	VFN_AC
F-BCO	Fault line	Berzet - Ceyssat route - fault line outcrop series	0,50	0,75	0,25	0,50	0,25	1,00	0,50	0,50	0,50	1,00	0,00	0,25	1,00
F-CCR	Fault line	Chemin de Crête - fault line outcrop series	0,25	0,75	0,25	1,00	0,75	1,00	0,75	1,00	0,75	1,00	0,50	1,00	0,50
F-GAR	Fault line	Gorges de l'Artière - Fault facet, Dolmen de Samson and the tectonically influenced valley	0,50	1,00	0,50	0,50	0,50	0,50	0,75	0,50	0,75	1,00	0,25	0,50	1,00
F-GEV	Fault line	Gorges d'Enval - Fault facet and the tectonically influenced valley	0,75	0,75	0,75	0,50	0,50	0,50	0,75	1,00	0,75	1,00	0,50	0,50	0,75
F-MPE	Fault line	La Montagne Percée - fault line outcrop and viewpoint	0,25	1,00	0,50	1,00	0,50	0,50	1,00	1,00	0,75	1,00	0,75	0,50	0,50
F-PCH	Fault line	Puy Charmont - Fault line outcrops	0,50	0,50	0,00	0,25	0,75	1,00	0,75	1,00	0,75	1,00	0,50	0,25	0,25
F-PCX	Fault line	Puy de Chateix - Fault line outcrops	0,25	0,75	0,25	0,25	0,50	0,50	0,50	1,00	0,75	1,00	0,50	0,50	0,50
F-RSA	Fault line	Rocher de Salut - fault line outcrop and viewpoint	0,25	0,75	0,50	0,75	0,25	0,50	1,00	1,00	1,00	1,00	1,00	0,50	0,50
F-VRN	Fault line	Route de la Nugère at Volvic - Fault line outcrops	0,50	0,75	0,50	0,50	0,25	0,00	0,50	1,00	0,75	1,00	0,75	0,25	1,00
F-VSR	Fault line	Varennes - Saulzet route- fault line outcrop series	0,25	0,75	0,25	0,50	0,75	1,00	0,50	0,50	0,50	1,00	0,00	0,25	1,00
F-VVO	Fault line	Vierge de Volvic - fault line outcrop and viewpoint	0,50	0,75	0,50	0,50	0,50	0,50	1,00	0,50	0,50	1,00	0,25	0,50	0,50
H-CSA	Hydrology	Cascade des Saliens	0,50	1,00	0,25	1,00	0,25	0,50	0,75	1,00	1,00	1,00	0,75	0,50	0,50
H-FBC	Hydrology	Fontaine du Bois, Chambois	0,25	0,75	0,50	1,00	0,25	0,00	0,75	0,50	1,00	1,00	0,25	0,25	1,00
H-FOK	Hydrology	'Foker' mineral spring at Ceyssat	0,25	1,00	0,75	1,00	0,25	0,00	0,50	0,50	1,00	1,00	0,25	0,75	1,00
H-LAY	Hydrology	The lava flow blocked Lac d'Aydat	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,25	1,00	1,00
H-LCA	Hydrology	The lava flow blocked Lac de la Cassière	0,50	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,25	1,00	1,00
H-MSI	Hydrology	Meanders of the Sioule	0,25	1,00	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	0,75	0,50
H-SCP	Hydrology	Spring of a paleovalley at 'Chez Pierre'	0,50	0,75	0,50	1,00	0,25	0,50	0,75	1,00	1,00	1,00	0,25	0,50	1,00
H-SSO	Hydrology	Source de Louchadière - Saint Ours	0,50	0,75	0,50	1,00	0,25	0,50	0,75	0,50	1,00	1,00	0,00	0,25	1,00
H-VOS	Hydrology	The spring of Volvic	0,00	0,75	1,00	0,75	0,25	0,00	0,50	0,50	1,00	1,00	0,00	0,50	1,00
I-BER	Inverted relief	Puy de Berzet - inverted relief	0,25	0,50	0,25	0,25	0,75	0,50	0,75	1,00	1,00	1,00	1,00	0,75	0,00
I-BON	Inverted relief	Bonnabaud - inverted relief	0,25	0,75	0,50	1,00	0,75	1,00	0,75	1,00	0,75	1,00	0,75	1,00	1,00
I-CCG	Inverted relief	Croix Chemagrand - Inverted relief and granite-lava contact	0,50	0,75	0,25	0,75	0,50	0,00	0,75	1,00	1,00	1,00	0,50	0,75	0,75
I-LCR	Inverted relief	Front ending of the Montagne de la Serre at Le Crest	0,50	1,00	0,50	1,00	0,75	0,50	1,00	1,00	0,75	1,00	0,75	0,50	1,00
I-PCO	Inverted relief	Puy de Cros - inverted relief	0,25	0,50	0,25	0,25	0,75	0,50	1,00	1,00	1,00	1,00	0,75	0,75	0,50

VIII/C Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
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VFN_ANV	VFN_AAV	VFN_VEC	VFN_VIRN	VFN_AFV	VTR_PROM	VTR_OV	VTR_VVC	VTR_IP	VTR_NV	VTR_TI	VTR_TGS	VTR_HS	VTR_RS	VSE	VSA	VPR	VFN	VTR	MV	AV
0,50	0,50	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,25	0,25	0,00	1,00	0,75	2,00	2,25	1,75	4,25	2,75	6,00	7,00
0,50	1,00	1,00	1,00	0,75	0,50	0,50	0,75	0,00	0,75	0,50	0,50	1,00	1,00	2,25	3,50	3,25	4,75	5,50	9,00	10,25
0,25	0,25	1,00	1,00	1,00	0,00	1,00	0,50	0,00	0,50	0,50	0,50	1,00	0,75	2,50	2,25	2,50	4,50	4,75	7,25	9,25
0,75	0,75	0,75	1,00	0,50	0,25	0,00	0,50	0,50	0,25	0,50	0,00	1,00	0,75	2,75	2,75	2,75	4,50	3,75	8,25	8,25
0,75	0,75	1,00	1,00	0,25	0,50	0,50	0,75	0,00	0,75	0,25	0,50	1,00	1,00	2,75	3,00	3,00	4,25	5,25	8,75	9,50
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,25	0,25	0,00	1,00	0,75	1,25	3,50	2,50	3,00	2,75	7,25	5,75
0,50	0,50	1,00	1,00	0,00	0,00	0,00	0,75	0,00	0,25	0,25	0,00	1,00	0,75	1,50	2,50	2,75	3,50	3,00	6,75	6,50
0,50	0,75	1,00	1,00	0,00	0,50	0,75	0,50	0,00	0,75	0,50	0,50	1,00	0,75	2,25	2,75	3,50	3,75	5,25	8,50	9,00
1,00	1,00	0,75	1,00	0,75	0,00	0,00	1,00	0,00	0,25	0,25	1,00	1,00	1,00	2,25	1,75	2,75	5,50	4,50	6,75	10,00
0,50	0,25	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,25	0,25	0,00	1,00	0,75	1,75	2,75	1,75	4,00	2,75	6,25	6,75
0,50	0,50	0,75	1,00	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,50	1,00	0,75	2,25	2,50	2,25	4,00	6,75	7,00	10,75
0,25	0,25	0,50	0,75	0,50	0,25	0,25	0,50	0,00	0,25	0,50	0,00	1,00	1,00	2,75	2,50	3,25	2,75	3,75	8,50	6,50
0,50	0,25	0,75	1,00	0,25	0,00	0,25	0,50	0,00	0,00	0,00	0,75	1,00	0,75	2,50	1,50	2,50	3,75	3,25	6,50	7,00
0,50	0,75	0,75	1,00	0,75	0,50	0,25	0,50	1,00	0,50	0,75	0,50	1,00	1,00	3,00	1,25	3,00	4,75	6,00	7,25	10,75
0,75	0,25	0,75	1,00	1,00	1,00	0,75	0,75	1,00	1,00	1,00	0,75	1,00	1,00	3,50	4,00	3,00	4,75	8,25	10,50	13,00
0,75	0,25	0,75	1,00	0,75	0,75	0,75	0,75	0,00	0,75	0,75	0,75	1,00	0,75	3,25	4,00	3,25	4,50	6,25	10,50	10,75
0,50	0,50	1,00	1,00	0,50	0,00	0,25	0,75	0,00	0,25	0,25	0,00	1,00	0,75	2,75	4,00	3,50	4,00	3,25	10,25	7,25
0,50	0,75	0,75	1,00	0,50	0,00	0,25	0,50	0,75	0,25	0,50	0,25	1,00	0,75	2,75	2,50	2,75	4,50	4,25	8,00	8,75
0,50	0,50	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,00	0,25	0,75	1,00	0,75	2,75	2,00	2,25	4,00	3,25	7,00	7,25
0,75	0,50	1,00	1,00	1,00	1,00	0,75	1,00	1,00	0,75	1,00	0,75	1,00	1,00	2,50	1,25	2,50	5,25	8,25	6,25	13,50
0,50	0,50	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	1,00	0,75	1,25	3,00	3,75	2,75	2,25	8,00	5,00
0,50	0,75	0,75	1,00	0,50	0,50	0,25	0,50	0,00	0,25	0,25	0,00	1,00	0,75	2,50	3,50	3,50	4,50	3,50	9,50	8,00
0,50	0,50	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,25	0,25	0,00	0,75	0,50	2,25	2,25	3,25	4,00	2,25	7,75	6,25
0,50	0,50	0,75	1,00	0,75	0,25	0,75	0,50	0,75	0,75	0,75	0,50	1,00	1,00	3,00	3,25	3,00	4,50	6,25	9,25	10,75
0,50	0,50	0,75	1,00	0,00	0,00	0,25	0,50	0,00	0,25	0,50	0,25	1,00	0,75	1,25	3,25	3,50	3,25	3,50	8,00	6,75

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Code	Category	Geosite	VSE_RAR	VSE_REP	VSE_KGI	VSE_LI	VSA_VP	VSA_SF	VSA_SLN	VSA_EFS	VPR_CC	VPR_PL	VPR_VU	VPR_SNV	VFN_AC
I-PFR	Inverted relief	Puy de Frimont - inverted relief	0,25	1,00	0,50	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,00
I-QRH	Inverted relief	Quarry of the Montagne de la Serre close to Rouillas-Haut	0,50	1,00	0,25	1,00	0,25	0,00	0,75	0,50	0,75	1,00	0,50	0,50	1,00
I-RED	Inverted relief	Mont Redon - inverted relief	0,50	1,00	0,50	1,00	0,50	0,50	0,75	1,00	0,75	1,00	0,50	0,50	0,50
I-SPC	Inverted relief	St. Pierre-le-Chastel - inverted relief	0,25	0,75	0,50	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,75	1,00	1,00
D-CHO	Lava dome	Puy Chopine	0,50	1,00	1,00	1,00	0,75	0,50	1,00	1,00	1,00	1,00	0,50	0,25	0,50
D-CLI	Lava dome	Le Cliersou	0,25	1,00	1,00	1,00	1,00	0,50	1,00	1,00	0,75	1,00	0,50	0,50	0,50
D-DOM	Lava dome	Puy de Dôme	0,25	1,00	1,00	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	1,00
D-GRO	Lava dome	Puy des Grosmanaux	0,75	0,50	0,75	0,25	0,25	1,00	0,75	1,00	1,00	1,00	0,75	0,50	0,50
D-GSA	Lava dome	Grand Sault	0,25	0,50	0,50	0,75	0,50	0,50	1,00	1,00	1,00	1,00	1,00	0,25	0,25
D-GSU	Lava dome	Grand Suchet	0,25	0,75	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,50
D-GSY	Lava dome	Grand Sarcouy	0,25	1,00	0,75	1,00	0,75	1,00	1,00	1,00	0,75	1,00	0,25	0,50	0,50
D-KIL	Lava dome	Cratère Kilian	0,25	0,75	1,00	1,00	0,00	0,50	0,50	1,00	1,00	1,00	0,75	0,25	0,00
D-MCR	Lava dome	Puy Montchar	0,25	0,50	0,50	0,50	0,25	0,50	0,50	1,00	0,75	1,00	0,75	0,50	0,25
D-PPD	Lava dome	Petit Puy de Dôme	0,25	0,75	1,00	1,00	0,75	0,50	1,00	1,00	1,00	1,00	0,75	0,50	0,50
L-ARG	Lava flow	Argnat lava flow outcrop	0,25	0,50	0,25	0,25	0,25	0,00	0,50	0,50	0,75	1,00	0,25	0,25	1,00
L-CCP	Lava flow	Gorges de la Sioule and Côme lava flow front at Peschadoire	0,50	1,00	0,50	0,50	0,50	1,00	0,75	1,00	1,00	1,00	0,50	0,50	0,50
L-CTG	Lava flow	Trou de Glace - Côme lava flow outcrops	0,50	1,00	0,75	1,00	0,75	0,50	0,75	1,00	1,00	1,00	0,75	0,50	1,00
L-GFG	Lava flow	La Fontaine gelée - lava tube	0,50	1,00	0,25	1,00	0,25	0,00	0,75	1,00	0,75	1,00	0,25	0,50	0,50
L-GRH	Lava flow	La Grotte de Ribbe Haute - lava levée	0,50	1,00	0,50	0,50	0,50	0,50	0,75	0,50	0,75	1,00	0,50	0,50	0,50
L-GRP	Lava flow	La Grotte et Maison de la Pierre	0,75	1,00	1,00	1,00	0,50	0,50	0,75	1,00	1,00	1,00	0,50	1,00	1,00
L-LBS	Lava flow	Outcrop of the lava flow basement of Puy de la Vache and Lassolas at Saint-Saturnin	0,75	1,00	0,75	1,00	0,25	0,00	0,75	1,00	0,75	1,00	0,00	0,25	0,50
L-LCP	Lava flow	Outcrop of the lava channel of Puy de la Vache and Lassolas at Ponteix	0,50	0,75	0,50	0,50	0,25	0,00	0,50	1,00	1,00	1,00	0,50	0,75	1,00
L-LLC	Lava flow	The lava lake of the Côme lava flow	0,75	1,00	0,50	1,00	0,50	0,50	0,75	1,00	1,00	1,00	0,75	0,50	0,50
L-LLN	Lava flow	Columnar basalts of the lava lake at Nébouzat	0,25	1,00	0,75	0,50	0,25	0,50	0,50	0,50	0,75	1,00	0,50	0,25	1,00
L-UCH	Lava flow	Lava flow outcrop at Chanonat	0,25	1,00	0,50	1,00	0,50	0,50	0,50	0,50	1,00	1,00	0,75	0,25	0,75
L-PBR	Lava flow	Les Bramauds- pressure ridges	0,25	0,75	0,25	0,25	1,00	1,00	0,75	1,00	1,00	1,00	0,75	0,75	0,50

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VFN_ANV	VFN_AAV	VFN_VEC	VFN_VIRN	VFN_AFV	VTR_PROM	VTR_OV	VTR_VVC	VTR_IP	VTR_NV	VTR_TI	VTR_TGS	VTR_HS	VTR_RS	VSE	VSA	VPR	VFN	VTR	MV	AV
0,50	0,50	1,00	1,00	0,50	0,50	0,00	0,75	0,75	0,00	0,00	0,00	1,00	1,00	2,75	3,75	3,50	3,50	4,00	10,00	7,50
0,50	0,50	0,75	1,00	0,25	0,25	0,00	0,50	0,50	0,25	0,25	0,00	0,75	0,50	2,75	1,50	2,75	4,00	3,00	7,00	7,00
0,50	0,50	0,75	1,00	0,00	0,50	0,25	0,50	0,50	0,50	0,50	0,50	0,75	0,50	3,00	2,75	2,75	3,25	4,50	8,50	7,75
0,50	0,75	0,75	1,00	0,75	0,50	0,75	0,50	1,00	0,75	0,75	0,50	1,00	1,00	2,50	4,00	3,50	4,75	6,75	10,00	11,50
0,75	0,25	0,75	1,00	0,50	0,75	0,25	0,75	0,00	0,25	0,25	0,25	1,00	0,75	3,50	3,25	2,75	3,75	4,25	9,50	8,00
0,75	0,50	0,75	1,00	0,25	0,75	0,50	0,50	0,75	0,75	0,50	0,50	1,00	0,75	3,25	3,50	2,75	3,75	6,00	9,50	9,75
1,00	0,25	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	1,00	2,75	4,00	3,75	5,00	8,75	10,50	13,75
0,75	0,25	0,75	1,00	0,25	0,00	0,00	0,75	0,00	0,25	0,25	0,00	1,00	0,75	2,25	3,00	3,25	3,50	3,00	8,50	6,50
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	2,00	3,00	3,25	3,00	2,50	8,25	5,50
1,00	0,50	0,75	1,00	0,25	0,50	0,50	0,75	0,00	0,50	0,25	0,50	1,00	0,75	2,75	4,00	3,75	4,00	4,75	10,50	8,75
0,75	0,25	0,75	1,00	0,50	1,00	0,50	0,75	0,00	0,50	0,50	0,50	1,00	0,75	3,00	3,75	2,50	3,75	5,50	9,25	9,25
0,75	0,25	0,75	1,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	3,00	2,00	3,00	2,75	2,50	8,00	5,25
0,75	0,25	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,75	0,50	1,75	2,25	3,00	3,00	1,75	7,00	4,75
0,75	0,25	0,75	1,00	0,00	0,25	0,25	0,75	0,00	0,50	0,25	0,25	1,00	0,75	3,00	3,25	3,25	3,25	4,00	9,50	7,25
0,50	0,25	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,25	0,00	0,00	1,00	0,75	1,25	1,25	2,25	4,00	2,50	4,75	6,50
0,50	0,50	1,00	1,00	0,50	0,00	0,00	0,75	0,00	0,25	0,25	0,00	0,75	0,50	2,50	3,25	3,00	4,00	2,50	8,75	6,50
0,50	0,50	0,75	1,00	0,00	0,25	0,50	0,50	0,00	0,50	0,25	0,75	0,75	0,50	3,25	3,00	3,25	3,75	4,00	9,50	7,75
0,25	0,25	0,75	1,00	0,00	0,00	0,25	0,50	0,00	0,25	0,25	0,25	0,75	0,50	2,75	2,00	2,50	2,75	2,75	7,25	5,50
0,50	0,25	0,75	1,00	0,00	0,00	0,25	0,50	0,00	0,25	0,25	0,00	0,75	0,50	2,50	2,25	2,75	3,00	2,50	7,50	5,50
1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	3,75	2,75	3,50	5,75	9,00	10,00	14,75
0,50	0,50	0,75	1,00	0,50	0,25	0,25	0,50	0,00	0,50	0,50	0,50	1,00	1,00	3,50	2,00	2,00	3,75	4,50	7,50	8,25
0,50	0,50	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,50	0,50	0,00	0,75	0,50	2,25	1,75	3,25	4,25	2,75	7,25	7,00
0,75	0,50	0,75	1,00	0,25	0,00	0,00	0,75	0,00	0,25	0,00	0,00	0,75	0,75	3,25	2,75	3,25	3,75	2,50	9,25	6,25
0,50	0,50	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,25	0,00	0,00	1,00	1,00	2,50	1,75	2,50	4,00	2,75	6,75	6,75
0,50	0,50	0,75	1,00	0,75	0,00	0,00	0,50	0,00	0,25	0,00	0,00	1,00	1,00	2,75	2,00	3,00	4,25	2,75	7,75	7,00
0,50	0,25	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,25	0,25	0,00	0,75	0,50	1,50	3,75	3,50	3,00	2,25	8,75	5,25

VIII/C Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
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Code	Category	Geosite	VSE_RAR	VSE_REP	VSE_KGI	VSE_LI	VSA_VP	VSA_SF	VSA_SLN	VSA_EFS	VPR_CC	VPR_PL	VPR_VU	VPR_SNV	VFN_AC
L-PCY	Lava flow	Ceyssat- pressure ridges	0,25	0,75	0,50	0,50	0,75	0,50	0,75	1,00	1,00	1,00	0,75	0,75	0,25
L-PRC	Lava flow	Lava flow of Puy de Combe-grasse- pressure ridges	0,50	1,00	0,75	0,50	0,50	0,00	1,00	1,00	1,00	1,00	0,50	0,75	0,75
L-PRP	Lava flow	Lava flow of Puy de Poucharet- pressure ridges	0,50	0,75	0,50	0,50	0,75	0,50	0,75	1,00	1,00	1,00	0,75	0,75	0,75
L-PVA	Lava flow	Vauriat , lava flow of Louchadière - pressure ridges	0,25	0,75	0,75	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,75	0,50	0,50
L-PVI	Lava flow	Outcrop of the lava flow of Pariou at Villars	0,25	0,75	0,75	1,00	0,50	0,00	0,75	1,00	1,00	1,00	0,50	0,75	0,50
L-QCB	Lava flow	Quarry of Chambols	0,25	0,75	0,50	1,00	0,50	0,50	0,25	0,00	0,50	1,00	0,50	0,75	0,00
L-QCS	Lava flow	Quarry of Ceyssat	0,25	1,00	0,25	1,00	0,50	0,50	0,50	0,50	0,50	1,00	0,75	0,50	0,50
L-QGO	Lava flow	The quarries of Volvic stone at Les Goulots	0,25	1,00	1,00	1,00	1,00	1,00	0,75	0,50	0,50	1,00	0,25	0,75	0,75
L-QMF	Lava flow	Quarry of the lava flow of Puy de la Mey at Fontfreyde	0,25	0,75	0,50	1,00	0,50	0,50	0,50	0,50	0,50	1,00	0,25	0,75	0,75
L-RME	Lava flow	Roche Merle - tumulus	0,25	1,00	0,25	0,50	0,50	0,00	1,00	1,00	1,00	1,00	0,75	0,50	0,50
L-SAY	Lava flow	Lava flow outcrop - Sayat	0,25	0,50	0,25	0,50	0,25	0,00	0,50	0,50	0,75	1,00	0,25	0,25	1,00
M-ACH	Maar	Maar d'Anchald	0,50	1,00	0,50	1,00	0,75	1,00	1,00	1,00	1,00	0,50	0,75	0,75	1,00
M-AMP	Maar	Narse d'Ampoix	0,25	0,75	0,75	1,00	0,50	0,50	1,00	1,00	1,00	1,00	0,25	0,25	0,00
M-BCL	Maar	Bois de Clerzat	0,25	0,25	0,25	0,75	0,50	1,00	0,75	1,00	1,00	1,00	1,00	0,75	0,50
M-BEL	Maar	Maar de Beauloup	0,25	0,50	0,25	0,75	0,75	1,00	0,75	1,00	1,00	1,00	0,75	0,75	1,00
M-BEU	Maar	Maar de Beaunit	0,25	0,75	0,75	1,00	0,75	1,00	1,00	1,00	0,75	1,00	0,50	0,75	1,00
M-CRM	Maar	Creux Morel	0,25	0,75	0,50	1,00	0,50	0,50	0,75	1,00	1,00	1,00	0,75	0,50	0,50
M-ENV	Maar	Maar d'Enval	0,25	0,50	0,75	0,75	0,75	1,00	0,75	1,00	1,00	1,00	0,75	1,00	0,75
M-ESP	Maar	Narse de l'Espinasse	0,25	0,75	0,75	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,25	0,50	0,75
M-MCT	Maar	Maar de Monchatre	0,25	0,50	0,50	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,50
M-NIP	Maar	Nid de la Poule	0,25	0,75	1,00	1,00	0,75	0,50	0,75	1,00	1,00	1,00	0,75	0,75	0,50
M-VIL	Maar	Maar de Villars	0,25	0,75	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,75	0,75
O-BCP	Other	Hercynian base outcrop at 'Chez Pierre'	0,25	0,50	0,25	0,25	0,25	0,00	0,50	0,50	0,75	1,00	0,50	0,50	1,00
O-GBC	Other	Outcrop of Manson granite at Beaune-le-Chaud	0,25	1,00	0,25	0,25	0,50	0,50	0,25	0,00	0,50	1,00	0,50	0,00	0,00
O-PGG	Other	Granite outcrop of Pontgibaud	0,25	0,75	0,50	0,50	0,25	0,50	0,50	0,50	0,75	1,00	0,50	0,50	1,00
O-PMQ	Other	Puy de Manson quarry	0,25	1,00	0,50	0,50	0,50	0,50	0,50	0,00	0,75	1,00	0,50	0,75	0,00
O-SCR	Other	Sandstone outcrop at Crouzol	0,25	0,75	0,25	0,75	0,25	0,00	0,50	0,50	0,50	1,00	0,25	0,25	1,00
S-BAR	Scoria cone	Puy de Barme and its scoria quarry	0,25	0,75	0,75	1,00	0,75	1,00	0,50	1,00	0,50	1,00	0,25	0,50	0,50
S-BCH	Scoria cone	Bois de Chanat	0,50	1,00	0,50	1,00	0,50	0,50	0,75	1,00	1,00	1,00	0,75	0,75	0,50

VIII/C Geosite inventory of the Chaîne des Puy - Limagne Fault World Heritage site -
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VF _N _ANV	VF _N _AAV	VF _N _VEC	VF _N _VIRN	VF _N _AFV	VTR _PROM	VTR _OV	VTR _VVC	VTR _IP	VTR _NV	VTR _TI	VTR _TGS	VTR _HS	VTR _RS	VSE	VSA	VPR	VFN	VTR	MV	AV
0,50	0,50	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	1,00	0,75	2,00	3,00	3,50	3,00	2,25	8,50	5,25
0,75	0,25	0,75	1,00	0,50	0,25	0,50	0,50	1,00	0,50	0,50	0,50	0,75	0,50	2,75	2,50	3,25	4,00	5,00	8,50	9,00
0,50	0,25	0,75	1,00	0,50	0,00	0,25	0,50	0,00	0,50	0,25	0,25	0,75	0,50	2,25	3,00	3,50	3,75	3,00	8,75	6,75
0,50	0,50	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,25	0,25	0,00	1,00	0,75	2,25	4,00	3,25	3,25	2,75	9,50	6,00
0,75	1,00	1,00	1,00	0,50	0,25	0,50	0,75	0,00	0,75	0,50	0,50	1,00	1,00	2,75	2,25	3,25	4,75	5,25	8,25	10,00
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,00	0,00	0,50	0,75	0,50	2,50	1,25	2,75	2,75	2,25	6,50	5,00
0,50	0,50	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,25	0,00	0,00	1,00	0,75	2,50	2,00	2,75	3,25	2,50	7,25	5,75
0,75	0,00	0,75	1,00	0,25	0,00	0,25	0,50	0,00	0,25	0,25	0,75	1,00	0,75	3,25	3,25	2,50	3,50	3,75	9,00	7,25
0,50	0,50	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,25	0,00	0,25	0,75	0,50	2,50	2,00	2,50	4,00	2,25	7,00	6,25
0,50	0,25	0,75	1,00	0,25	0,25	0,00	0,50	0,00	0,25	0,25	0,00	0,75	0,50	2,00	2,50	3,25	3,25	2,50	7,75	5,75
0,50	0,50	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,00	0,00	0,00	1,00	0,75	1,50	1,25	2,25	4,25	2,25	5,00	6,50
0,50	0,50	1,00	1,00	0,50	0,25	0,25	0,75	0,50	0,50	0,75	0,25	1,00	0,75	3,00	3,75	3,00	4,50	5,00	9,75	9,50
0,50	0,25	0,50	1,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,75	0,50	2,75	3,00	2,50	2,25	2,00	8,25	4,25
0,50	0,25	0,75	1,00	0,25	0,25	0,25	0,50	0,00	0,25	0,25	0,00	1,00	0,75	1,50	3,25	3,75	3,25	3,25	8,50	6,50
0,50	0,50	0,75	1,00	0,75	0,00	0,00	0,50	0,00	0,00	0,00	0,00	1,00	0,75	1,75	3,50	3,50	4,50	2,25	8,75	6,75
0,50	0,00	0,75	1,00	0,50	0,25	0,25	0,50	0,75	0,50	0,50	0,50	0,50	0,25	2,75	3,75	3,00	3,75	4,00	9,50	7,75
0,75	0,25	0,75	1,00	0,00	0,00	0,25	0,75	0,00	0,25	0,25	0,00	1,00	0,75	2,50	2,75	3,25	3,25	3,25	8,50	6,50
1,00	0,50	0,75	1,00	0,50	0,00	0,25	0,75	0,00	0,25	0,25	0,00	1,00	0,75	2,25	3,50	3,75	4,50	3,25	9,50	7,75
0,75	0,25	0,50	0,75	0,25	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,75	0,50	2,75	3,75	2,75	3,25	4,75	9,25	8,00
0,25	0,25	0,75	1,00	0,00	0,00	0,25	0,50	0,00	0,25	0,25	0,00	0,75	0,50	2,25	3,75	3,75	2,75	2,50	9,75	5,25
0,75	0,25	0,75	1,00	0,00	0,50	0,75	0,75	0,00	0,75	0,50	0,50	1,00	0,75	3,00	3,00	3,50	3,25	5,50	9,50	8,75
0,50	0,50	1,00	1,00	0,50	0,25	0,50	0,75	0,00	0,50	0,25	0,25	1,00	0,75	2,75	4,00	3,25	4,25	4,25	10,00	8,50
0,50	0,75	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,25	0,00	0,00	1,00	0,75	1,25	1,25	2,75	4,50	2,50	5,25	7,00
0,50	0,50	0,75	0,75	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	1,00	0,75	1,75	1,25	2,00	2,50	2,25	5,00	4,75
0,50	0,50	1,00	1,00	0,75	0,00	0,00	1,00	0,00	0,25	0,50	0,00	1,00	1,00	2,00	1,75	2,75	4,75	3,75	6,50	8,50
0,50	0,50	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	1,00	0,75	2,25	1,50	3,00	2,75	2,25	6,75	5,00
1,00	0,75	0,75	1,00	0,75	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,75	0,50	2,00	1,25	2,00	5,25	2,00	5,25	7,25
0,75	0,50	0,75	1,00	0,25	0,25	0,25	0,50	0,00	0,25	0,25	0,00	1,00	0,75	2,75	3,25	2,25	3,75	3,25	8,25	7,00
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,25	0,25	0,00	1,00	0,75	3,00	2,75	3,50	3,25	2,75	9,25	6,00

VIII/C Geosite inventory of the Chaîne des Puy - Limagne Fault World Heritage site -
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Code	Category	Geosite	VSE_RAR	VSE_REP	VSE_KGI	VSE_LI	VSA_VP	VSA_SF	VSA_SLN	VSA_EFS	VPR_CC	VPR_PL	VPR_VU	VPR_SNV	VFN_AC
S-BES	Scoria cone	Puy Besace	0,25	0,25	0,50	0,25	0,25	1,00	0,75	1,00	1,00	1,00	1,00	0,25	0,00
S-BLE	Scoria cone	Puy de Bleymas and its scoria quarry	0,25	0,75	0,75	0,75	0,25	0,50	0,50	1,00	0,75	1,00	0,50	0,75	0,50
S-BNE	Scoria cone	Puy de la Bannière	0,25	0,50	0,50	0,25	0,25	1,00	0,75	1,00	1,00	1,00	0,75	0,50	0,50
S-BNS	Scoria cone	Puy des Bannières	0,25	0,25	0,25	0,75	0,25	1,00	0,50	1,00	1,00	1,00	0,75	0,50	0,25
S-CGR	Scoria cone	Puy de Combegrasse	0,25	1,00	0,75	1,00	0,75	0,50	1,00	1,00	1,00	1,00	0,50	0,75	0,50
S-CGX	Scoria cone	Chuquet-Genestoux scoriaceous outcrop	0,25	0,75	0,75	1,00	0,25	0,00	0,50	0,50	0,75	1,00	0,50	0,50	0,25
S-CHR	Scoria cone	Puy de Charmont	0,25	0,75	0,50	0,75	0,50	1,00	0,75	1,00	1,00	1,00	0,75	0,75	0,50
S-CHU	Scoria cone	Puy de Chaumont	0,25	0,50	0,50	1,00	0,50	1,00	0,75	1,00	0,75	1,00	0,50	0,50	0,50
S-COM	Scoria cone	Puy de Côme	0,50	1,00	0,75	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,50	0,50	0,50
S-COQ	Scoria cone	Puy de la Coquille	0,25	0,50	0,75	1,00	0,50	1,00	1,00	1,00	0,75	1,00	0,50	0,50	0,50
S-ENF	Scoria cone	Puy de l'Enfer and its scoria quarry	0,25	0,75	0,75	1,00	0,75	0,50	1,00	1,00	0,75	1,00	0,50	0,75	0,75
S-ESP	Scoria cone	Puy de l'Espinasse and its scoria quarry	0,25	0,75	0,50	1,00	0,50	0,50	0,50	0,50	0,50	1,00	0,50	0,75	0,75
S-FIL	Scoria cone	Puy Fillou	0,25	0,50	0,25	0,75	0,25	0,50	0,50	1,00	0,50	1,00	0,75	0,25	0,25
S-GLI	Scoria cone	Puy de la Goulie	0,25	0,25	0,25	0,75	0,25	1,00	0,75	1,00	1,00	1,00	0,75	0,50	0,50
S-GNN	Scoria cone	Puy Gonnard	0,25	0,50	0,75	1,00	0,50	0,50	1,00	1,00	0,75	1,00	0,50	0,50	0,75
S-GOL	Scoria cone	Puy des Goules	0,25	1,00	0,75	1,00	0,75	1,00	1,00	1,00	0,75	1,00	0,50	0,75	0,50
S-GOT	Scoria cone	Puy des Gouttes	0,50	1,00	1,00	1,00	0,75	1,00	1,00	1,00	0,75	1,00	0,50	0,75	0,50
S-GRN	Scoria cone	Puy de Grave Noire and its scoria quarry	0,25	0,75	1,00	1,00	0,75	1,00	1,00	0,50	0,50	1,00	0,50	0,75	0,75
S-JUM	Scoria cone	Puy de Jumes	0,25	0,75	0,75	1,00	0,50	1,00	1,00	1,00	0,75	1,00	0,50	0,75	0,50
S-LAC	Scoria cone	Puy de Laschamps	0,25	0,75	0,75	1,00	0,50	1,00	0,50	1,00	1,00	1,00	0,75	0,75	0,50
S-LAS	Scoria cone	Puy de Lassolas	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,50	1,00	0,25	0,75	0,50
S-LEM	Scoria cone	Puy de Lemptégy	0,75	1,00	1,00	1,00	1,00	0,50	1,00	0,50	0,50	1,00	0,50	1,00	1,00
S-LOU	Scoria cone	Puy de Louchadiere	0,25	0,75	0,75	1,00	0,50	1,00	0,75	1,00	0,75	1,00	0,75	0,75	0,50
S-LOV	Scoria cone	Puy la de Louve scoria quarry of Gare de Volvic	0,25	0,75	0,75	1,00	0,50	0,50	0,50	0,50	0,50	1,00	0,25	0,75	0,50
S-MCE	Scoria cone	Puy Montchié	0,25	0,25	0,75	0,25	0,50	1,00	0,75	1,00	1,00	1,00	1,00	0,50	0,50
S-MEC	Scoria cone	Puy de Mercoeur	0,25	0,75	0,50	0,75	0,50	1,00	0,75	1,00	1,00	1,00	0,75	0,50	0,50
S-MET	Scoria cone	Puy de Monteillet	0,25	0,50	0,25	0,75	0,50	0,50	0,75	1,00	1,00	1,00	0,75	0,50	0,25
S-MEY	Scoria cone	Puy de la Mey	0,25	0,75	0,75	1,00	0,50	1,00	0,75	1,00	1,00	1,00	0,75	0,50	0,50
S-MGY	Scoria cone	Puy de Montgy	0,25	0,25	0,25	0,25	0,50	0,50	0,75	1,00	1,00	1,00	1,00	0,50	0,25

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VFN_ANV	VFN_AAV	VFN_VEC	VFN_VIRN	VFN_AFV	VTR_PROM	VTR_OV	VTR_VVC	VTR_IP	VTR_NV	VTR_TI	VTR_TGS	VTR_HS	VTR_RS	VSE	VSA	VPR	VFN	VTR	MV	AV
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	1,25	3,00	3,25	2,75	2,50	7,50	5,25
0,75	0,50	1,00	1,00	0,25	0,00	0,00	0,75	0,00	0,25	0,00	0,00	1,00	0,75	2,50	2,25	3,00	4,00	2,75	7,75	6,75
0,75	0,50	1,00	1,00	0,00	0,25	0,25	0,75	0,00	0,50	0,25	0,25	1,00	0,75	1,50	3,00	3,25	3,75	4,00	7,75	7,75
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,50	0,25	1,50	2,75	3,25	3,00	1,25	7,50	4,25
0,75	0,25	0,75	1,00	0,50	0,50	0,50	0,75	0,75	0,50	0,75	0,50	1,00	0,75	3,00	3,25	3,25	3,75	6,00	9,50	9,75
0,50	0,50	0,75	1,00	0,50	0,00	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	2,75	1,25	2,75	3,50	2,50	6,75	6,00
0,75	0,25	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,25	0,25	0,00	0,75	0,50	2,25	3,25	3,50	3,50	2,25	9,00	5,75
0,75	0,25	0,75	1,00	0,25	0,25	0,25	0,75	0,00	0,25	0,25	0,25	1,00	0,75	2,25	3,25	2,75	3,50	3,75	8,25	7,25
0,75	0,50	0,75	1,00	0,00	1,00	0,00	0,75	0,00	0,50	0,25	0,25	1,00	0,75	3,25	3,75	3,00	3,50	4,50	10,00	8,00
0,50	0,25	0,75	1,00	0,00	0,50	0,50	0,75	0,50	0,50	0,25	0,50	0,75	0,50	2,50	3,50	2,75	3,00	4,75	8,75	7,75
0,75	0,25	0,75	1,00	0,50	0,50	0,50	0,50	0,00	0,50	0,50	0,50	0,75	0,50	2,75	3,25	3,00	4,00	4,25	9,00	8,25
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,25	0,25	0,00	0,50	0,25	2,50	2,00	2,75	3,50	1,75	7,25	5,25
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	1,75	2,25	2,50	3,00	2,50	6,50	5,50
0,50	0,25	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,50	0,25	1,50	3,00	3,25	3,00	1,25	7,75	4,25
0,50	0,00	0,75	1,00	0,25	0,00	0,25	0,50	0,00	0,00	0,25	0,00	0,50	0,25	2,50	3,00	2,75	3,25	1,75	8,25	5,00
0,75	0,25	0,75	1,00	0,50	0,75	0,50	0,75	0,75	0,50	0,50	0,50	1,00	0,75	3,00	3,75	3,00	3,75	6,00	9,75	9,75
0,75	0,25	0,75	1,00	0,75	1,00	0,75	1,00	0,75	0,75	0,50	0,50	1,00	1,00	3,50	3,75	3,00	4,00	7,25	10,25	11,25
0,50	1,00	1,00	1,00	1,00	0,75	0,25	0,50	0,50	0,50	0,50	0,50	1,00	0,75	3,00	3,25	2,75	5,25	5,25	9,00	10,50
0,50	0,25	0,75	1,00	0,00	0,75	0,50	0,50	0,75	0,50	0,75	0,50	0,75	0,50	2,75	3,50	3,00	3,00	5,50	9,25	8,50
0,75	0,25	0,75	1,00	0,75	0,00	0,00	0,50	0,00	0,25	0,25	0,25	1,00	0,75	2,75	3,00	3,50	4,00	3,00	9,25	7,00
0,75	0,25	0,75	1,00	0,50	1,00	0,75	0,75	0,50	0,75	0,50	0,75	0,75	0,75	3,50	3,50	2,50	3,75	6,50	9,50	10,25
1,00	0,25	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	3,75	3,00	3,00	5,00	9,00	9,75	14,00
0,75	0,25	0,75	1,00	0,50	0,50	0,25	0,50	0,50	0,50	0,25	0,25	0,50	0,25	2,75	3,25	3,25	3,75	3,50	9,25	7,25
0,75	0,50	0,75	1,00	0,75	0,25	0,25	0,75	0,00	0,50	0,50	0,00	0,75	0,50	2,75	2,00	2,50	4,25	3,50	7,25	7,75
0,50	0,25	0,75	1,00	0,00	0,00	0,00	0,75	0,00	0,25	0,25	0,00	1,00	0,75	1,50	3,25	3,50	3,00	3,00	8,25	6,00
0,75	0,00	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,25	0,25	0,00	0,75	0,50	2,25	3,25	3,25	3,00	2,25	8,75	5,25
0,75	0,25	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,50	0,25	1,75	2,75	3,25	3,00	1,25	7,75	4,25
0,75	0,25	0,75	1,00	0,50	0,50	0,25	0,75	0,00	0,25	0,25	0,25	0,75	0,75	2,75	3,25	3,25	3,75	3,75	9,25	7,50
0,50	0,00	0,75	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,50	0,25	1,00	2,75	3,50	2,50	1,25	7,25	3,75

VIII/C Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
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Code	Category	Geosite	VSE_RAR	VSE_REP	VSE_KGI	VSE_LI	VSA_VP	VSA_SF	VSA_SLN	VSA_EFS	VPR_CC	VPR_PL	VPR_VU	VPR_SNV	VFN_AC
S-MOD	Scoria cone	Puy Monténard	0,25	0,75	0,50	0,75	0,75	1,00	1,00	1,00	0,75	0,75	0,75	0,50	0,50
S-MOR	Scoria cone	Puy de la Moreno	0,25	0,50	0,25	1,00	0,25	0,50	0,50	1,00	1,00	1,00	0,75	0,50	0,50
S-NAI	Scoria cone	Puy Nain	0,25	0,50	0,25	1,00	0,50	0,00	1,00	1,00	0,75	1,00	0,50	0,50	0,50
S-NUG	Scoria cone	Puy de la Nugère	0,25	0,50	1,00	0,50	0,50	1,00	0,50	1,00	1,00	1,00	0,75	0,75	0,50
S-PAR	Scoria cone	Puy de Pariou	0,25	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,50	1,00	0,50
S-PAU	Scoria cone	Puy de Paugnat and its scoria quarry	0,25	0,75	0,75	1,00	0,75	1,00	0,75	1,00	0,50	1,00	0,50	0,75	0,50
S-POU	Scoria cone	Puy de Poucharet	0,50	1,00	0,50	1,00	0,50	0,50	1,00	1,00	1,00	1,00	0,50	0,75	0,00
S-ROD	Scoria cone	Puy de la Rodde	0,25	0,25	0,50	0,25	0,50	1,00	0,75	1,00	1,00	1,00	0,75	0,50	0,50
S-SAL	Scoria cone	Puy de Salomon	0,25	0,50	0,75	0,75	0,00	1,00	0,75	1,00	1,00	1,00	1,00	0,50	0,50
S-TEN	Scoria cone	Puy de Ténuzet and its scoria quarry	0,25	0,75	0,75	1,00	1,00	1,00	0,75	0,00	0,25	0,00	0,25	1,00	0,75
S-TOU	Scoria cone	Puy de la Toupe	0,50	0,75	0,50	1,00	0,50	0,50	0,75	0,00	0,50	0,25	0,50	0,25	0,00
S-TRE	Scoria cone	Puy de Tressous	0,50	0,75	0,50	0,50	0,50	0,50	0,75	1,00	1,00	1,00	0,75	0,50	0,50
S-VAC	Scoria cone	Puy de la Vache and its scoria quarry	0,25	1,00	1,00	1,00	1,00	0,50	1,00	1,00	1,00	1,00	0,50	0,75	0,50
S-VER	Scoria cone	Puy de Verrières	0,25	0,50	0,50	0,25	0,50	1,00	0,75	1,00	1,00	1,00	0,75	0,75	0,50
S-VIC	Scoria cone	Puy de Vichatel	0,25	0,75	0,75	1,00	0,75	1,00	0,75	1,00	0,75	1,00	0,50	0,75	0,50

VIII/C Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
assessment with the method of Vujičić et al. (2011)

VFN_ANV	VFN_AAV	VFN_VEC	VFN_VIRN	VFN_AFV	VTR_PROM	VTR_OV	VTR_VVC	VTR_IP	VTR_NV	VTR_TI	VTR_TGS	VTR_HS	VTR_RS	VSE	VSA	VPR	VFN	VTR	MV	AV
0,50	0,00	0,75	1,00	0,50	0,25	0,25	0,50	0,50	0,25	0,50	0,25	0,75	0,50	2,25	3,75	2,75	3,25	3,75	8,75	7,00
0,75	0,00	0,75	1,00	0,75	0,00	0,00	0,50	0,00	0,25	0,00	0,00	1,00	0,75	2,00	2,25	3,25	3,75	2,50	7,50	6,25
0,75	0,25	0,75	1,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	2,00	2,50	2,75	3,25	2,50	7,25	5,75
0,75	0,50	1,00	1,00	0,50	0,75	0,50	0,75	0,00	0,75	0,50	0,75	1,00	0,75	2,25	3,00	3,50	4,25	5,75	8,75	10,00
0,75	0,25	0,75	1,00	0,25	1,00	0,75	0,75	1,00	0,75	1,00	0,75	0,75	0,50	3,25	4,00	3,25	3,50	7,25	10,50	10,75
0,75	0,00	0,75	1,00	0,25	0,25	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,25	2,75	3,50	2,75	3,25	4,00	9,00	7,25
0,75	0,25	0,75	0,75	0,00	0,25	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	3,00	3,00	3,25	2,50	2,75	9,25	5,25
0,75	0,25	0,75	1,00	0,25	0,00	0,00	0,75	0,00	0,25	0,25	0,00	1,00	0,75	1,25	3,25	3,25	3,50	3,00	7,75	6,50
0,50	0,25	0,75	1,00	0,00	0,00	0,00	0,75	0,00	0,25	0,25	0,00	1,00	0,75	2,25	2,75	3,50	3,00	3,00	8,50	6,00
0,75	0,25	0,75	1,00	0,50	0,00	0,25	0,50	0,00	0,00	0,00	0,25	0,75	0,50	2,75	2,75	1,50	4,00	2,25	7,00	6,25
0,75	0,50	0,75	0,75	0,50	0,00	0,00	0,75	0,00	0,00	0,00	0,00	1,00	0,75	2,75	1,75	1,50	3,25	2,50	6,00	5,75
0,75	0,25	0,75	1,00	0,50	0,00	0,00	0,50	0,00	0,25	0,25	0,00	0,50	0,25	2,25	2,75	3,25	3,75	1,75	8,25	5,50
1,00	0,50	0,75	1,00	0,50	1,00	0,50	0,75	0,75	0,75	0,75	0,75	1,00	0,75	3,25	3,50	3,25	4,25	7,00	10,00	11,25
0,50	0,25	0,75	1,00	0,25	0,00	0,00	0,50	0,00	0,25	0,25	0,00	0,50	0,25	1,50	3,25	3,50	3,25	1,75	8,25	5,00
0,50	0,25	0,75	1,00	0,50	0,25	0,25	0,50	0,50	0,50	0,50	0,25	0,75	0,50	2,75	3,50	3,00	3,50	4,00	9,25	7,50

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Visited geosite	Date of answering	Im_VSE_RAR	Im_VSE_REP	Im_VSE_KGI	Im_VSE_LI	Im_VSA_VP	Im_VSA_SF	Im_VSA_SLN	Im_VSA_EFS	Im_VPR_CC	Im_VPR_PL	Im_VPR_VU	Im_VPR_SNV	Im_VFN_AC	Im_VFN_ANV	Im_VFN_AAV	Im_VFN_VEC	Im_VFN_VIRN	Im_VFN_AFV	Im_VTR_PROM
Puy de Lemptégny	2019.07.25	0,75	0,75	1,00	1,00	1,00	0,50	1,00	1,00	1,00	1,00	1,00	0,50	0,75	1,00	0,50	0,75	1,00	1,00	1,00
Puy de Combebrasse	2019.07.30	0,75	0,75	0,50	0,75	0,75	0,75	0,75	0,75	0,75	0,75	1,00	0,75	0,75	0,75	0,75	0,75	0,50	0,25	0,75
Puy de la Vache	2019.07.31	0,75	0,25	0,25	0,50	1,00	0,25	0,50	0,75	1,00	0,50	0,75	0,75	0,25	0,50	0,00	0,25	0,25	0,25	0,50
Puy de Combebrasse	2019.08.01	0,25	0,75	0,50	0,50	0,75	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,00	1,00	1,00	0,75	0,00	0,00	0,50
Puy de Lemptégny	2019.08.01	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	1,00	0,50	0,50	0,50	0,50	0,50	0,50	0,50
Lac d'Aydat	2019.08.02	1,00	0,50	1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,50	0,75	1,00	0,75	0,75	0,75	1,00	1,00
Lac d'Aydat	2019.08.02	0,75	1,00	1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,50	1,00	1,00	0,50	0,75	0,75	1,00	0,75
Puy de la Vache	2019.08.03	0,75	0,50	0,75	0,50	0,75	0,75	1,00	0,75	0,75	1,00	1,00	1,00	0,00	0,50	0,25	0,00	0,75	0,50	0,25
Puy de Lemptégny	2019.08.04	1,00	1,00	0,50	1,00	1,00	0,50	1,00	0,50	1,00	1,00	1,00	0,75	0,00	1,00	0,50	0,25	1,00	0,50	1,00
Puy de la Vache	2019.08.04	0,75	0,75	0,75	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	0,75	0,75	0,75	0,75	0,75	0,75
Puy de Lemptégny	2019.08.05	0,75	0,75	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,25	1,00	1,00	0,50	0,50	0,50	1,00
Puy de Lemptégny	2019.08.05	0,75	0,75	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,25	1,00	1,00	0,50	0,50	0,50	1,00
Puy de Lemptégny	2019.08.08	1,00	1,00	1,00	1,00	0,50	0,75	1,00	1,00	1,00	1,00	1,00	1,00	0,00	1,00	1,00	0,25	1,00	0,50	0,50
Vierge de Volvic - Affleurement de la faille de Limagne	2019.08.09	1,00	0,75	0,75	1,00	0,75	0,75	0,75	1,00	0,75	1,00	1,00	1,00	0,75	0,75	0,75	0,75	0,50	0,50	0,25
Puy des Gouttes	2019.08.09	0,00	0,00	1,00	0,50	1,00	0,75	1,00	1,00	1,00	0,50	1,00	0,75	0,75	1,00	0,00	0,00	1,00	1,00	1,00
Puy de Paugnat	2019.08.10	0,50	0,50	0,25	0,75	1,00	0,75	0,75	0,50	1,00	1,00	1,00	1,00	1,00	0,50	0,00	0,25	0,50	1,00	0,50

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Im_VTR_OV	Im_VTR_VVC	Im_VTR_IP	Im_VTR_NV	Im_VTR_TI	Im_VTR_TGS	Im_VTR_HS	Im_VTR_RS	Sex	Age	Highest level of education	Experience in geosciences / tourism	Distance of home to the geosite	Home	Interest in geotourism	Hiking frequency
1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	Homme	19 - 25	Enseignement supérieur	Oui, dans le tourisme	0 - 25 km	Clermont-Ferrand	5	Quelques mois
0,50	0,25	1,00	0,50	0,25	0,25	0,25	0,50	Femme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Belgique	5	Hebdomadaire
0,00	0,00	0,25	0,25	0,00	0,00	0,00	0,00	Homme	Moins que 18	Enseignement secondaire	Non, aucun	25 - 50 km	Mont-Dore	4	Hebdomadaire
0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	Femme	Plus de 60	Enseignement secondaire	Non, aucun	0 - 25 km	Clermont-Ferrand	3	Hebdomadaire
0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	Homme	46 - 60	Enseignement secondaire	Non, aucun	Plus de 100 km	Tancoigne	4	Hebdomadaire
0,25	0,50	1,00	0,50	0,50	0,25	0,50	0,50	Femme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Saint-Affrique	5	Hebdomadaire
0,00	0,75	1,00	1,00	1,00	0,75	1,00	1,00	Femme	19 - 25	Enseignement supérieur	Non, aucun	Plus de 100 km	Saint-Affrique	4	Au moins une fois par mois
0,00	0,25	0,50	0,75	0,25	0,25	0,00	0,00	Homme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Hague / Pays-Bas	3	Au moins une fois par an
1,00	1,00	0,75	0,75	1,00	1,00	1,00	1,00	Homme	19 - 25	Enseignement supérieur	Oui, dans les deux domaines	0 - 25 km	Clermont-Ferrand	5	Hebdomadaire
0,50	0,50	0,75	0,25	0,75	0,25	0,25	0,25	Homme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Aydat	3	Au moins une fois par mois
1,00	1,00	1,00	0,50	1,00	1,00	0,50	0,50	Homme	46 - 60	Enseignement supérieur	Non, aucun	Plus de 100 km	Saverne	3	Au moins une fois par mois
1,00	1,00	1,00	0,50	1,00	1,00	0,50	0,50	Homme	46 - 60	Enseignement supérieur	Non, aucun	Plus de 100 km	Saverne	3	Au moins une fois par mois
1,00	1,00	1,00	0,50	1,00	1,00	0,00	0,00	Femme	35 - 45	Enseignement supérieur	Oui, dans le géoscience	Plus de 100 km	Caen	3	Jamais
0,75	0,75	0,75	0,50	0,75	1,00	0,50	0,50	Femme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Boulogne-Billancourt	3	Au moins une fois par an
1,00	1,00	0,75	0,75	1,00	1,00	1,00	0,25	Femme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Cambrai	4	Au moins une fois par mois
0,00	0,75	1,00	0,50	0,75	0,00	0,75	0,00	Femme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Orléans	5	Au moins une fois par an

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
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Visited geosite	Date of answering	Im_VSE_RAR	Im_VSE_REP	Im_VSE_KGI	Im_VSE_LI	Im_VSA_VP	Im_VSA_SF	Im_VSA_SLN	Im_VSA_EFS	Im_VPR_CC	Im_VPR_PL	Im_VPR_VU	Im_VPR_SNV	Im_VFN_AC	Im_VFN_ANV	Im_VFN_AAV	Im_VFN_VEC	Im_VFN_VIRN	Im_VFN_AFV	Im_VTR_PROM
Gorges de l'Artière - Affleurement de la faille de Limagne	2019.08.11	0,75	1,00	0,75	0,75	0,75	0,75	1,00	1,00	1,00	1,00	1,00	0,25	1,00	0,75	0,75	0,75	0,25	0,75	0,50
Puy de Combebrasse	2019.08.12	0,25	0,50	0,50	0,75	0,75	0,50	0,75	0,75	1,00	0,75	0,75	0,75	0,75	0,75	0,25	0,75	0,75	0,75	0,50
La narse d'Espinasse	2019.08.12	0,50	0,50	0,50	0,50	0,75	0,25	0,50	0,50	1,00	1,00	1,00	0,75	0,75	0,50	0,25	0,25	0,50	0,50	0,50
Puy de Lemptégny	2019.08.12	0,50	0,75	0,50	0,50	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,25	0,50	0,50	0,50	0,50
Puy de Lemptégny	2019.08.13	0,75	0,75	0,50	0,75	1,00	1,00	0,50	0,75	0,75	0,50	0,75	1,00	1,00	1,00	0,75	0,50	1,00	0,50	0,50
Gorges d'Enval - Affleurement de la faille de Limagne	2019.08.14	0,25	0,25	0,25	0,50	0,50	0,25	0,50	0,25	0,50	0,50	0,25	0,25	0,25	0,25	0,50	0,25	0,25	0,50	0,25
Puy de Lemptégny	2019.08.14	1,00	1,00	1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,25	0,25	0,25	0,25	1,00
Puy de Combebrasse	2019.08.14	0,75	0,75	0,75	1,00	1,00	0,75	0,75	1,00	1,00	1,00	1,00	0,75	0,00	0,25	0,25	0,50	0,00	0,25	0,50
Puy de Lemptégny	2019.08.15	0,25	0,75	0,75	1,00	1,00	0,50	0,75	1,00	1,00	1,00	1,00	1,00	0,50	0,75	0,50	0,00	0,75	0,50	0,75
Puy de Lemptégny	2019.08.15	0,50	1,00	0,25	1,00	0,75	0,25	0,75	1,00	1,00	1,00	1,00	1,00	0,50	0,75	0,25	0,50	0,50	0,50	0,50
Vierge de Volvic - Affleurement de la faille de Limagne	2019.08.15	0,50	0,75	0,50	0,50	1,00	0,75	0,25	0,75	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,75	1,00	0,75	0,25
Puy de Combebrasse	2019.08.16	0,25	0,25	0,00	0,75	1,00	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,50	0,75	0,75	0,75	0,50
Puy de Pariou	2019.08.17	1,00	0,75	0,50	0,75	0,75	0,50	1,00	0,75	1,00	0,75	1,00	1,00	1,00	0,50	0,50	0,50	0,75	0,75	0,50
Puy des Gouttes	2019.08.19	0,50	0,00	0,75	0,25	1,00	0,75	0,75	1,00	1,00	1,00	1,00	0,75	0,25	0,50	0,00	0,50	0,25	0,00	0,50
Vierge de Volvic - Affleurement de la faille de Limagne	2019.08.19	0,25	0,00	0,25	0,25	0,75	0,50	0,75	0,75	1,00	0,75	0,75	1,00	0,25	0,50	0,50	0,75	0,75	0,75	0,75
Mont Redon	2019.08.20	0,75	0,75	0,75	0,75	0,75	0,50	0,75	0,75	0,25	0,25	0,50	0,25	0,50	0,50	0,50	0,75	0,25	0,50	0,75

VIII/D Geosite inventory of the Chaîne des Puy - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Im_VTR_OV	Im_VTR_VVC	Im_VTR_IP	Im_VTR_NV	Im_VTR_TI	Im_VTR_TGS	Im_VTR_HS	Im_VTR_RS	Sex	Age	Highest level of education	Experience in geosciences / tourism	Distance of home to the geosite	Home	Interest in geotourism	Hiking frequency
1,00	0,75	0,75	0,75	0,50	0,75	0,50	0,50	Homme	Plus de 60	Enseignement supérieur	Non, aucun	0 - 25 km	Ceyrat	3	Hebdomadaire
0,25	0,25	0,75	0,75	0,75	0,25	0,50	0,25	Femme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	La Haie-Fouassière	4	Au moins une fois par mois
0,75	0,75	0,75	0,50	0,50	0,50	0,25	0,00	Femme	Plus de 60	Enseignement supérieur	Oui, dans le tourisme	25 - 50 km	Chamalières	4	Hebdomadaire
0,75	0,75	0,75	0,50	0,75	0,75	0,50	0,25	Homme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Bordeaux	4	Au moins une fois par an
0,75	1,00	0,50	0,50	0,75	1,00	0,25	0,50	Homme	46 - 60	Enseignement secondaire	Non, aucun	Plus de 100 km	Valence	5	Hebdomadaire
0,25	0,25	0,50	0,50	0,50	0,50	0,50	0,50	Femme	Moins que 18	Enseignement primaire	Non, aucun	0 - 25 km	Saint-Avoid	3	Au moins une fois par an
1,00	0,75	0,75	0,75	0,75	1,00	0,00	0,00	Homme	35 - 45	Enseignement secondaire	Non, aucun	Plus de 100 km	Valenciennes	5	Quelques mois
0,50	0,75	1,00	1,00	0,25	0,50	0,00	0,00	Femme	Plus de 60	Enseignement supérieur	Non, aucun	0 - 25 km	Aydat	3	Au moins une fois par mois
0,75	0,75	0,75	0,50	1,00	1,00	0,50	0,25	Femme	46 - 60	Enseignement supérieur	Non, aucun	Plus de 100 km	Pau	3	Au moins une fois par mois
0,75	1,00	1,00	0,75	1,00	0,25	0,00	0,00	Homme	19 - 25	Enseignement supérieur	Non, aucun	Plus de 100 km	Cannes	5	Quelques mois
0,00	0,00	0,00	0,50	0,75	0,00	0,00	0,25	Femme	19 - 25	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	3	Au moins une fois par mois
0,75	0,25	1,00	0,25	0,50	0,25	0,25	0,25	Femme	46 - 60	Enseignement supérieur	Non, aucun	25 - 50 km	Tallende	3	Au moins une fois par mois
0,50	0,75	0,50	1,00	0,50	0,00	0,00	0,00	Homme	46 - 60	Enseignement supérieur	Non, aucun	Plus de 100 km	Aix-les-Bains	4	Au moins une fois par mois
0,00	0,25	0,75	0,75	0,00	0,00	0,00	0,00	Femme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Orcines	4	Au moins une fois par mois
0,00	0,25	0,50	0,00	0,50	0,00	0,00	0,00	Homme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	Chateaugay	2	Quelques mois
0,25	0,50	0,75	0,25	0,25	0,25	0,25	0,25	Homme	Plus de 60	Enseignement supérieur	Non, aucun	0 - 25 km	France	4	Au moins une fois par mois

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
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Visited geosite	Date of answering	Im_VSE_RAR	Im_VSE_REP	Im_VSE_KGI	Im_VSE_LI	Im_VSA_VP	Im_VSA_SF	Im_VSA_SLN	Im_VSA_EFS	Im_VPR_CC	Im_VPR_PL	Im_VPR_VU	Im_VPR_SNV	Im_VFN_AC	Im_VFN_ANV	Im_VFN_AAV	Im_VFN_VEC	Im_VFN_VIRN	Im_VFN_AFV	Im_VTR_PROM
Puy de Lemptégny	2019.08.20	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,50	0,50	1,00	1,00	0,50
Puy de Lemptégny	2019.08.21	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	1,00	0,50	0,75	0,75	1,00
Maar de Beaunit	2019.08.21	1,00	0,75	0,50	0,75	1,00	0,75	0,75	1,00	1,00	0,75	0,75	0,50	1,00	1,00	0,25	0,50	0,50	0,75	1,00
Puy de Pariou	2019.08.21	1,00	1,00	0,75	0,50	0,75	0,50	1,00	1,00	1,00	1,00	1,00	0,75	0,50	0,50	0,50	0,75	0,75	0,75	0,75
Puy de Pagnat	2019.08.22	1,00	1,00	0,50	1,00	1,00	0,25	1,00	1,00	1,00	1,00	1,00	0,75	0,50	1,00	1,00	0,25	0,00	0,25	1,00
Puy de Lemptégny	2019.08.22	0,25	0,50	0,50	1,00	1,00	0,50	0,75	0,75	1,00	1,00	0,75	1,00	0,75	0,50	0,50	0,25	0,75	0,75	0,50
Lac d'Aydat	2019.08.24	1,00	0,75	0,75	1,00	1,00	0,50	0,75	1,00	1,00	0,50	1,00	1,00	0,00	0,00	0,00	0,00	0,25	0,50	0,25
La narse d'Espinasse	2019.08.24	0,25	0,75	0,75	0,75	1,00	0,50	0,75	1,00	0,75	0,75	1,00	0,75	0,50	0,75	0,50	0,25	0,25	0,25	0,50
Vierge de Volvic - Affleurement de la faille de Limagne	2019.08.27	0,50	0,00	0,75	0,00	1,00	0,00	0,75	1,00	1,00	1,00	1,00	0,75	1,00	1,00	1,00	0,00	1,00	1,00	1,00
Puy de Lemptégny	2019.08.31	0,25	1,00	1,00	1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,00	1,00	1,00	0,50	0,75	1,00	1,00
Gorges de l'Artière - Affleurement de la faille de Limagne	2019.09.01	1,00	1,00	1,00	1,00	0,50	0,50	0,50	0,50	1,00	1,00	1,00	0,50	0,25	0,00	0,00	0,75	0,50	0,50	0,50
Maar de Villars	2019.09.01	0,50	0,50	0,50	1,00	1,00	0,75	0,75	1,00	1,00	1,00	1,00	1,00	0,00	0,50	0,50	0,75	0,75	0,75	0,50
Lac d'Aydat	2019.09.06	0,50	0,50	0,50	0,75	1,00	0,50	0,75	0,75	0,75	0,50	0,75	1,00	0,75	0,50	0,50	0,50	0,25	0,25	0,75
Puy de Lemptégny	2019.09.06	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Maar de Villars	2019.09.07	0,75	0,50	0,25	0,50	1,00	0,75	0,75	0,75	1,00	0,50	0,75	0,75	0,25	0,25	0,25	0,25	0,00	0,00	0,50
Maar de Villars	2019.09.07	0,75	0,50	0,25	0,50	1,00	0,75	0,75	0,75	1,00	0,50	0,75	0,75	0,25	0,25	0,25	0,25	0,00	0,00	0,50
Maar de Villars	2019.09.07	0,75	0,50	0,25	0,50	1,00	0,75	0,75	0,75	1,00	0,50	0,75	0,75	0,25	0,25	0,25	0,25	0,00	0,00	0,50

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
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Im_VTR_OV	Im_VTR_VVC	Im_VTR_IP	Im_VTR_NV	Im_VTR_TI	Im_VTR_TGS	Im_VTR_HS	Im_VTR_RS	Sex	Age	Highest level of education	Experience in geosciences / tourism	Distance of home to the geosite	Home	Interest in geotourism	Hiking frequency
1,00	1,00	0,75	1,00	1,00	1,00	0,50	1,00	Homme	Plus de 60	Enseignement secondaire	Oui, dans le tourisme	Plus de 100 km	Tamniès	4	Au moins une fois par mois
1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	Homme	26 - 35	Enseignement secondaire	Oui, dans le tourisme	0 - 25 km	Clermont-Ferrand	5	Au moins une fois par mois
1,00	0,25	1,00	0,00	0,00	0,75	0,50	0,75	Homme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Seyssins	3	Quelques mois
0,50	1,00	0,75	0,50	0,75	0,50	0,75	0,50	Femme	19 - 25	Enseignement supérieur	Non, aucun	Plus de 100 km	Chalon-sur-Saône	4	Jamais
0,00	0,75	1,00	0,00	0,50	0,00	0,75	0,25	Femme	46 - 60	Enseignement supérieur	Oui, dans le géoscience	Plus de 100 km	Hérault	5	Hebdomadaire
1,00	0,75	0,75	0,50	1,00	0,75	0,00	0,50	Femme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Paris	3	Quelques mois
0,75	0,25	0,75	0,50	0,25	0,75	0,00	0,50	Homme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	Billom	4	Au moins une fois par an
0,75	1,00	0,75	0,75	1,00	0,75	1,00	1,00	Homme	Plus de 60	Enseignement supérieur	Oui, dans le tourisme	Plus de 100 km	Bordeaux	3	Au moins une fois par an
1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	Femme	19 - 25	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	1	Hebdomadaire
0,75	1,00	1,00	1,00	1,00	1,00	0,75	1,00	Homme	46 - 60	Enseignement secondaire	Oui, dans le tourisme	Plus de 100 km	Villefranche-sur-Saône	5	Quelques mois
1,00	0,25	0,75	0,50	0,75	0,75	0,25	0,25	Femme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Ceyrat	5	Hebdomadaire
0,00	0,50	1,00	0,50	1,00	0,50	0,75	0,75	Homme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	4	Hebdomadaire
0,75	0,50	1,00	0,75	0,75	0,50	0,00	0,25	Homme	Plus de 60	Enseignement secondaire	Non, aucun	0 - 25 km	Clermont-Ferrand	3	Au moins une fois par mois
1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	Homme	35 - 45	Enseignement secondaire	Non, aucun	Plus de 100 km	Lyon	4	Hebdomadaire
0,50	0,75	0,75	0,50	0,50	0,50	0,25	0,25	Homme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	2	Au moins une fois par mois
0,50	0,75	0,75	0,50	0,50	0,50	0,25	0,25	Homme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	2	Au moins une fois par mois
0,50	0,75	0,75	0,50	0,50	0,50	0,25	0,25	Homme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	2	Au moins une fois par mois

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
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Visited geosite	Date of answering	Im_VSE_RAR	Im_VSE_REP	Im_VSE_KGI	Im_VSE_LI	Im_VSA_VP	Im_VSA_SF	Im_VSA_SLN	Im_VSA_EFS	Im_VPR_CC	Im_VPR_PL	Im_VPR_VU	Im_VPR_SNV	Im_VFN_AC	Im_VFN_ANV	Im_VFN_AAV	Im_VFN_VEC	Im_VFN_VIRN	Im_VFN_AFV	Im_VTR_PROM
Maar de Villars	2019.09.07	0,75	0,75	0,25	0,75	1,00	0,75	1,00	1,00	0,75	0,50	0,50	0,25	1,00	0,50	0,25	0,75	1,00	1,00	1,00
Maar de Villars	2019.09.08	0,25	0,25	0,50	0,50	0,75	0,50	1,00	1,00	1,00	1,00	1,00	0,75	0,75	0,75	0,75	0,50	0,25	0,50	0,50
Lac d'Aydat	2019.09.09	0,50	0,50	0,75	0,50	0,75	0,50	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,50	0,50	0,50	0,75
La narse d'Espinasse	2019.09.09	1,00	0,75	0,50	0,75	0,75	0,75	0,75	1,00	1,00	1,00	1,00	1,00	0,50	0,75	0,75	0,50	0,50	0,50	0,50
Gorges de l'Artière - Affleurement de la faille de Limagne	2019.09.10	0,75	0,75	0,50	0,25	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,75	0,50	0,75	0,75	0,25	0,25
Puy de Combebrasse	2019.09.13	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	0,75	0,75	0,50	1,00	0,75	0,75
Puy de Louchadière	2019.09.15	1,00	1,00	0,25	1,00	1,00	1,00	1,00	1,00	0,50	0,25	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,50	1,00
Vierge de Volvic - Affleurement de la faille de Limagne	2019.09.15	1,00	1,00	1,00	1,00	1,00	0,75	0,50	0,50	0,25	1,00	1,00	1,00	0,00	0,50	0,00	0,00	0,00	0,00	0,25
Montagne de la Serre	2019.09.21	0,50	0,50	0,50	0,50	0,75	0,75	1,00	0,75	0,00	0,50	1,00	0,75	0,25	1,00	0,50	0,50	0,75	0,75	0,75
Puy de Pariou	2019.09.22	1,00	1,00	1,00	1,00	1,00	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,50	0,50	0,00	0,50	0,50	0,75
Puy de Combebrasse	2019.09.26	0,50	0,75	0,25	0,75	0,75	0,25	0,75	0,75	0,75	0,25	0,75	0,75	0,75	0,75	0,50	0,50	0,25	0,25	0,25
Puy de Dôme	2019.09.28	1,00	1,00	1,00	0,75	1,00	1,00	1,00	0,75	0,75	0,75	1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	0,75
Puy de Dôme	2019.09.28	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,50	1,00	0,50	1,00	1,00	0,50
Maar de Villars	2019.10.06	1,00	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,50
Maar de Villars	2019.10.06	1,00	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,50
Puy de Combebrasse	2019.10.10	0,50	0,50	0,75	0,75	1,00	0,75	1,00	0,75	1,00	1,00	1,00	1,00	0,75	0,75	0,50	0,50	0,75	0,50	0,50

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Im_VTR_OV	Im_VTR_VVC	Im_VTR_IP	Im_VTR_NV	Im_VTR_TI	Im_VTR_TGS	Im_VTR_HS	Im_VTR_RS	Sex	Age	Highest level of education	Experience in geosciences / tourism	Distance of home to the geosite	Home	Interest in geotourism	Hiking frequency
0,00	0,50	0,25	0,50	0,25	0,25	0,50	0,50	Femme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	4	Hebdomadaire
0,00	0,00	0,75	0,25	0,75	0,25	0,25	0,75	Homme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	3	Hebdomadaire
0,50	0,75	1,00	0,75	0,75	0,50	0,50	0,50	Homme	35 - 45	Enseignement supérieur	Non, aucun	Plus de 100 km	Thonon-les-Bains	4	Quelques mois
0,50	0,50	0,75	0,25	0,50	0,50	0,25	0,50	Femme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Saint-Amant-Tallende	4	Au moins une fois par mois
0,25	0,25	0,50	0,50	0,25	0,25	0,25	0,25	Homme	19 - 25	Enseignement secondaire	Non, aucun	0 - 25 km	Chamalières	3	Hebdomadaire
0,50	1,00	1,00	0,75	0,75	0,50	0,50	0,50	Homme	Plus de 60	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	5	Au moins une fois par mois
1,00	0,50	1,00	1,00	1,00	0,25	0,50	0,50	Homme	Plus de 60	Enseignement supérieur	Oui, dans le tourisme	0 - 25 km	Clermont-Ferrand	5	Jamais
0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	Homme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Volvic	3	Au moins une fois par mois
0,50	0,50	0,75	0,50	0,50	0,50	0,50	0,75	Homme	Plus de 60	Enseignement secondaire	Non, aucun	0 - 25 km	Chadrat	4	Hebdomadaire
0,00	1,00	1,00	0,50	0,75	0,00	0,00	0,00	Femme	46 - 60	Enseignement supérieur	Non, aucun	Plus de 100 km	Osny	4	Au moins une fois par mois
0,00	0,75	0,75	0,50	1,00	0,25	0,50	0,50	Homme	Plus de 60	Enseignement supérieur	Non, aucun	50 - 100 km	France	4	Hebdomadaire
1,00	1,00	0,75	1,00	0,75	1,00	0,75	1,00	Homme	46 - 60	Enseignement supérieur	Oui, dans les deux domaines	0 - 25 km	Clermont-Ferrand	5	Hebdomadaire
0,75	0,75	1,00	0,75	1,00	0,75	0,50	0,50	Femme	35 - 45	Enseignement supérieur	Oui, dans le géoscience	0 - 25 km	Clermont-Ferrand	5	Au moins une fois par mois
1,00	0,75	1,00	0,75	0,00	0,75	0,00	0,00	Homme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	4	Hebdomadaire
1,00	0,75	1,00	0,75	0,00	0,75	0,00	0,00	Homme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	4	Hebdomadaire
0,50	0,25	0,50	0,50	0,50	0,25	0,25	0,25	Femme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Aubière	3	Hebdomadaire

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Visited geosite	Date of answering	Im_VSE_RAR	Im_VSE_REP	Im_VSE_KGI	Im_VSE_LI	Im_VSA_VP	Im_VSA_SF	Im_VSA_SLN	Im_VSA_EFS	Im_VPR_CC	Im_VPR_PL	Im_VPR_VU	Im_VPR_SNV	Im_VFN_AC	Im_VFN_ANV	Im_VFN_AAV	Im_VFN_VEC	Im_VFN_VIRN	Im_VFN_AFV	Im_VTR_PROM
Vierge de Volvic - Affleurement de la faille de Limagne	2019.10.24	0,75	0,50	0,50	1,00	0,75	0,50	0,75	0,50	0,50	0,25	0,25	0,75	0,25	0,50	0,00	0,75	0,00	0,25	0,50
Vierge de Volvic - Affleurement de la faille de Limagne	2019.10.25	1,00	0,75	0,50	1,00	1,00	0,75	0,75	1,00	0,75	0,50	1,00	0,50	0,25	0,75	0,75	0,50	0,25	0,00	0,25
Puy de Combebrasse	2019.10.27	0,75	0,75	1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	0,50	1,00	0,50	0,50	0,25	0,25	0,50
Maar de Beaunit	2019.10.27	1,00	0,75	0,50	1,00	1,00	0,25	0,75	0,75	1,00	1,00	1,00	1,00	0,50	1,00	0,50	1,00	0,25	0,25	0,75
Vierge de Volvic - Affleurement de la faille de Limagne	2019.10.30	1,00	0,75	0,75	1,00	1,00	0,50	0,75	1,00	1,00	1,00	1,00	1,00	0,25	1,00	0,75	0,50	0,50	0,75	0,75
Puy de Dôme	2019.11.10	0,25	0,25	0,75	0,50	0,75	0,50	0,75	1,00	0,75	0,75	0,75	0,75	0,75	0,50	1,00	0,75	0,50	0,50	0,75
Lac d'Aydat	2019.12.03	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,50	0,50	0,50	0,75	1,00
Gorges de l'Artière - Affleurement de la faille de Limagne	2019.12.30	0,50	0,75	0,75	0,75	1,00	0,75	0,75	1,00	1,00	1,00	1,00	1,00	0,50	0,75	0,75	1,00	0,75	0,75	0,75
Maar de Beaunit	2020.01.02	0,75	0,75	0,25	1,00	0,50	0,50	0,75	1,00	0,75	0,75	0,50	0,50	0,00	0,50	0,50	0,25	0,50	0,50	0,50
Maar de Beaunit	2020.01.12	1,00	1,00	0,50	1,00	1,00	0,50	0,75	1,00	1,00	1,00	1,00	1,00	0,75	0,25	0,25	0,50	0,75	0,50	0,25
Puy de Combebrasse	2020.01.20	0,50	0,75	0,50	0,75	1,00	0,50	1,00	1,00	1,00	1,00	1,00	1,00	0,75	0,75	0,50	0,50	0,25	0,25	0,75
Maar de Beaunit	2020.02.06	0,75	0,50	0,25	0,75	0,25	0,25	0,25	0,75	1,00	0,75	1,00	0,50	0,50	0,25	0,25	0,75	0,75	0,50	0,25
Puy de Pagnat	2020.02.15	0,25	0,75	0,25	0,75	1,00	0,75	1,00	1,00	1,00	1,00	1,00	0,75	0,25	0,75	0,25	0,75	0,25	0,50	0,75
Puy de Louchadière	2020.03.15	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,75	0,75	0,75	0,75	0,75
Puy de Pagnat	2020.03.15	0,50	0,75	0,25	1,00	1,00	0,50	0,50	0,75	0,75	0,75	0,75	0,75	0,50	0,50	0,50	0,50	0,75	0,50	0,50

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Im_VTR_OV	Im_VTR_VVC	Im_VTR_IP	Im_VTR_NV	Im_VTR_TI	Im_VTR_TGS	Im_VTR_HS	Im_VTR_RS	Sex	Age	Highest level of education	Experience in geosciences / tourism	Distance of home to the geosite	Home	Interest in geotourism	Hiking frequency
0,25	0,25	1,00	0,75	0,25	0,25	0,25	0,00	Homme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Chateaugay	4	Au moins une fois par mois
0,25	0,75	0,75	0,25	0,75	0,25	0,50	0,50	Femme	Plus de 60	Enseignement secondaire	Non, aucun	0 - 25 km	Volvic	3	Hebdomadaire
0,25	0,25	0,75	0,75	0,25	0,25	0,50	0,25	Femme	19 - 25	Enseignement supérieur	Non, aucun	0 - 25 km	Beaumont	2	Au moins une fois par mois
0,50	0,25	1,00	0,75	0,25	0,75	0,25	0,00	Femme	19 - 25	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	4	Hebdomadaire
0,50	0,75	1,00	0,25	1,00	0,50	0,50	0,00	Femme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	Cébazat	3	Hebdomadaire
0,50	0,50	0,50	0,50	0,75	0,50	0,50	0,50	Homme	46 - 60	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	3	Hebdomadaire
0,75	0,75	1,00	0,75	0,75	0,75	0,75	0,75	Homme	35 - 45	Enseignement supérieur	Non, aucun	0 - 25 km	Cournon-d'Auvergne	3	Au moins une fois par mois
0,75	0,75	0,75	0,75	0,75	0,75	1,00	1,00	Homme	46 - 60	Enseignement supérieur	Oui, dans le tourisme	0 - 25 km	Saint-Bonnet-près-Orcival	5	Hebdomadaire
0,75	0,75	1,00	0,50	1,00	1,00	0,50	0,50	Femme	46 - 60	Enseignement supérieur	Non, aucun	25 - 50 km	Clermont-Ferrand	5	Hebdomadaire
0,25	0,50	1,00	0,25	0,50	0,25	0,00	0,00	Femme	26 - 35	Enseignement supérieur	Oui, dans le tourisme	0 - 25 km	Charbonnières-les-Varennes	5	Au moins une fois par mois
0,25	0,25	1,00	0,25	0,25	0,25	0,00	0,00	Femme	35 - 45	Enseignement supérieur	Non, aucun	25 - 50 km	Clermont-Ferrand	4	Au moins une fois par mois
0,25	0,25	0,75	0,25	0,50	0,25	0,25	0,25	Femme	19 - 25	Enseignement supérieur	Non, aucun	25 - 50 km	Clermont-Ferrand	3	Au moins une fois par mois
0,25	0,75	1,00	0,25	0,50	0,25	0,25	0,25	Homme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	Chamalières	3	Hebdomadaire
0,50	0,75	0,50	0,75	1,00	0,50	0,75	0,75	Femme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	3	Au moins une fois par mois
0,50	0,50	1,00	0,75	0,50	0,50	0,25	0,25	Homme	46 - 60	Enseignement supérieur	Oui, dans le géoscience	25 - 50 km	Maringues	4	Au moins une fois par mois

VIII/D Geosite inventory of the Chaîne des Puy - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Visited geosite	Date of answering	Im_VSE_RAR	Im_VSE_REP	Im_VSE_KGI	Im_VSE_LI	Im_VSA_VP	Im_VSA_SF	Im_VSA_SLN	Im_VSA_EFS	Im_VPR_CC	Im_VPR_PL	Im_VPR_VU	Im_VPR_SNV	Im_VFN_AC	Im_VFN_ANV	Im_VFN_AAV	Im_VFN_VEC	Im_VFN_VIRN	Im_VFN_AFV	Im_VTR_PROM
Puy de Louchadière	2020.03.17	1,00	0,50	0,50	0,75	1,00	0,50	1,00	1,00	0,75	1,00	1,00	1,00	1,00	0,75	0,25	0,50	0,75	0,25	0,50
Puy de Louchadière	2020.03.17	1,00	0,50	0,50	0,75	1,00	0,50	1,00	1,00	0,75	1,00	1,00	1,00	1,00	0,75	0,25	0,50	0,75	0,25	0,50
Puy de Louchadière	2020.03.25	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,75	1,00	0,75	0,75	0,75	0,75	0,75
Grand Sarcouy	2020.04.17	0,75	0,75	0,50	0,75	0,75	0,50	0,75	0,75	0,75	0,75	1,00	1,00	1,00	0,75	0,75	0,75	0,50	0,50	0,50

VIII/D Geosite inventory of the Chaîne des Puys - Limagne Fault World Heritage site -
answers of (geo)tourists from M-GAM survey

Im_VTR_OV	Im_VTR_VVC	Im_VTR_IP	Im_VTR_NV	Im_VTR_TI	Im_VTR_TGS	Im_VTR_HS	Im_VTR_RS	Sex	Age	Highest level of education	Experience in geosciences / tourism	Distance of home to the geosite	Home	Interest in geotourism	Hiking frequency
0,50	0,50	0,75	0,75	0,25	0,25	0,50	0,25	Femme	19 - 25	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	4	Quelques mois
0,50	0,50	0,75	0,75	0,25	0,25	0,50	0,25	Femme	19 - 25	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	4	Quelques mois
0,50	0,75	0,50	0,75	1,00	0,50	0,75	0,75	Femme	26 - 35	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	3	Au moins une fois par mois
0,50	0,25	1,00	0,50	0,50	0,25	0,25	0,25	Homme	19 - 25	Enseignement supérieur	Non, aucun	0 - 25 km	Clermont-Ferrand	5	Hebdomadaire

VIII/E/1 Puy de la Poix - bitumen spring – CF-1001



The bitumen spring of Puy de la Poix, one of the rare example of ‘developed’ geosites in the urban area, featuring an interpretative panel (in front) and a protective fencing around the outsource channel

VIII/E/2 Rue Cheval - Oligocene sediments – CF-1002



A relatively well-preserved section of Oligocene sedimentation in Clermont-Ferrand, located in a yet not urbanized part of the city, at Rue Cheval. However, the site is highly vulnerable, due to natural erosion, vegetation of the talus and the potential of non-respective slope stabilization works

VIII/E/3 Quarry of Gandaillat - Oligocene sediments – CF-1102



Three geosites on one image: from the abandoned quarry of Gandaillat, the peperitic neck of Puy de Crouel is visible (in the middle). The city itself is located behind the hill. The Puy de Dôme in the background is outside the city limits, but it is the iconic element of the Chaîne des Puy, and a geosite both in the national and the local (World Heritage property) inventory.

VIII/E/4 Puy Longue - Anthropogenic garbage deposit – CF-1103



Anthropogenic 'sediments' at Puy Longue, deposited in forms of several terraces on a previous hill. It is a well visible feature from the city with a didactic potential as a reminder of consumption, also bearing educational value as a viewpoint to the urban area and the Chaîne des Puy in the background.

VIII/E/5 Rue Desdevises du Dèzert 20 - Grave Noire lava flow + spring – CF-1210



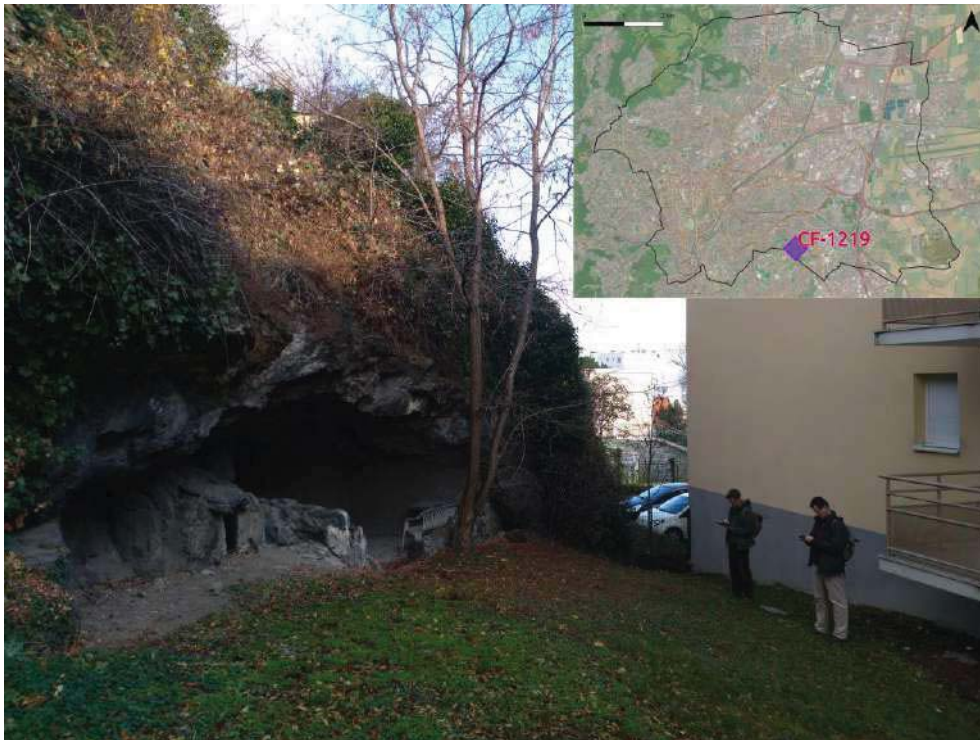
A potential symbiosis of urban environment and geob heritage at Desdevises du Dèzert 20. The significant, columnar outcrop of the Grave Noire lava flow was composed into a garage, which is now used as a small art gallery.

VIII/E/6 Creux de l'enfer - Grave Noire lava flow – CF-1217



The front of the Grave Noire lava flow at Creux de l'Enfer, containing also clinker, xenoliths of the sedimentary basin and scoria. It was an ancient quarry and since several decades, it functions as an urban park, an important ecological niche as well

VIII/E/7 Saint-Astrimoine - Grave Noire lava flow – CF-1219



The Grave Noire lava flow front under the church of Saint-Astrimoine is an example of community involvement in geosite management. The small cavity or opening (maybe enlarged from a small, exposed lava tube) functions now as a community barbecue place and a meeting point for the nearby houses.

VIII/E/8 Margeride tram stop - Grave Noire lava flow – CF-1220



Being one of the most significant outcrops of the Grave Noire lava flow, the site at Margeride has an elevated educational potential for two reasons. It is situated under the Campus of Cézeux and regularly visited as a study site in geological curriculums. On the other hand, it is a direct connection to citizens because of the tram stop, which should be further improved with interpretation of the site.

VIII/E/9 Saint-Alyre - travertine spring – CF-1401



The ‘petrified spring’ of Saint-Alyre, an example of travertine sedimentation was a tourist attraction during the XXth century, together with its adjacent spa. The spring became inactive in the 2000s, probably in connection to some construction works in the nearby Place de Jaude.

VIII/E/10 Rue Nohanent 184 – stromatolithes – CF-1511



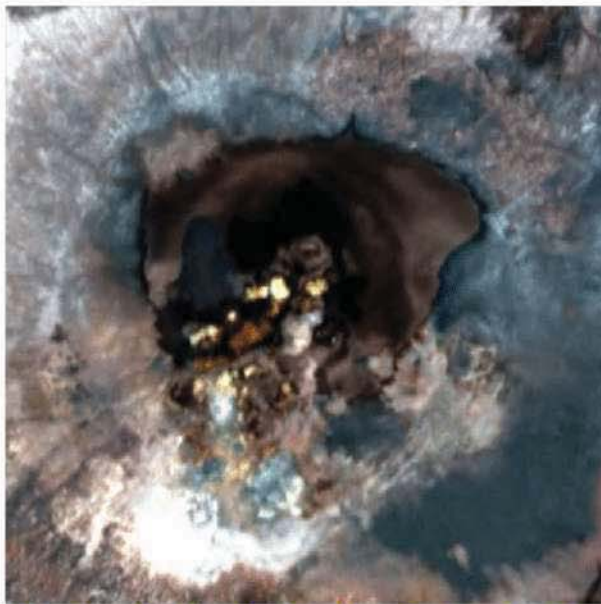
Besides the quarry of Gandaillat, which is situated outside the urbanized area of the city, the geosite of Rue Nohanent 184 is the only, currently known place in the city, where stromatolithes can be seen in the outcrops of the Oligocene Limagne sediments.

Code	Geosite	Prim. Geol. Int.	Secon. Geol. Int.	Edu. Int.	Rarety	Geohist. Imp.	Pres. State	Geohist. Int. Score	Eff. Prot	Heritage Stars'	Nat. Vuln.	Anthr. Threat	Prot.&Vuln.
CF-1001	Puy de la Poix - bitumen spring	3	3	2	3	0	2	37	1	3	2	2	8
CF-1002	R. Cheval - Oligocene sediments	2	1	1	2	0	1	20	3	1	2	2	8
CF-1003	Puy de Var - inverted relief	3	3	2	2	0	3	37	2	3	1	2	8
CF-1101	Puy de Crouel - peperitic volcanic neck	3	3	3	3	2	3	46	1	3	1	1	6
CF-1102	Quarry of Gandaillat - Oligocene sediments	3	3	3	3	0	2	40	1	3	2	2	8
CF-1103	Puy Longue - Anthropogenic garbage deposit	2	1	2	1	0	2	23	3	2	3	2	10
CF-1104	R. Oradou 62 - Oligocene sediments	2	1	1	1	0	1	18	3	1	1	2	7
CF-1105	R. Oradou 98 - Oligocene sediments	1	1	1	2	0	0	14	3	1	1	2	7
CF-1106	R. Oradou 98 - Grave Noire lava flow	1	1	1	1	0	1	14	3	1	1	2	7
CF-1107	R. Oradou 118 - Grave Noire lava flow	2	1	2	1	0	1	21	3	2	3	3	11
CF-1108	R. Oradou 128 - Grave Noire lava flow	2	2	2	1	0	2	26	3	2	2	2	9
CF-1109	Montferrand – marls mount	1	1	2	1	0	1	17	3	1	1	3	8
CF-1201	R. Pont-de-Naud 21 - Grave Noire lava flow	1	1	1	1	0	1	14	3	1	1	0	5
CF-1202	R. Marivaux 9 - Grave Noire lava flow	2	1	1	1	0	2	20	3	1	1	1	6
CF-1203	R. Docteur Chibret 2 - Grave Noire lava flow	1	1	1	1	0	2	16	3	1	1	1	6
CF-1204	Av. Léon Blum 65- Grave Noire lava flow	1	1	0	1	0	1	11	3	1	1	1	6
CF-1205	R. Neuf Soleils 38- Grave Noire lava flow	2	1	1	1	0	1	18	3	1	1	1	6
CF-1206	Résidence Cheops 2 - Grave Noire lava flow	2	2	1	1	0	2	23	3	2	1	2	8
CF-1207	R. Henry Andraud 21 - Grave Noire lava flow	3	2	2	1	0	2	30	3	2	2	2	9
CF-1208	Pilon of the viaduct of Saint-Jacques - Grave Noire lava flow	1	1	0	1	0	1	11	3	1	1	1	6
CF-1209	R. Pont Saint Jacques 62 - Grave Noire lava flow	1	1	0	1	0	1	11	3	1	0	0	4
CF-1210	R. Desdevises du Dèzert 20 - Grave Noire lava flow + spring	3	2	2	3	0	2	34	3	3	2	2	10
CF-1211	Cité Universitaire Dolet - Grave Noire lava flow	2	2	2	2	0	2	28	3	2	2	2	9
CF-1212	Imp.Dr. Cohendy - Grave Noire lava flow	2	2	1	2	0	2	25	3	2	2	3	10
CF-1213	R. Étienne Dolet 60 - Grave Noire lava flow	1	1	1	1	0	1	14	3	1	2	2	8
CF-1214	R. Roty 35 - Grave Noire lava flow	1	1	1	1	0	1	14	3	1	3	1	8
CF-1215	Al. Rocailles 2 - Grave Noire lava flow	2	2	2	1	0	2	26	3	2	2	1	8
CF-1216	Av. Landais 8 - Grave Noire lava flow	2	1	1	1	0	2	20	3	1	2	2	8
CF-1217	Creux de l'enfer - Grave Noire lava flow	3	2	3	3	1	3	41	1	3	2	2	8
CF-1218	R. Louis Dabert 20-24 - Grave Noire lava flow	1	1	1	1	0	1	14	3	1	2	2	8
CF-1219	Saint-Astrimoine - Grave Noire lava flow	2	2	3	2	0	3	33	3	3	3	3	12
CF-1220	Margeride tram stop - Grave Noire lava flow	2	2	3	2	0	2	31	3	2	2	2	9
CF-1221	R. Étienne et George Sauvestre - Alluvial infill of Maar de Gantière	1	1	1	2	0	1	16	3	1	3	1	8
CF-1222	Av. Léon Blum 76 - Grave Noire lava flow	1	1	1	1	0	1	14	3	1	2	1	7
CF-1401	Saint-Alyre - travertine spring	3	3	3	3	2	2	44	2	3	1	1	7
CF-1402	R. Durtol 85 - Oligocene sediments	1	1	1	2	0	1	16	3	1	2	1	7
CF-1403	R. Farnettes 31 - Oligocene sediments	1	1	1	2	0	1	16	3	1	2	2	8
CF-1404	Montjuzet - Oligocene sedimentary residual	2	1	2	1	2	2	27	2	2	1	3	8
CF-1501	Plateau of Côtes de Clermont inverted relief	3	2	3	2	1	2	37	2	3	2	1	8
CF-1502	Ch. Mouchette 40 - Oligocene sediments	2	1	1	2	0	1	20	3	1	2	2	8
CF-1503	Al. Écureuils 1 - Oligocene sediments	1	1	1	2	0	1	16	3	1	2	3	9

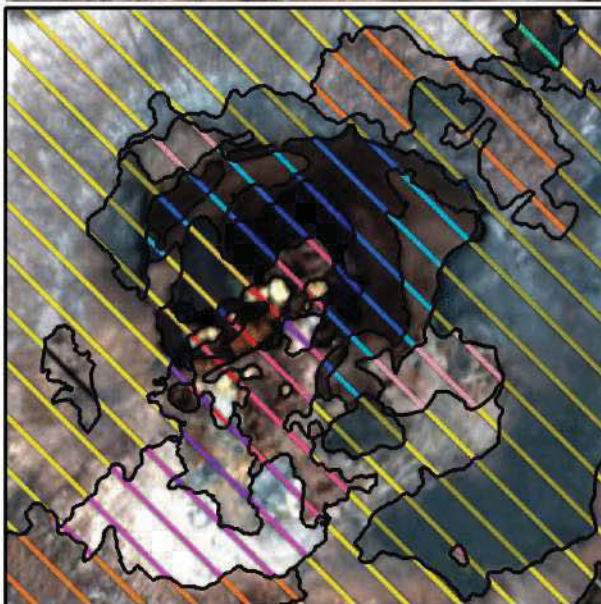
Code	Geosite	Prim. Geol. Int.	Secon. Geol. Int.	Edu. Int.	Rarety	Geohist. Imp.	Pres. State	Geohet. Int. Score	Eff. Prot	Heritage Stars'	Nat. Vuln.	Anthr. Threat	Prot.&Vuln.
CF-1504	R. Blanzat 245 - tephra and paleosol	3	3	3	3	0	2	40	3	3	2	2	10
CF-1505	R. Blanzat 237 - Oligocene sediments	2	1	1	2	0	1	20	3	1	3	2	9
CF-1506	Puy de Chanturgue - Miocene lava flow quarry	2	2	2	2	0	0	24	2	2	2	2	8
CF-1507	Puy de Chanturgue - landslides	3	2	2	2	0	2	32	2	3	1	2	8
CF-1508	Puy de Chanturgue - gullies with sedimentary flank outcrops	2	1	1	1	0	0	16	2	1	1	2	6
CF-1509	R. Puyou 7 - Oligocene sediments	1	1	1	2	0	1	16	3	1	2	2	8
CF-1510	R. Bouys 43 - Oligocene sediments	1	1	1	1	0	1	14	3	1	1	2	7
CF-1511	R. Nohanent 184 - stromatolithes	3	3	2	3	0	1	35	3	3	2	2	10
CF-1512	R. Victor Charreton 18 – Oligocene sediments	2	1	1	1	0	0	16	3	1	3	2	9
CF-1513	Rue V. Charreton x - Oligocene sediments	2	1	1	2	0	1	20	3	1	2	2	8
CF-1514	Rue V. Charreton y - Oligocene sediments	2	2	1	2	0	1	23	3	2	2	2	9
CF-1515	R. de Trémonteix - Oligocene sediments	3	2	1	2	0	1	27	3	2	1	2	8

VIII/G/1 Dallol - 02.01.2019

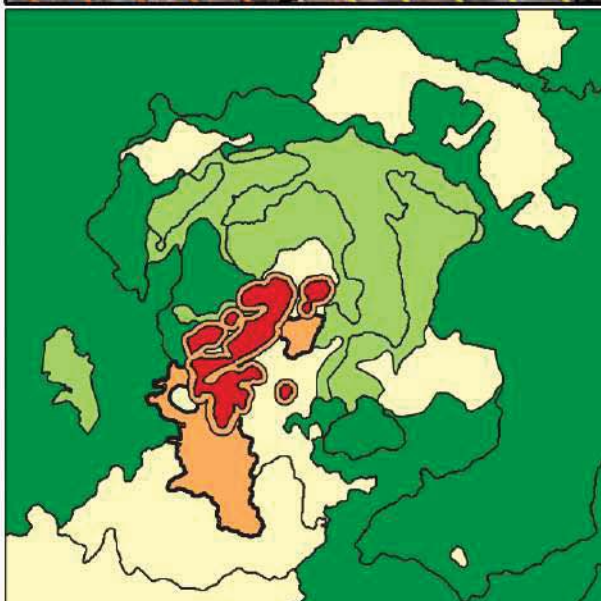
Satellite



Interpretation



Hazard



- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
- Ephemeral lake coverage 2
- Ephemeral lake coverage 3
- Inactive geothermal zone
- Mining ghost town
- Salt canyons
- Salt dome
- Salt pillars
- Salt plain
- Wadi

- Very low / Non existent
- Low
- Moderate
- High
- Very high

0 250 500 m

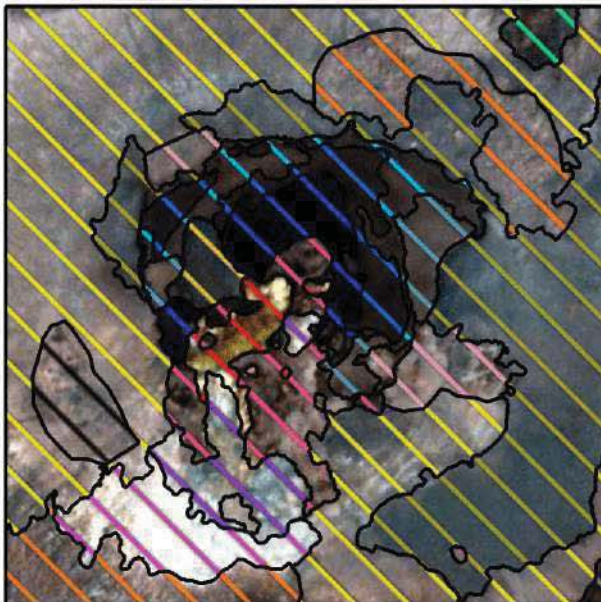


VIII/G/2 Dallol - 02.02.2019

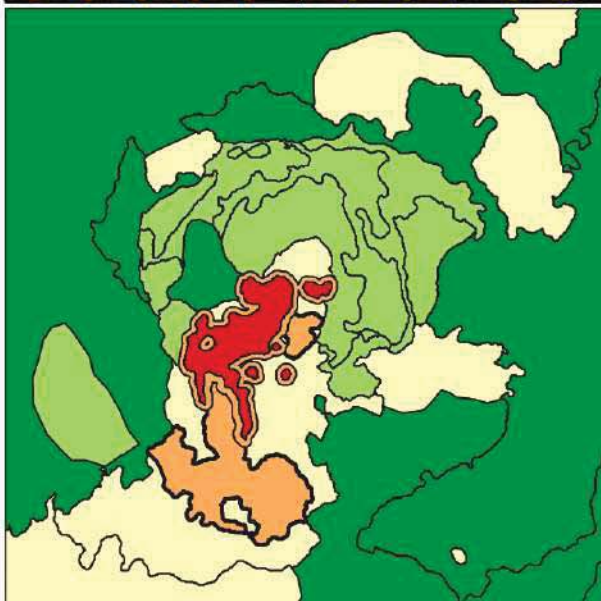
Satellite



Interpretation



Hazard



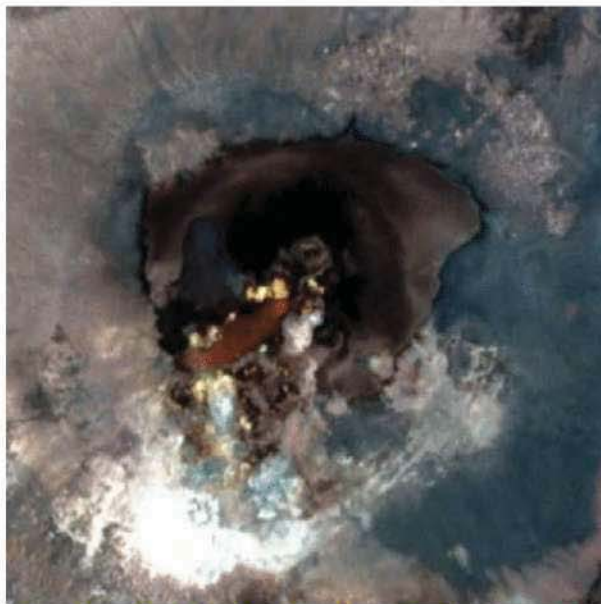
- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
- Ephemeral lake coverage 2
- Ephemeral lake coverage 3
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- Salt dome
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- Wadi

- Very low / Non existent
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- High
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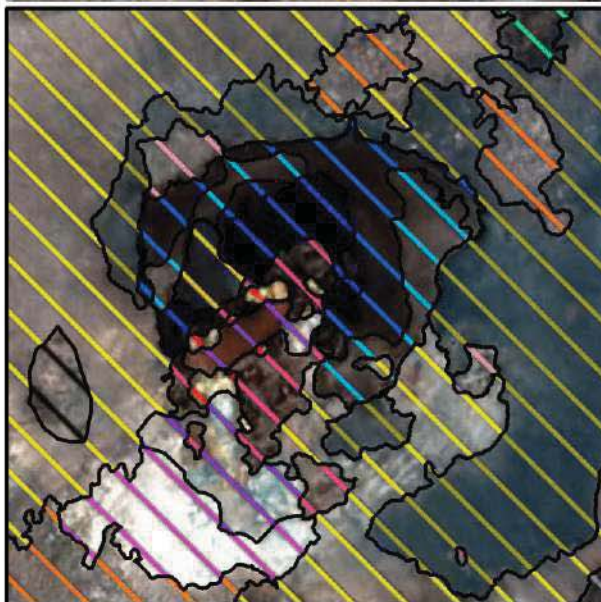
0 250 500 m

VIII/G/3 Dallol - 14.03.2019

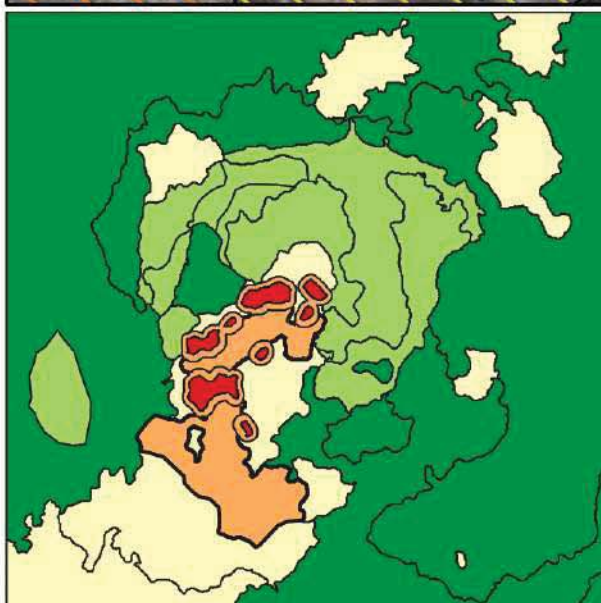
Satellite



Interpretation



Hazard



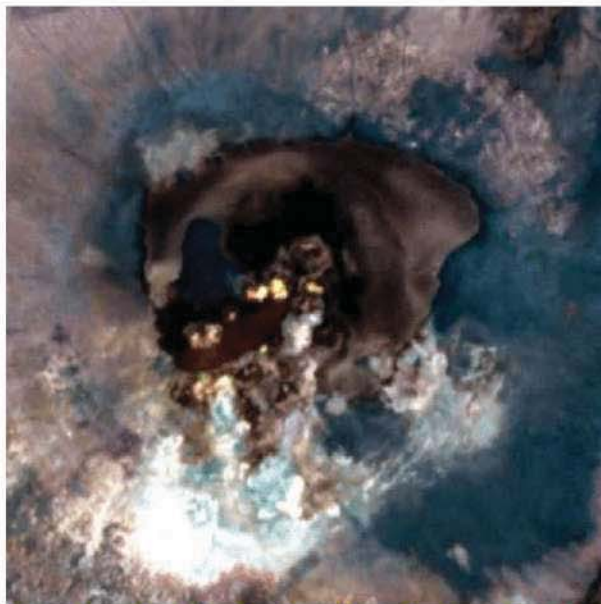
- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
- Ephemeral lake coverage 2
- Ephemeral lake coverage 3
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- Salt dome
- Salt pillars
- Salt plain
- Wadi

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- Very high

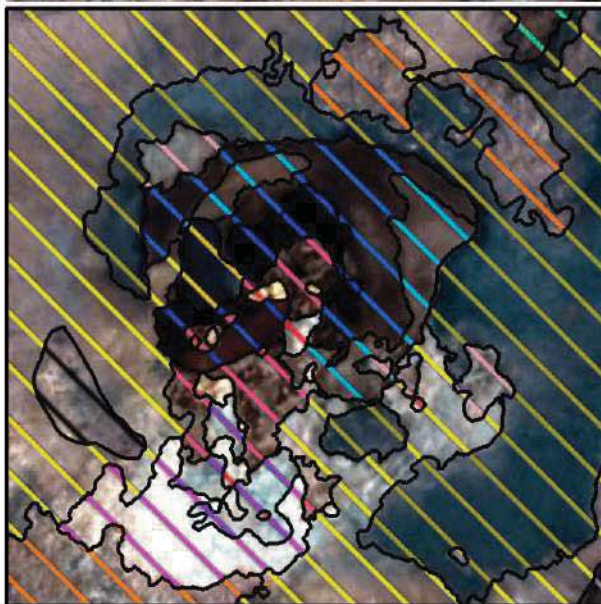
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VIII/G/4 Dallol - 04.04.2019

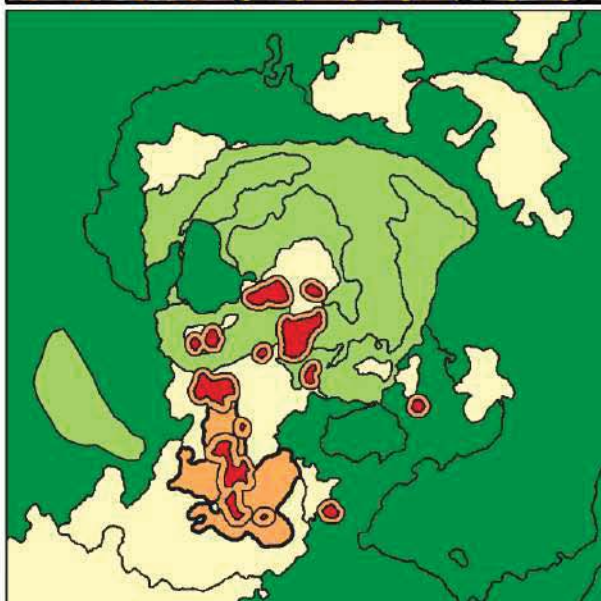
Satellite



Interpretation



Hazard



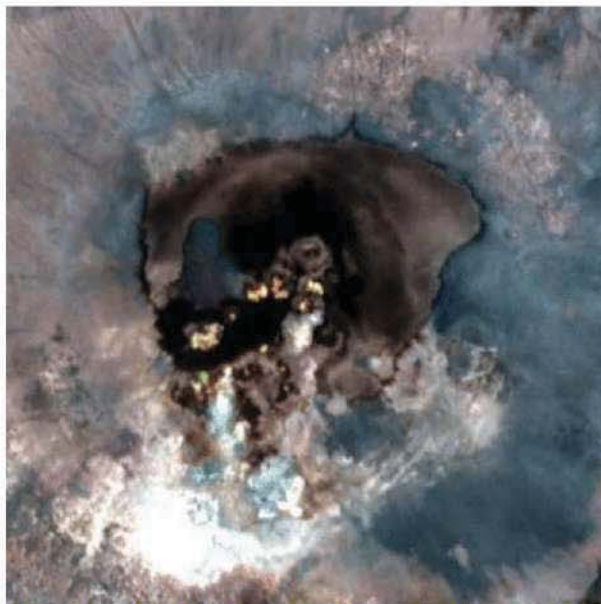
- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
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- Dallol salt dome base 2
- Ephemeral lake coverage 1
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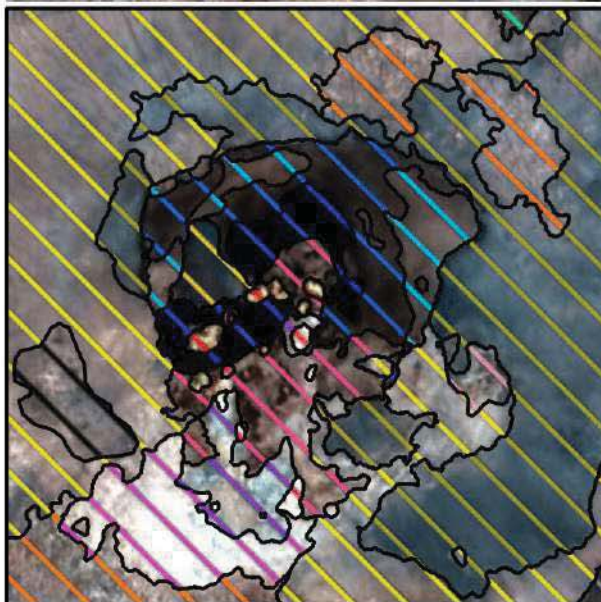
0 250 500 m

VIII/G/5 Dallol - 01.05.2019

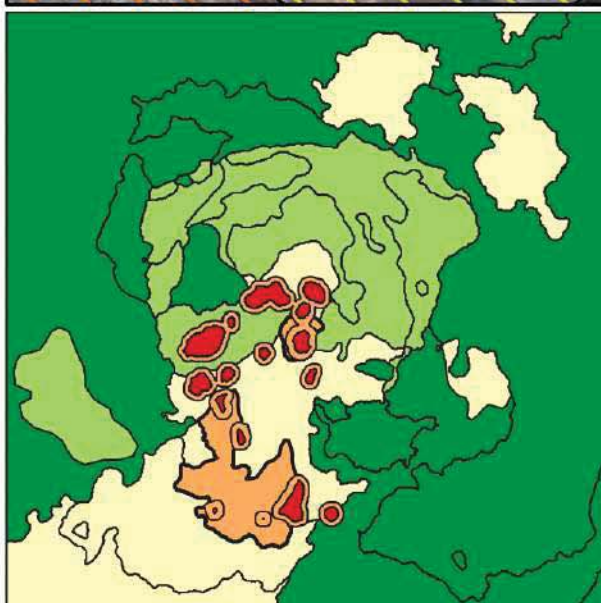
Satellite



Interpretation



Hazard



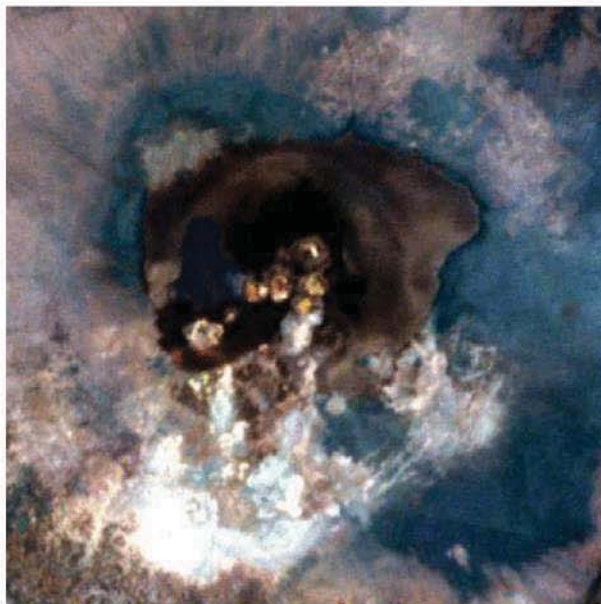
- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
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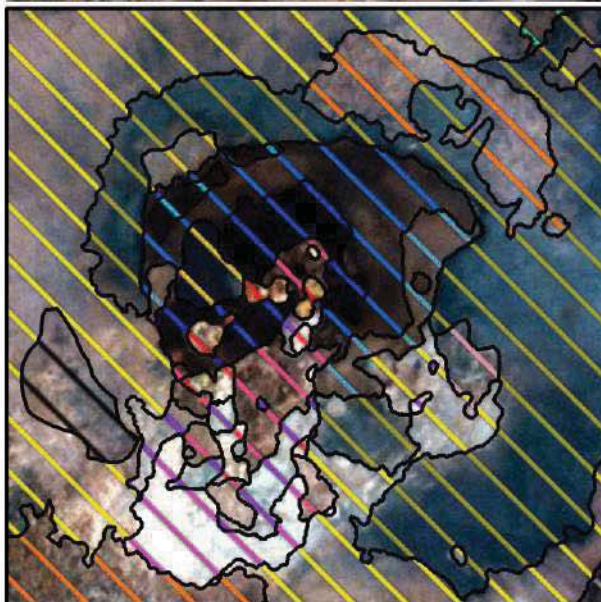
0 250 500 m

VIII/G/6 Dallol - 01.06.2019

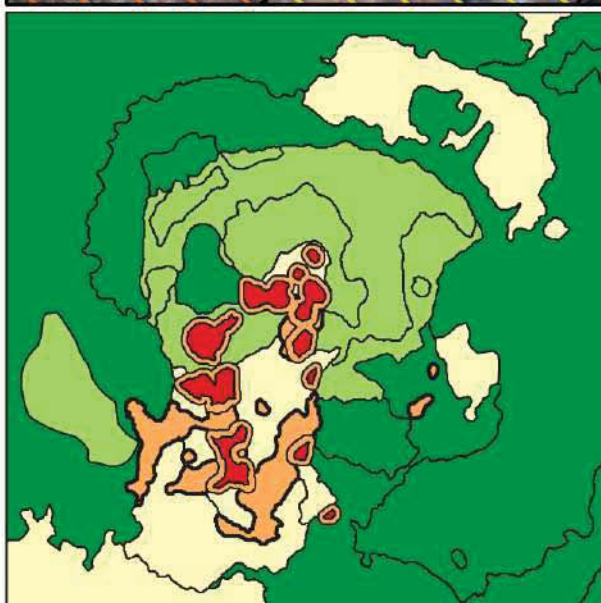
Satellite



Interpretation



Hazard



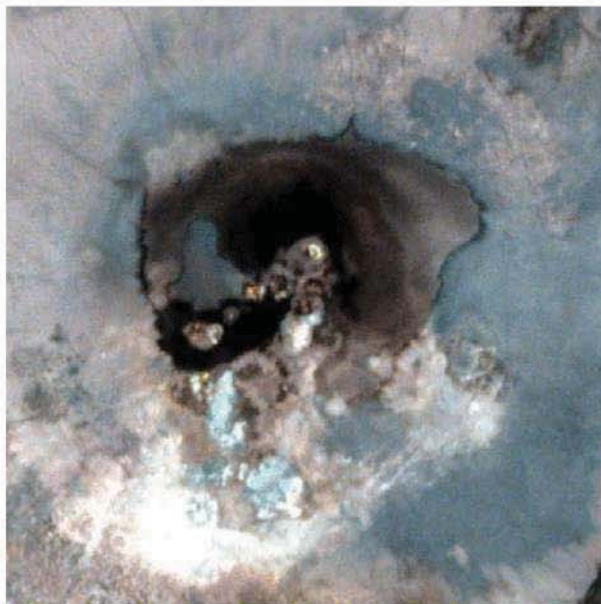
- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
- Ephemeral lake coverage 2
- Ephemeral lake coverage 3
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- Mining ghost town
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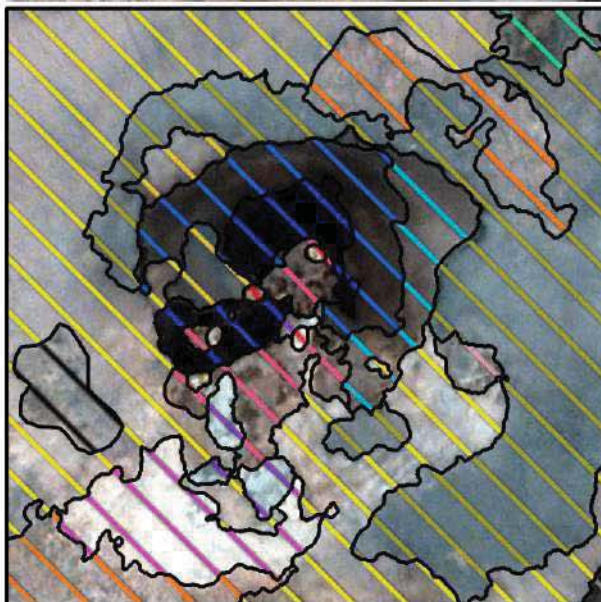
0 250 500 m

VIII/G/7 Dallol - 15.07.2019

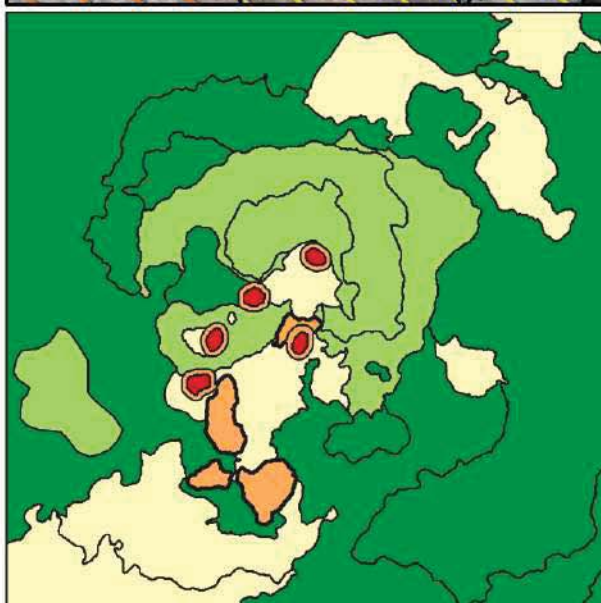
Satellite



Interpretation



Hazard



- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
- Ephemeral lake coverage 2
- Ephemeral lake coverage 3
- Inactive geothermal zone
- Mining ghost town
- Salt canyons
- Salt dome
- Salt pillars
- Salt plain
- Wadi

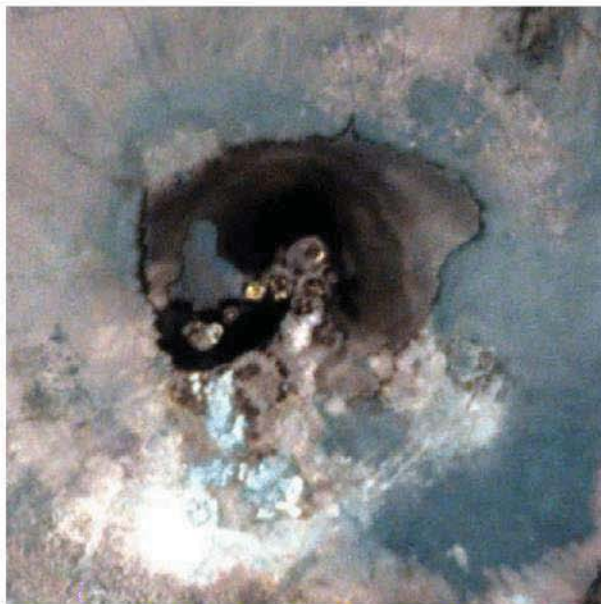
- Very low / Non existent
- Low
- Moderate
- High
- Very high

0 250 500 m

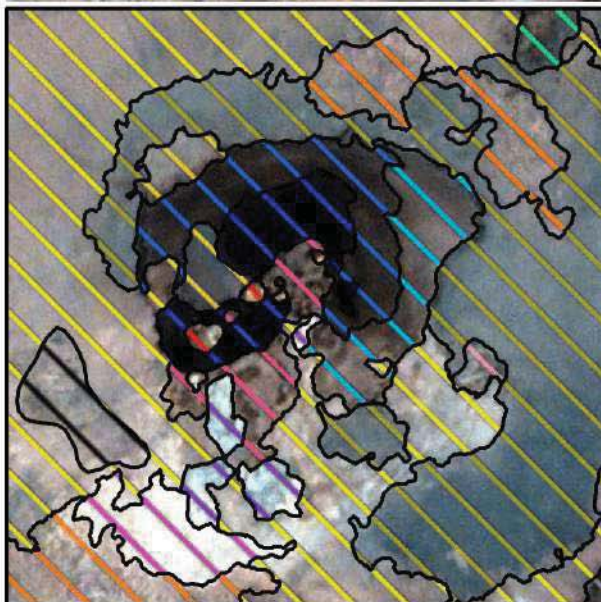


VIII/G/8 Dallol - 01.08.2019

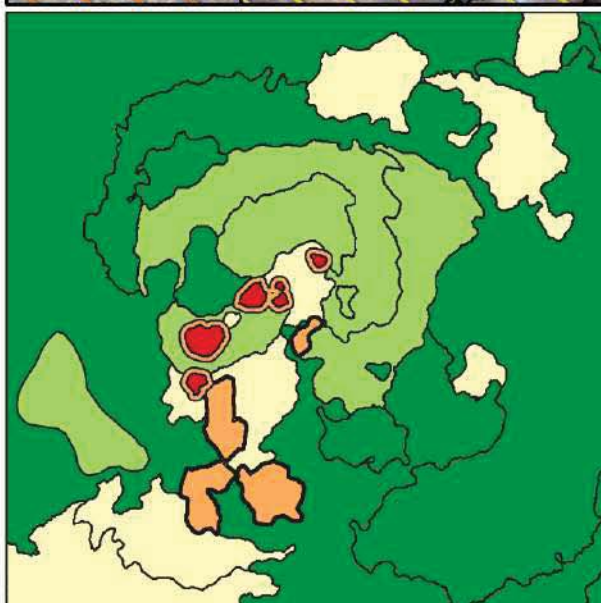
Satellite



Interpretation



Hazard



- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
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- Ephemeral lake coverage 3
- Inactive geothermal zone
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- Salt canyons
- Salt dome
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- Salt plain
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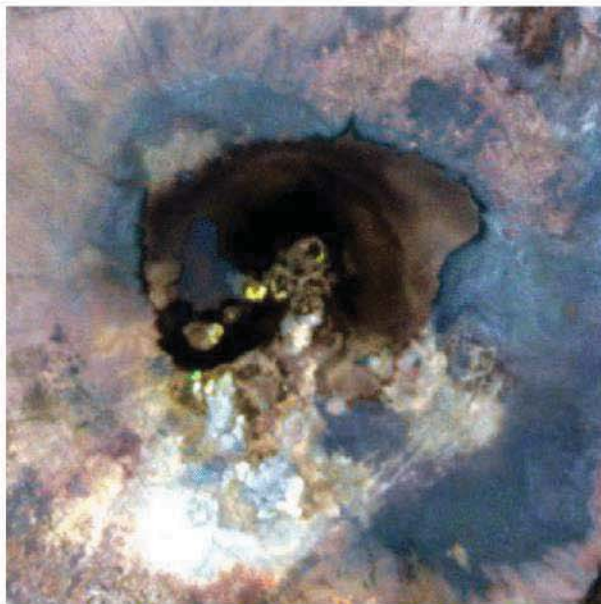
- Very low / Non existent
- Low
- Moderate
- High
- Very high

0 250 500 m

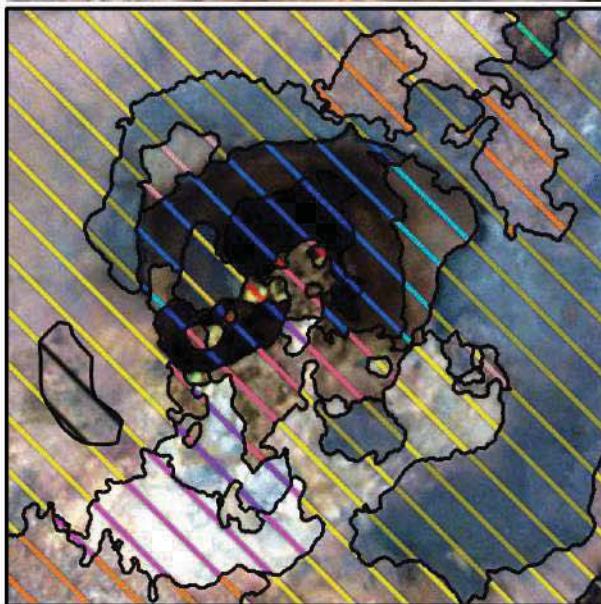


VIII/G/9 Dallol - 06.09.2019

Satellite



Interpretation



Hazard



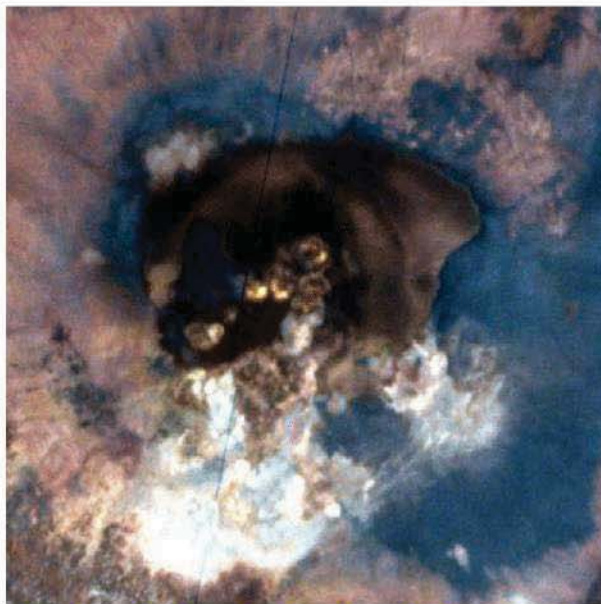
- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
- Ephemeral lake coverage 2
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- Salt canyons
- Salt dome
- Salt pillars
- Salt plain
- Wadi

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- Low
- Moderate
- High
- Very high

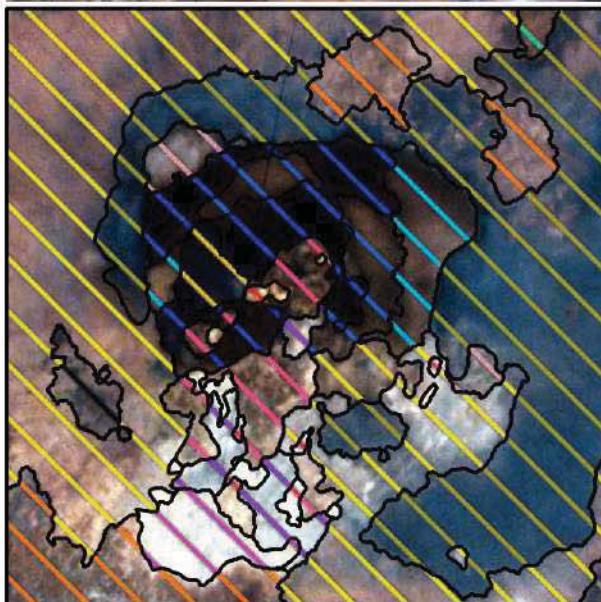
0 250 500 m

VIII/G/10 Dallol - 02.10.2019

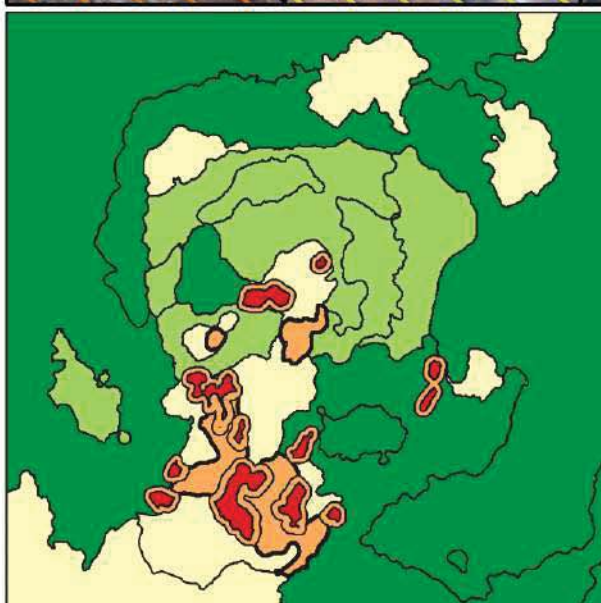
Satellite



Interpretation



Hazard



- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
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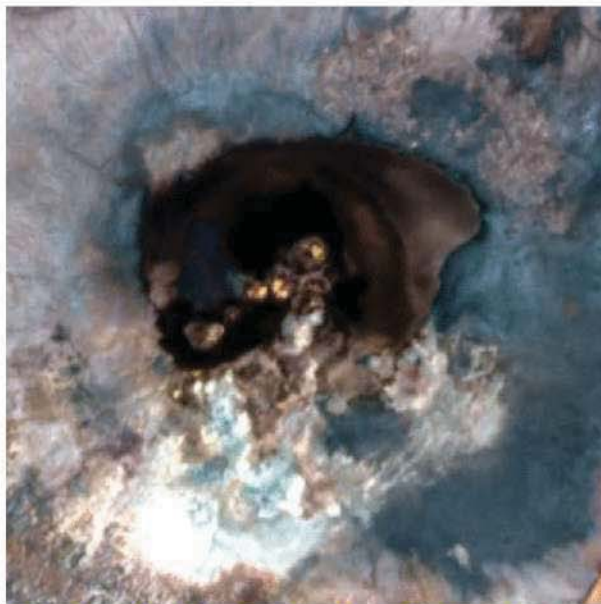
- Very low / Non existent
- Low
- Moderate
- High
- Very high

0 250 500 m

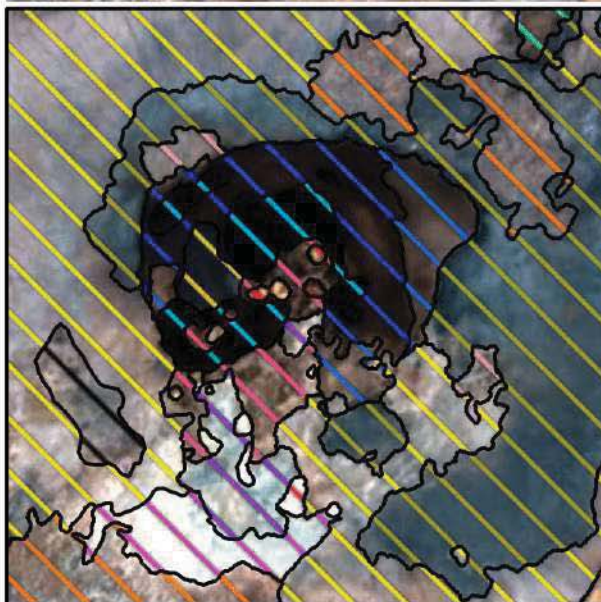


VIII/G/11 Dallol - 02.11.2019

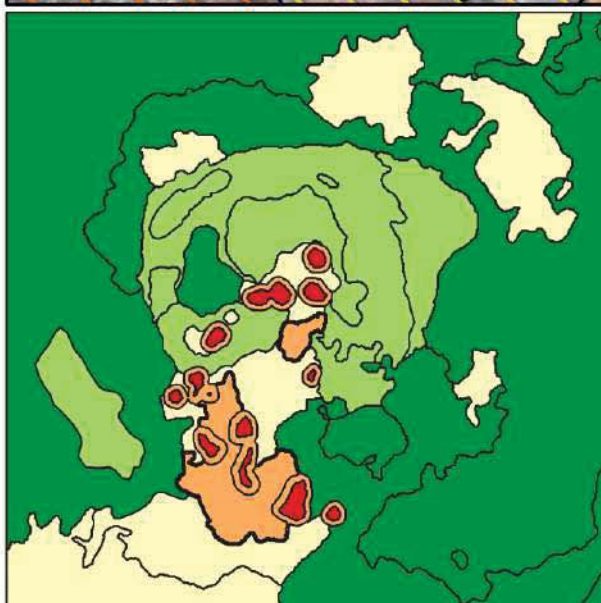
Satellite



Interpretation



Hazard



- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
- Ephemeral lake coverage 2
- Ephemeral lake coverage 3
- Inactive geothermal zone
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- Salt canyons
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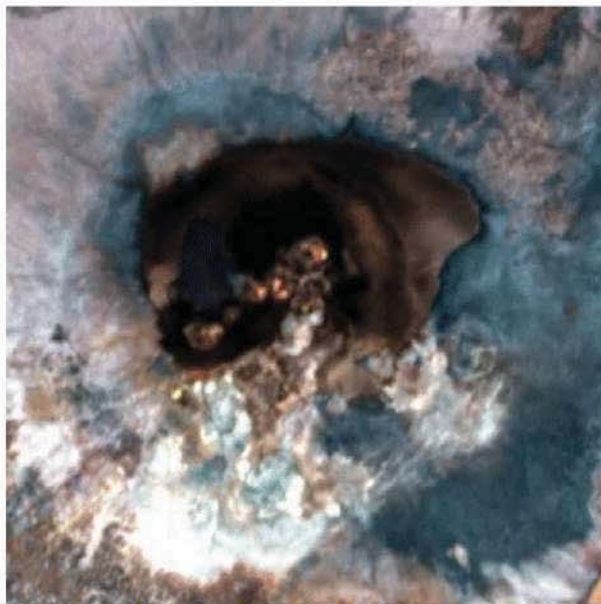
- Very low / Non existent
- Low
- Moderate
- High
- Very high

0 250 500 m

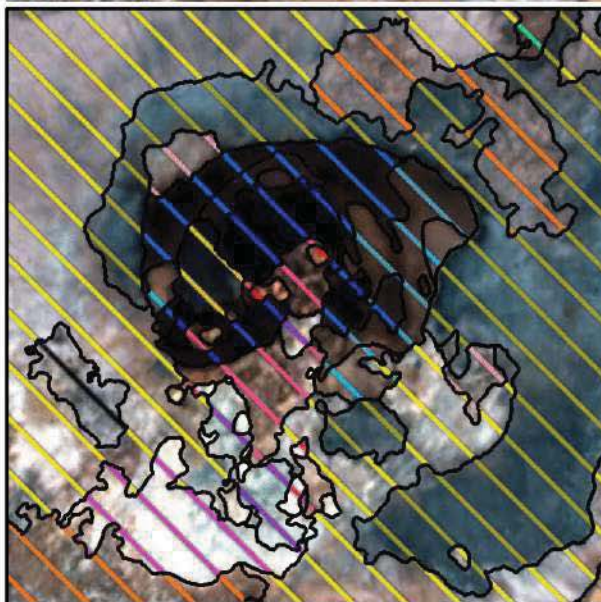


VIII/G/12 Dallol - 04.12.2019

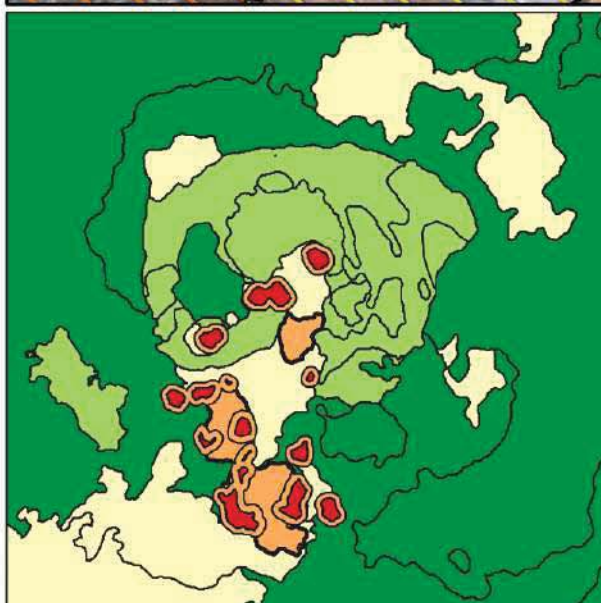
Satellite



Interpretation



Hazard



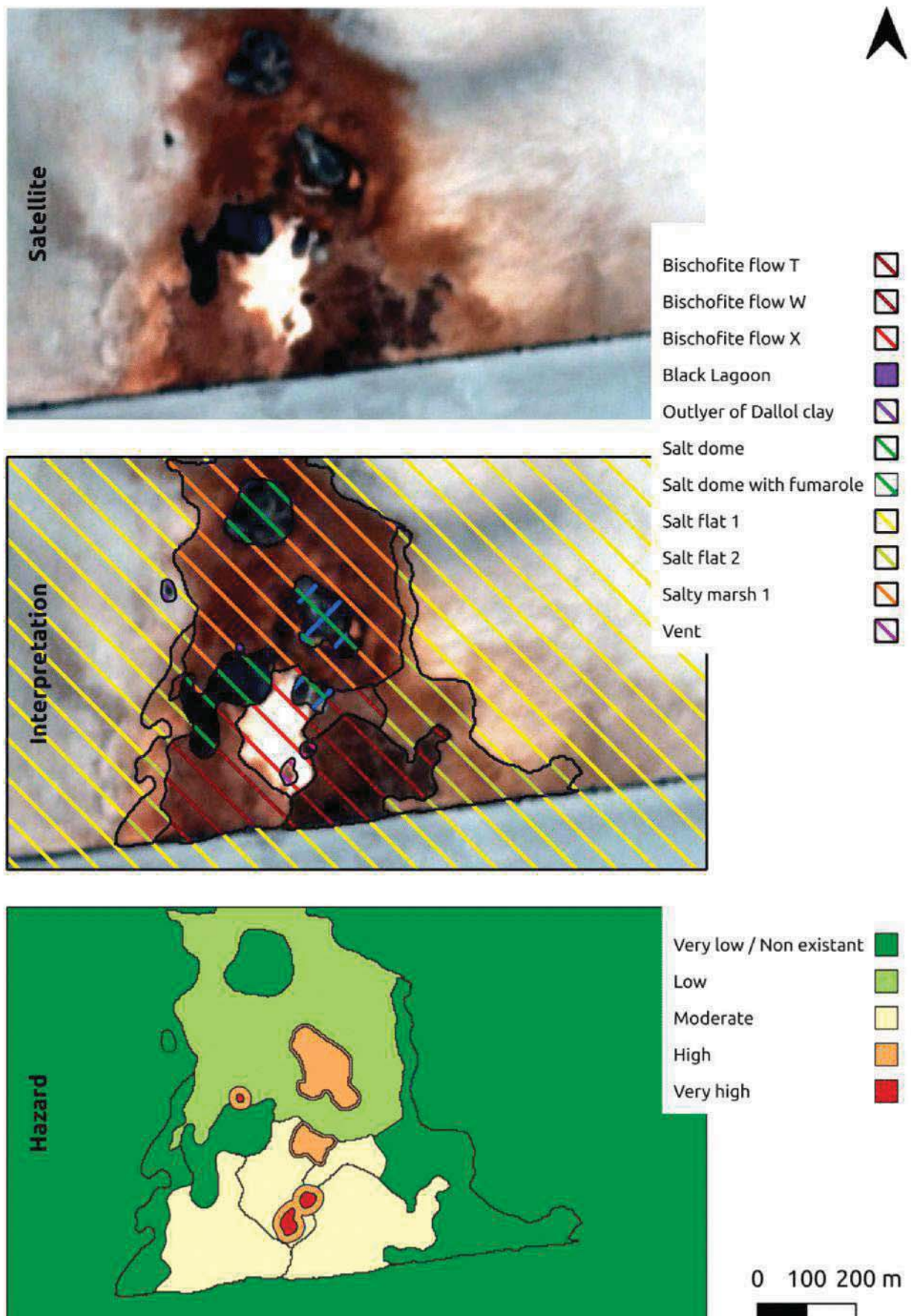
- Active geothermal zone
- Active/inactive transition zone
- Altered honeycomb surface
- Dallol salt dome base 1
- Dallol salt dome base 2
- Ephemeral lake coverage 1
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- Salt canyons
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- Very low / Non existent
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- Moderate
- High
- Very high

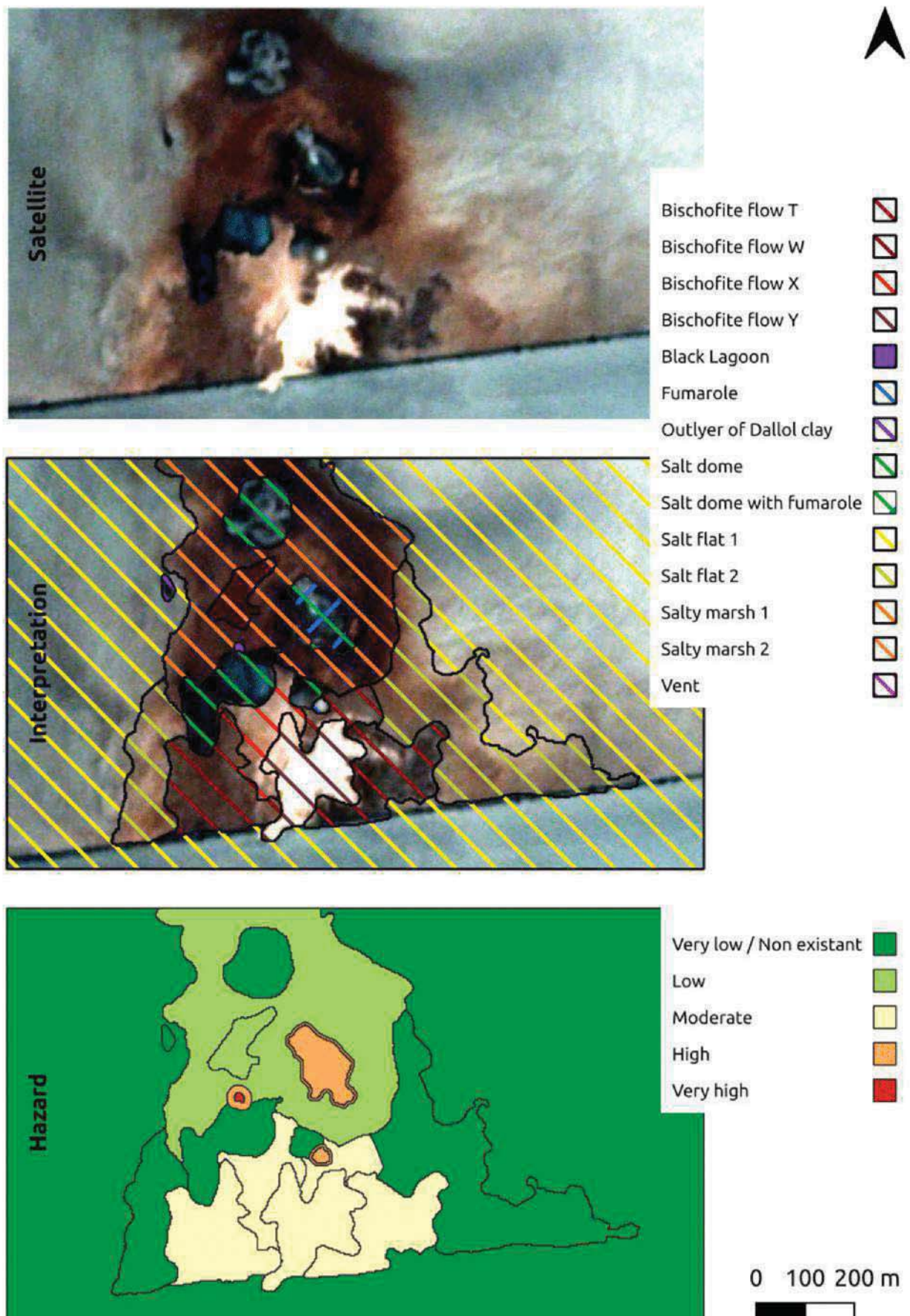
0 250 500 m



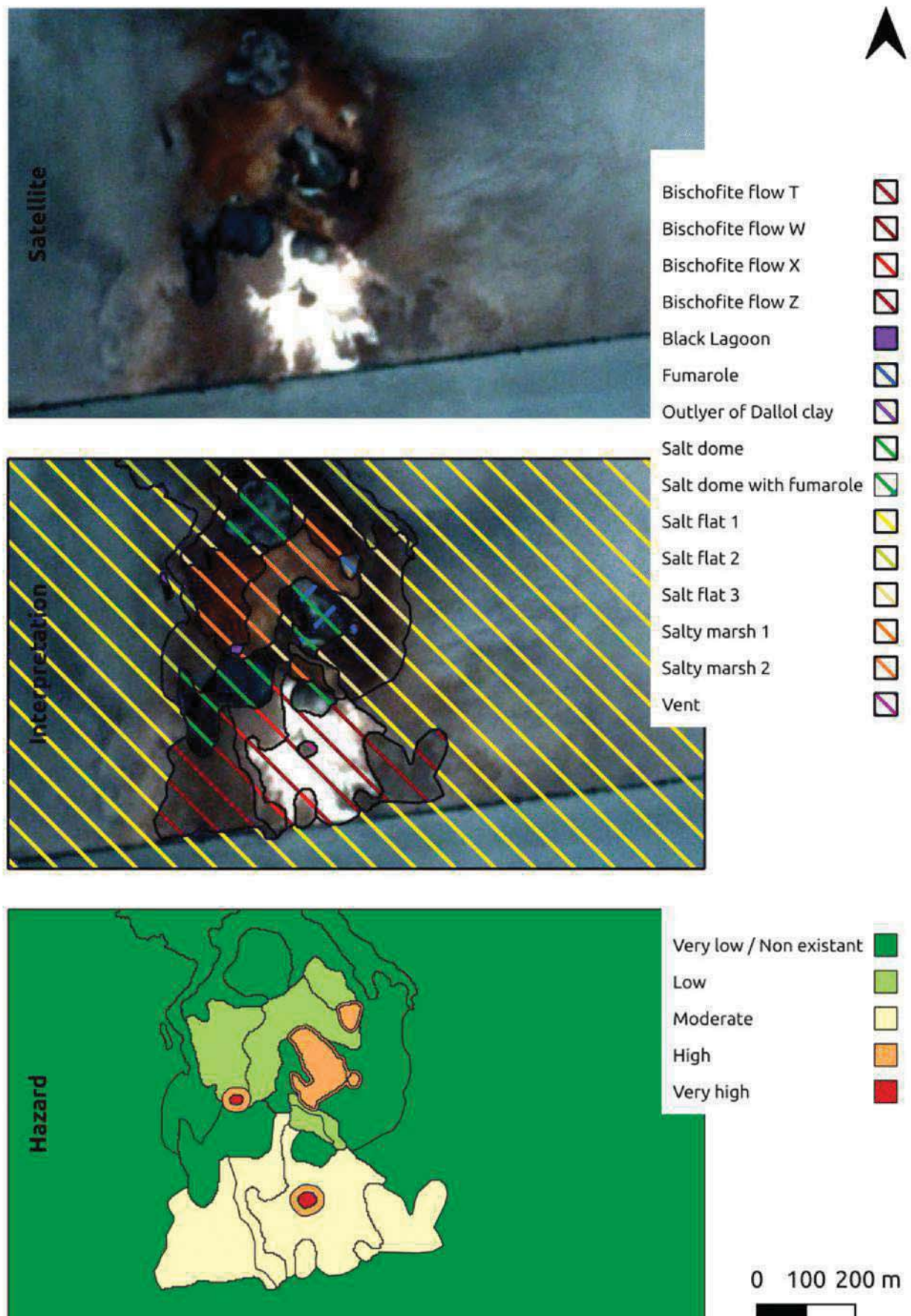
VIII/H/1 Black Mountain - 02.01.2019



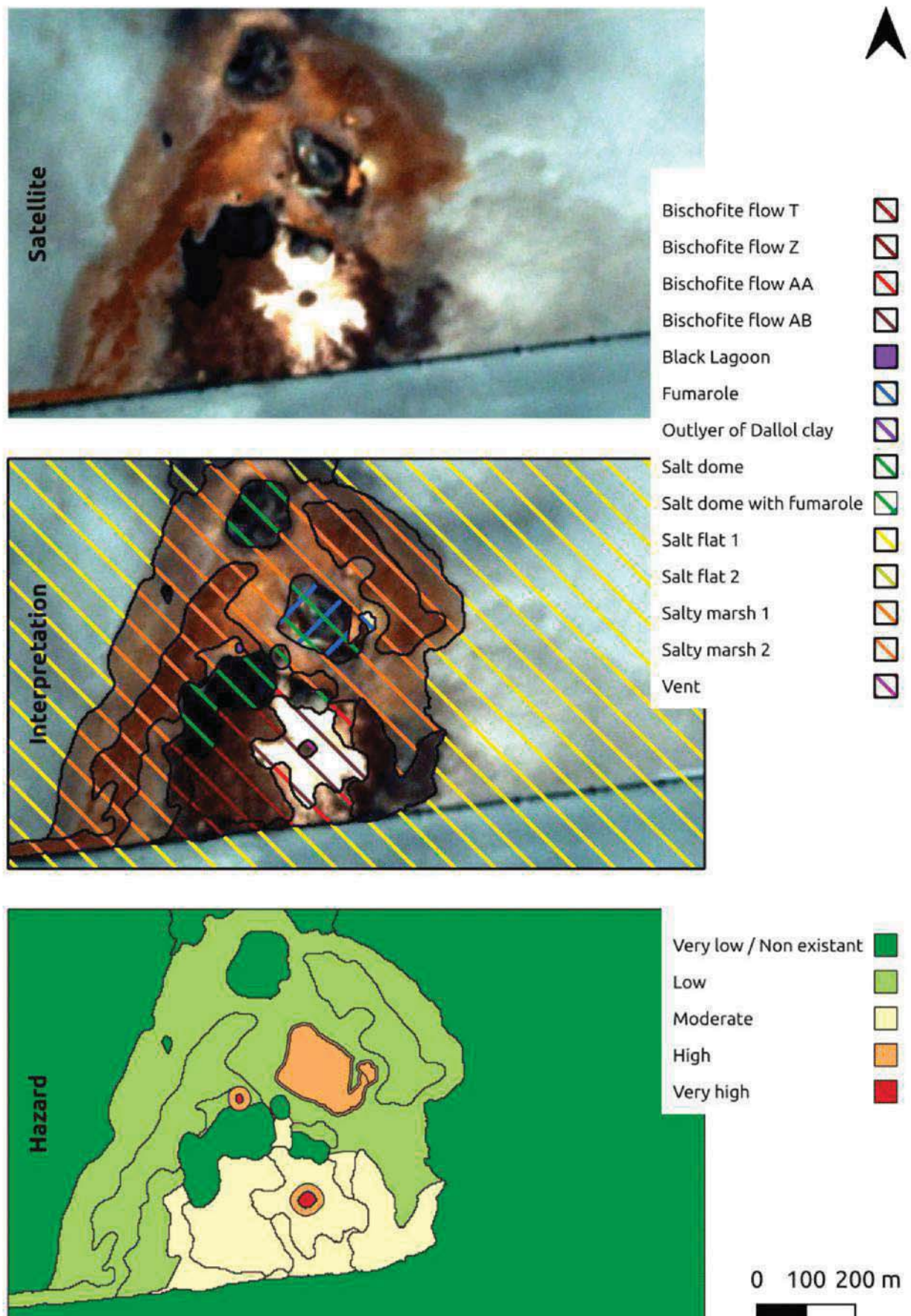
VIII/H/2 Black Mountain - 02.02.2019



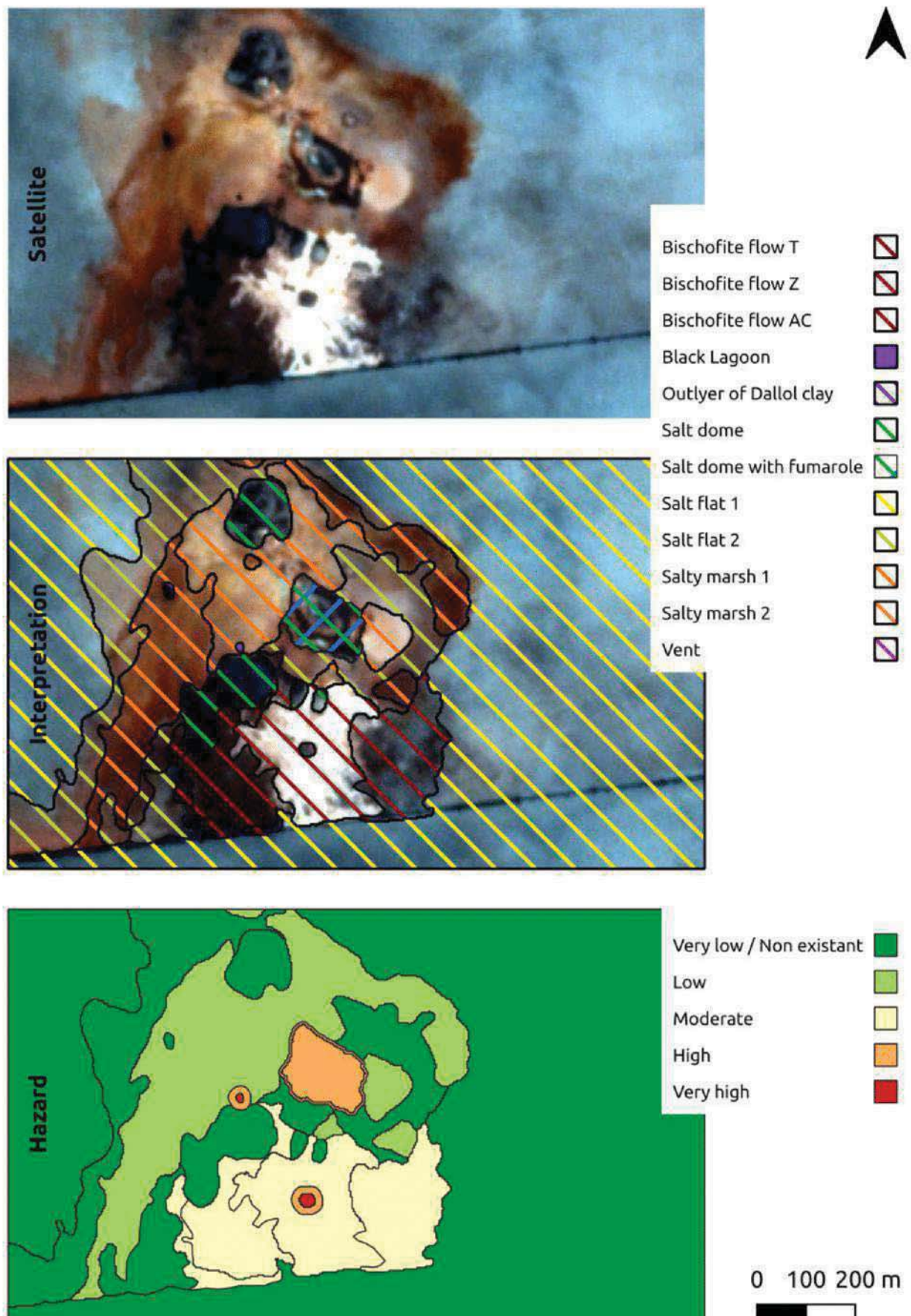
VIII/H/3 Black Mountain - 14.03.2019



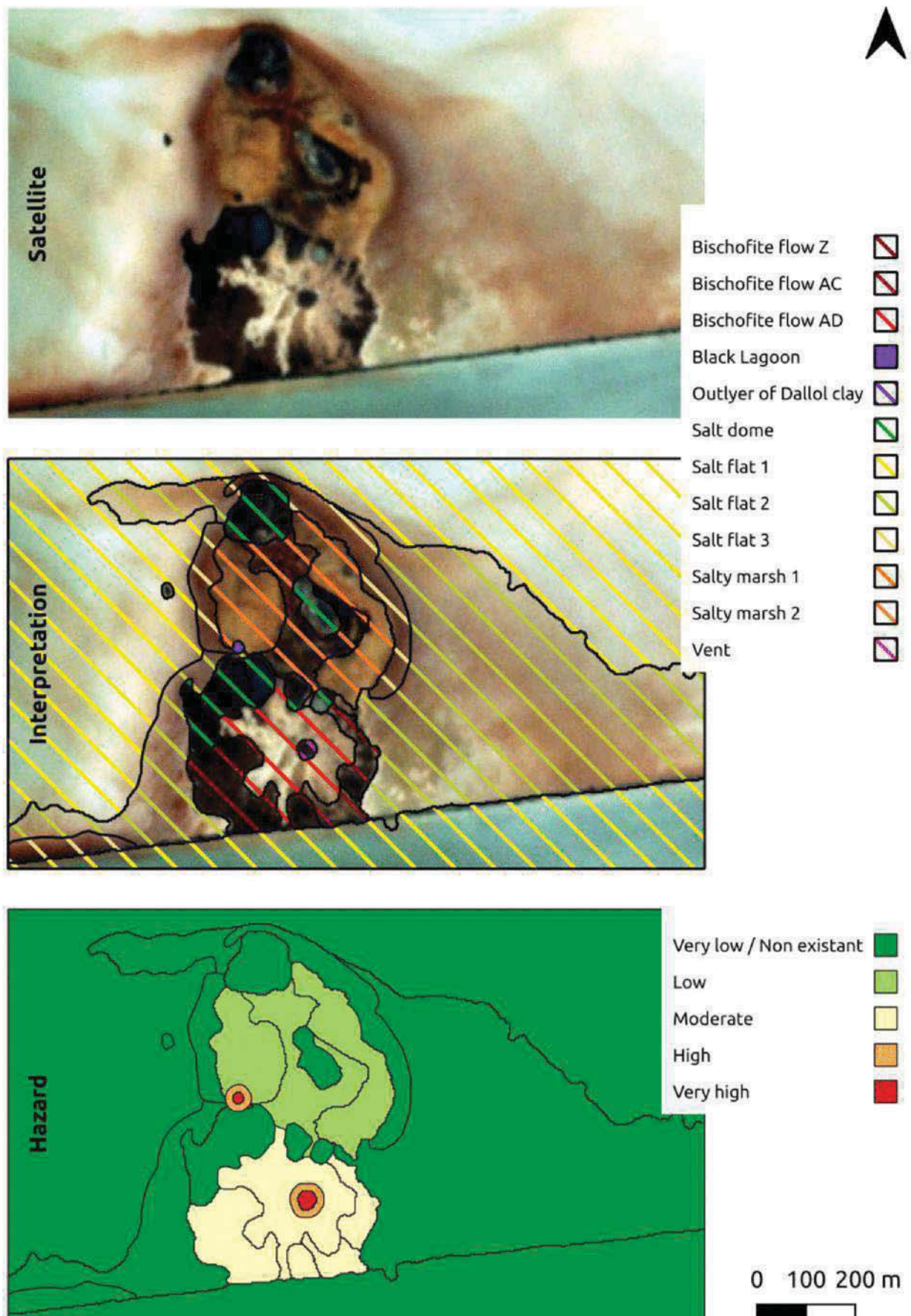
VIII/H/4 Black Mountain - 04.04.2019



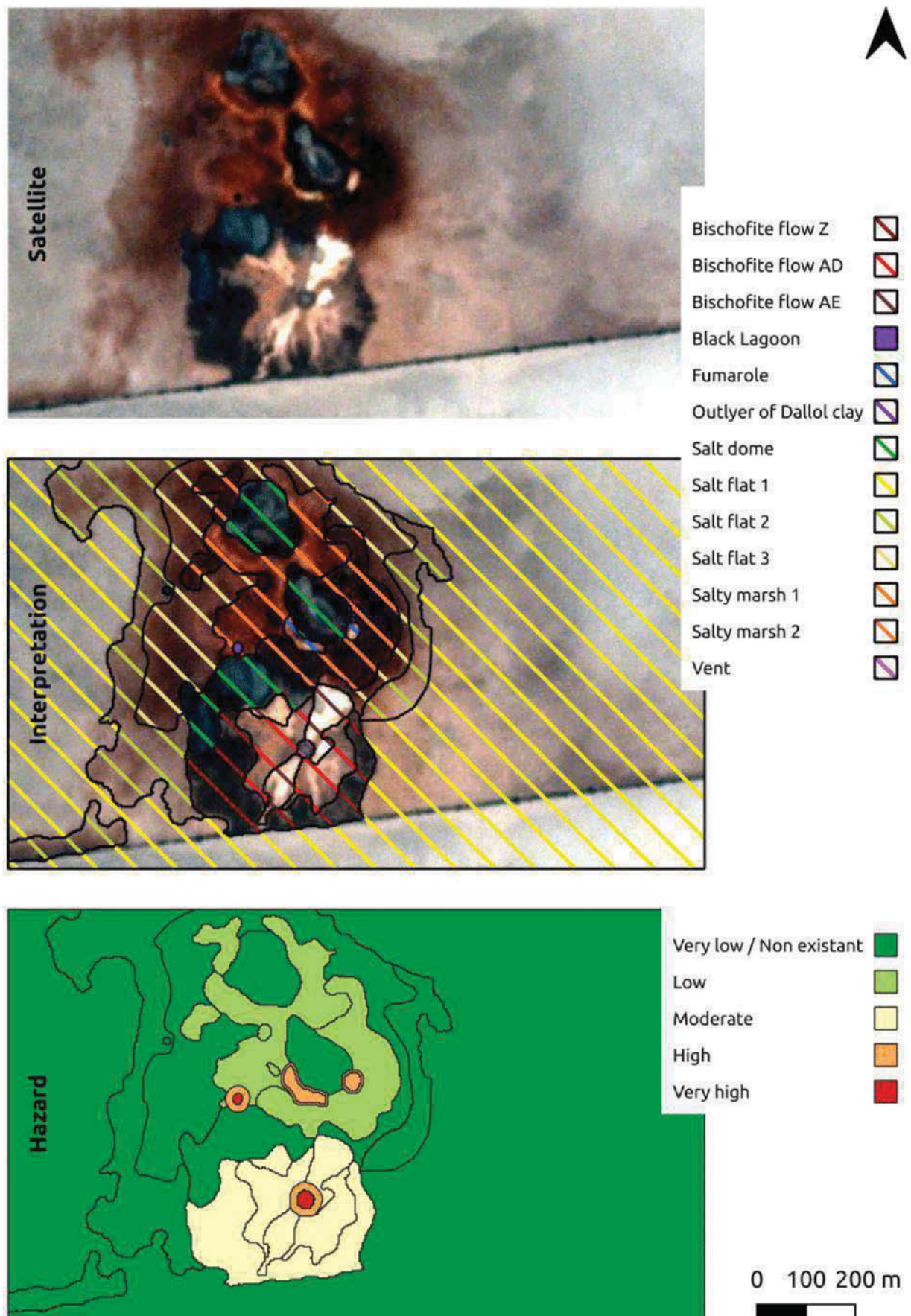
VIII/H/5 Black Mountain - 01.05.2019



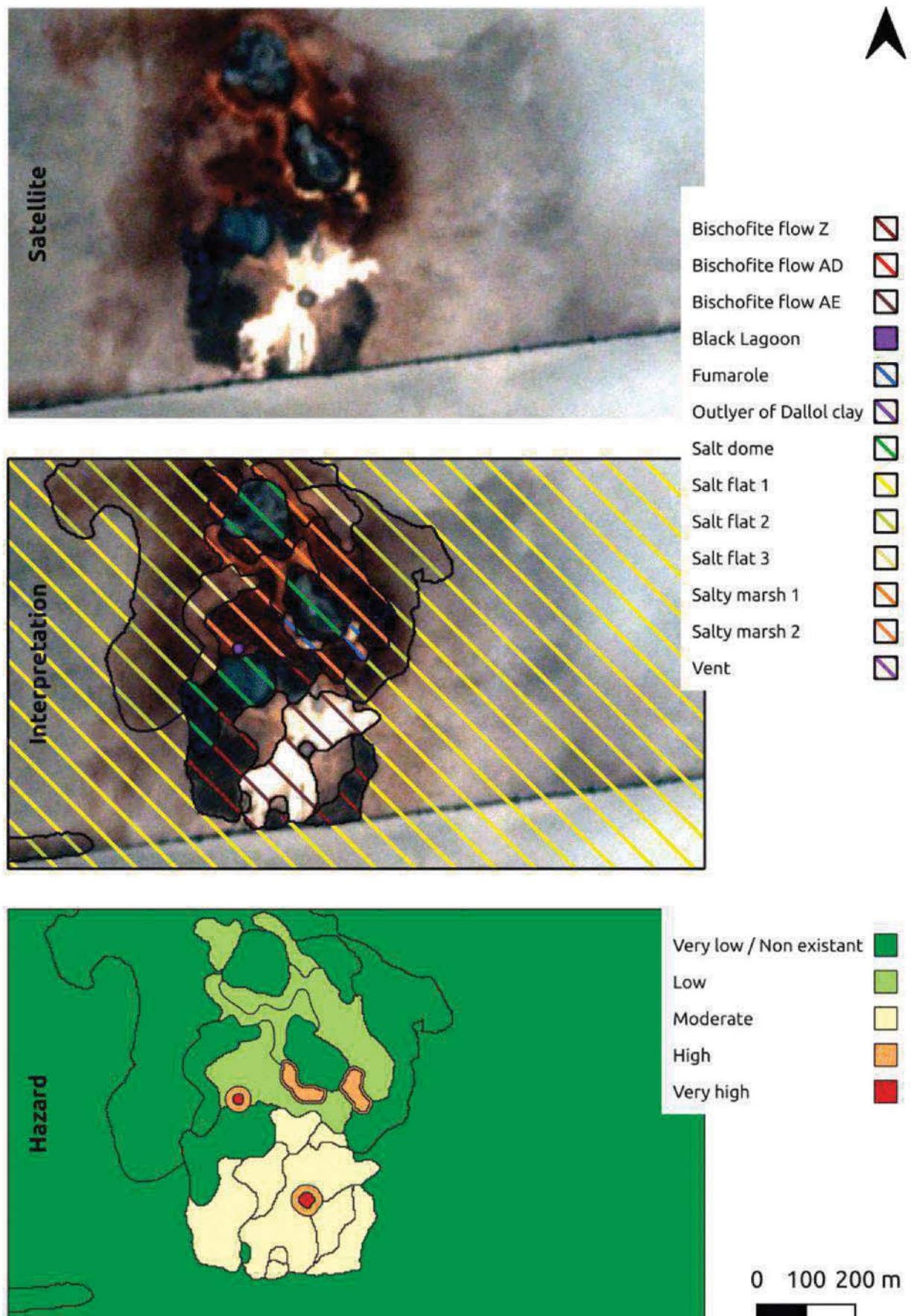
VIII/H/6 Black Mountain - 01.06.2019



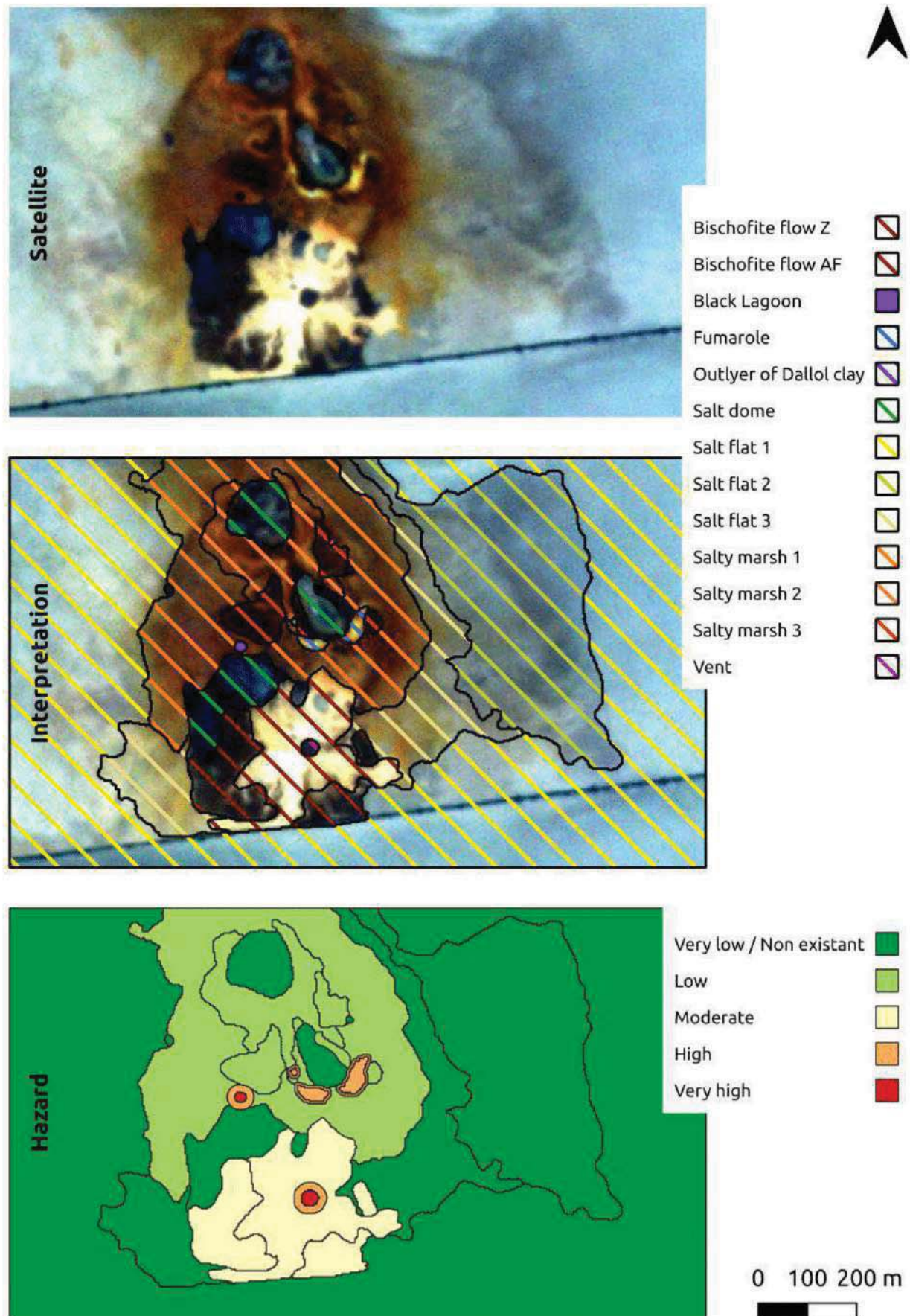
VIII/H/7 Black Mountain - 15.07.2019



VIII/H/8 Black Mountain - 01.08.2019



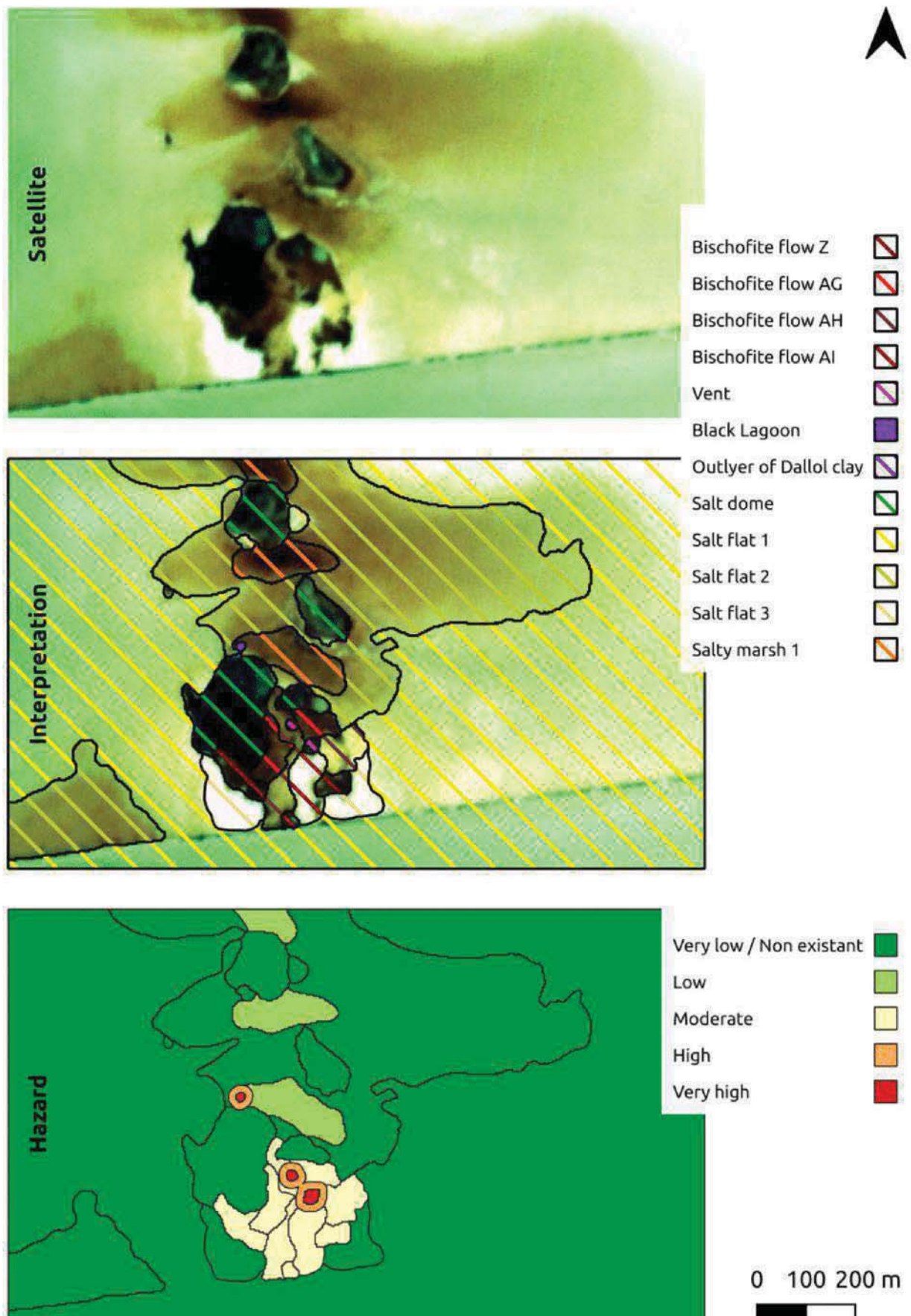
VIII/H/9 Black Mountain - 06.09.2019



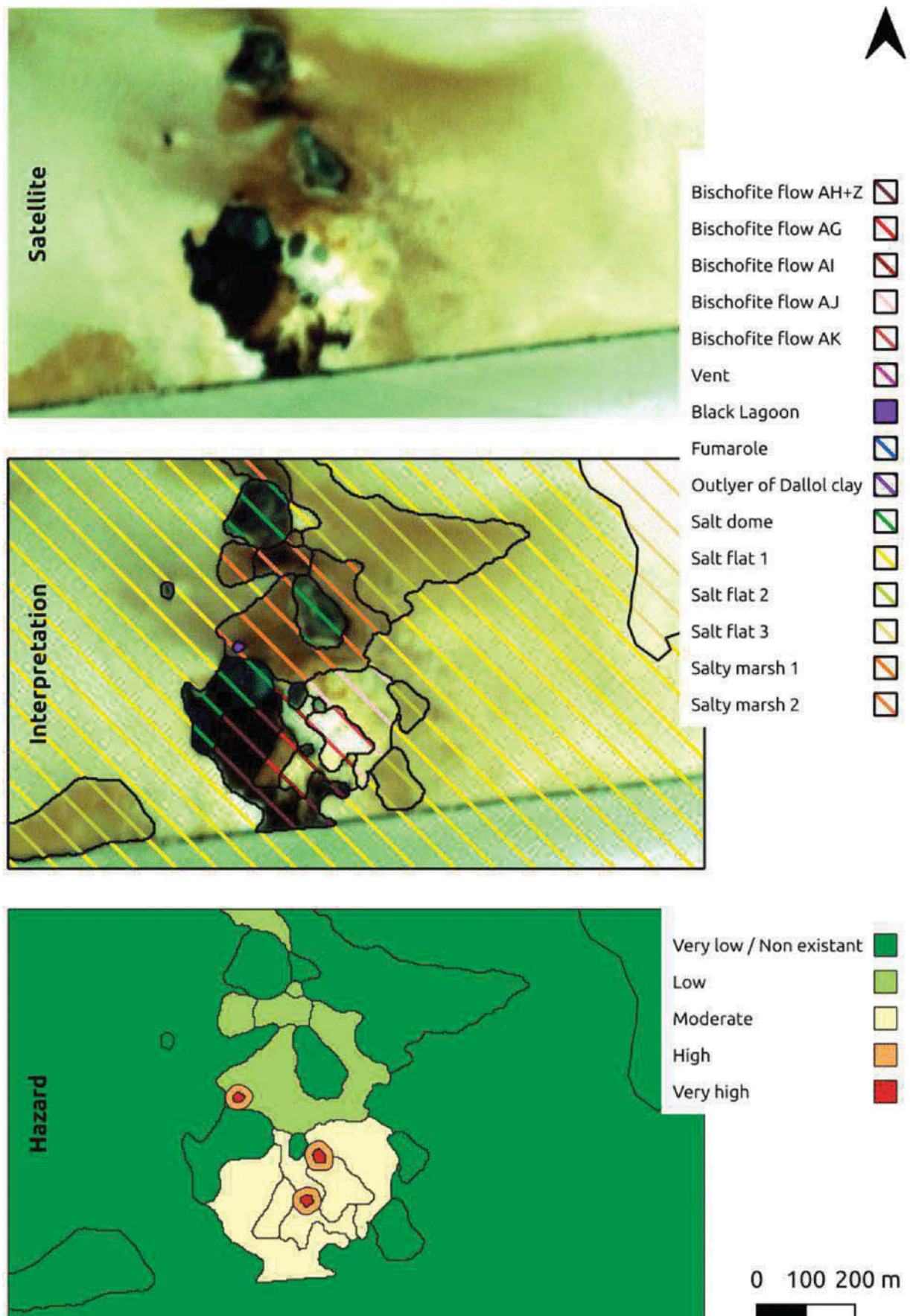
VIII/H/10 Black Mountain - 02.10.2019



VIII/H/11 Black Mountain - 02.11.2019



VIII/H/12 Black Mountain - 04.12.2019



Code	Geosite	VSE_RAR	VSE_REP	VSE_KGI	VSE_LI	VSA_VP	VSA_SF	VSA_SLN	VSA_EFS	VPR_CC	VPR_PL	VPR_VU	VPR_SNV	VFN_AC	VFN_ANV	VFN_AAV	VFN_VEC	VFN_VIRN	VFN_AFV	VTR_PRO	VTR_OV	VTR_VVC	VTR_IP	VTR_NV	VTR_TI	VTR_TGS	VTR_HS	VTR_RS	VSE	VSA	VPR	VFN	VTR	MV	AV
BM-01	Salt domes of Black M. area	0,50	1,00	1,00	0,50	0,75	1,00	0,75	1,00	1,00	0,00	0,75	0,75	0,25	1,00	0,25	0,50	0,75	0,00	0,00	0,25	0,00	0,00	0,25	0,00	0,00	0,00	3,00	3,50	2,50	2,75	0,75	9,00	3,50	
BM-02	Bischofite flows and their vents	1,00	1,00	1,00	0,50	0,50	1,00	0,50	1,00	1,00	0,00	0,50	0,50	0,25	1,00	0,25	0,50	0,75	0,00	0,00	0,25	0,00	0,25	0,00	0,00	0,00	3,50	3,00	2,00	2,75	0,75	8,50	3,50		
BM-03	Black Lagoon	0,25	0,75	1,00	0,25	0,25	0,50	0,75	0,50	1,00	0,00	0,50	0,50	0,50	1,00	0,25	0,50	0,75	0,00	0,00	0,25	0,00	0,25	0,00	0,00	0,00	2,25	2,00	2,00	3,00	0,75	6,25	3,75		
BM-04	Outlier of Dallol clay	0,25	0,75	0,00	0,50	0,50	0,00	0,75	0,50	1,00	0,00	0,25	0,25	0,50	1,00	0,25	0,50	0,75	0,00	0,00	0,50	0,00	0,25	0,00	0,25	0,00	1,50	1,75	1,50	3,00	1,00	4,75	4,00		
DA-01	The geothermal zone of D.	0,75	1,00	1,00	0,50	0,50	1,00	1,00	1,00	1,00	0,00	0,00	1,00	0,25	1,00	0,25	0,50	0,75	0,00	1,00	1,00	0,00	0,00	0,75	0,00	0,50	0,00	3,25	3,50	2,00	2,75	3,25	8,75	6,00	
DA-02	The central salt dome of Dallol	0,75	1,00	1,00	0,50	1,00	1,00	1,00	1,00	1,00	0,00	0,50	0,75	0,25	1,00	0,25	0,50	0,75	0,00	0,00	0,50	0,00	0,50	0,00	0,25	0,00	3,25	4,00	2,25	2,75	1,25	9,50	4,00		
DA-03	Salt canyon areas of D.	0,75	0,75	0,00	0,25	0,50	1,00	0,75	1,00	0,75	0,00	0,50	0,75	0,25	1,00	0,25	0,50	0,75	0,00	0,75	1,00	0,00	0,00	0,75	0,00	0,50	0,00	1,75	3,25	2,00	2,75	3,00	7,00	5,75	
DA-04	Altered honeycomb surface of D.	0,75	0,75	0,00	0,25	0,50	0,50	0,75	1,00	0,75	0,00	0,50	0,50	0,25	1,00	0,25	0,50	0,75	0,00	0,00	0,00	0,00	0,50	0,00	0,25	0,00	1,75	2,75	1,75	2,75	0,75	6,25	3,50		
DA-05	Salt pillars	0,25	0,25	0,00	0,75	0,00	0,00	0,50	1,00	0,25	0,00	0,25	0,50	0,25	1,00	0,25	0,50	0,75	0,00	0,00	0,50	0,00	0,50	0,00	0,25	0,00	1,25	1,50	1,00	2,75	1,25	3,75	4,00		
DA-06	Mining ghost town of Parsons Co.	0,25	0,75	0,00	1,00	0,50	0,00	0,25	0,25	1,00	0,00	0,25	0,50	0,25	1,00	0,25	0,50	0,75	0,00	0,75	0,75	0,00	0,75	0,00	0,50	0,00	2,00	1,00	1,75	2,75	2,75	4,75	5,50		
ND-01	Gaet'Alé - Yellow Lake brine pool	0,50	1,00	1,00	0,50	0,25	1,00	0,50	0,00	0,75	0,00	0,25	0,75	1,00	0,25	0,25	0,50	0,50	0,00	0,00	1,00	0,00	0,50	0,00	0,50	0,00	3,00	1,75	1,75	1,75	2,50	2,00	6,50	4,50	
ND-02	Asale - 'Skating rink'	0,25	0,75	1,00	0,50	0,25	0,00	0,50	1,00	0,75	0,00	0,00	0,50	1,00	0,25	0,25	0,50	0,50	0,00	0,00	1,00	0,00	0,75	0,00	0,50	0,00	2,50	1,75	1,25	1,25	2,50	2,25	5,50	4,75	
ND-03	Ancient seallevel outcrop at Hamed'Ela road	0,25	0,75	1,00	1,00	0,25	0,00	0,50	1,00	0,50	0,00	0,25	0,25	1,00	0,00	0,00	0,50	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,00	1,75	1,75	1,00	2,25	0,00	5,75	2,25		

Code	Geosite	SV_A_Repr		SV_B_KL		SV_C_SL		SV_D_Int		SV_E_GD		SV_F_Rar		SV_G_UL		PEU_A_Vuln		PEU_B_Acc		PEU_C_UL		PEU_D_Safe		PEU_E_Log		PEU_F_DP		PEU_G_AOV		PEU_H_Sce		PTU_I_Uni		PTU_J_OC		PTU_K_IP		PTU_L_EL		PTU_M_PRA		DR_A_DGE		DR_B_PARC		DR_C_LP		DR_D_A		DR_E_DP		SV		PEU		PTU		DR																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
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Code	Geosite	SV_Int	SV_Rep	SV_Rar	SV_PAL	ECI	ECOL_PS	AEST_VP	AEST_STR	CULT_REL	CULT_HIS	CULT_ART	CULT_GEO	ECO	SV_sum	ECOL_sum	AEST_sum	CULT_sum	AV_sum
BM-01	Salt domes of Black Mountain area	0,75	1,00	0,50	0,50	0,25	0,00	0,50	1,00	0,00	0,25	0,25	0,25	0,50	0,69	0,13	0,75	0,31	0,40
BM-02	Bischofite flows and their vents	0,50	1,00	1,00	0,25	0,25	0,00	0,25	0,50	0,00	1,00	0,25	1,00	0,50	0,69	0,13	0,38	0,69	0,40
BM-03	Black Lagoon	1,00	1,00	1,00	0,25	1,00	0,00	0,50	0,50	0,00	0,00	0,00	0,25	0,25	0,81	0,50	0,50	0,13	0,38
BM-04	Outlier of Dallol clay	0,75	0,75	0,50	0,75	0,50	0,00	0,25	0,50	0,00	0,00	0,00	0,25	0,25	0,69	0,25	0,38	0,13	0,25
DA-01	The geothermal zone of Dallol	0,75	1,00	1,00	0,50	1,00	0,00	1,00	1,00	0,00	0,50	0,50	0,50	0,75	0,81	0,50	1,00	0,56	0,69
DA-02	The central salt dome of Dallol	1,00	1,00	0,75	0,50	0,50	0,00	0,50	0,75	0,00	0,00	0,00	0,00	0,25	0,81	0,25	0,63	0,06	0,31
DA-03	Salt canyon areas of Dallol	0,75	1,00	1,00	0,75	0,50	0,00	1,00	1,00	0,00	0,25	0,75	0,25	0,50	0,88	0,25	1,00	0,44	0,56
DA-04	Altered honeycomb surface of Dallol	0,75	1,00	1,00	0,75	0,25	0,00	0,50	0,75	0,00	0,00	0,50	0,25	0,50	0,88	0,13	0,63	0,31	0,35
DA-05	Salt pillars	0,50	0,75	0,75	0,75	0,25	0,00	0,25	0,75	0,00	0,00	0,25	0,25	0,25	0,69	0,13	0,50	0,19	0,27
DA-06	Mining ghost town of Parsons Co.	0,25	0,50	1,00	0,00	0,50	0,00	0,50	0,50	0,00	1,00	0,50	0,50	0,50	0,44	0,25	0,50	0,63	0,46
ND-01	Gaet'Ale - Yellow Lake brine pool	1,00	1,00	0,75	0,25	0,75	0,00	0,25	0,75	0,25	0,25	0,25	0,25	0,50	0,75	0,38	0,50	0,38	0,42
ND-02	Asale - 'Skating rink'	0,75	1,00	1,00	0,75	0,25	0,00	0,50	1,00	0,50	0,50	0,75	0,50	0,50	0,88	0,13	0,75	0,69	0,52
ND-03	Ancient sealevel outcrop at Hamed'Ela road	0,50	0,75	0,50	0,75	0,25	0,00	0,25	0,50	0,00	0,00	0,00	0,25	0,25	0,63	0,13	0,38	0,13	0,21

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ζ. SCIENTIFIC ACTIVITY DURING THE PhD

ζ/A Papers

KARÁTSÓN D., GERTISSER R., TELBISZ T., **VEREB V.**, QUIDELLEUR X., DRUITT T., NOMIKOU P., KÓSIK SZ. (2018): Towards reconstruction of the lost Late Bronze Age intra-caldera island of Santorini, Greece. *Scientific Reports* 8(1): 1-8. paper: 7026. doi: 10.1038/s41598-018-25301-2

VEREB V., VAN WYK DE VRIES B., GUILBAUD M.N., KARÁTSÓN D. (2020): The urban geoheritage of Clermont-Ferrand: from inventory to management. *Quaestiones Geographicae* 39(3): 5-31. doi: 10.2478/quageo-2020-0020

KARÁTSÓN D., TELBISZ T., GERTISSER R., STRASSER T., NOMIKOU P., DRUITT T., **VEREB V.**, QUIDELLEUR X., KÓSIK SZ. (2020) Constraining the landscape of Late Bronze Age Santorini prior to the Minoan eruption: Insights from volcanological, geomorphological and archaeological findings. *Journal of Volcanology and Geothermal Research*. doi: 10.1016/j.jvolgeores.2020.106911

VEREB V., VAN WYK DE VRIES B., HAGOS M., KARÁTSÓN D. (2020): Geoheritage and Resilience of Dallol and the Northern Danakil Depression in Ethiopia. *Geoheritage* 12, 82. doi: 10.1007/s12371-020-00499-8e

ζ/B Conference presentations and abstracts

VEREB V., STEINMANN V., KERESZTURI Á. (2017) Swath Profile Analysis to understand Martian Fluvial Valleys' Morphology. 48th Lunar and Planetary Science Conference Houston (TX), United States of America, *Lunar and Planetary Institute Paper*, p. 1430

KARÁTSÓN D., GERTISSER R., TELBISZ T., **VEREB V.**, QUIDELLEUR X., NOMIKOU P., DRUITT T., KÓSIK SZ. (2017) Reconstructing 'Atlantis', the Late Bronze Age island of Santorini. In: La Monica M., Corsale L. (eds.) Explosive eruptions and the Mediterranean Civilizations through prehistory and history. Istituto Nazionale di Geofisica e Vulcanologi, p.50.

VEREB V., KARÁTSÓN D., VAN WYK DE VRIES B. (2018) Geoheritage is coming to town: preservation of geological features in an urban environment with the example of geomorphological mapping on Clermont-Ferrand. *Geophysical Research Abstracts* 20: EGU2018-11647

VEREB V., VAN WYK DE VRIES B., BARNIE T., HAGOS M. (2018) Exploiting a volcanic resource: mapping rapid changes at Dallol Volcano, Ethiopia with Planet satellite images and community engagement for risk reduction. *Geophysical Research Abstracts* 20: EGU2018-4447-2

VAN WYK DE VRIES B., **VEREB V.**, LEVEN C., KARÁTSÓN D., LAGMAY M., NAVARRO M., NÉMETH K. (2018) Rich and resilient volcanic territories maintained by geoheritage. *Geophysical Research Abstracts* 20: EGU2018-4472

VAN WYK DE VRIES B., **VEREB V.**, KARÁTSÓN D. (2018) The basis for a global thematic framework for geodiversity and geoheritage. *Geophysical Research Abstracts* 20: EGU2018-2944

KARÁTSÓN D., GERTISSER R., TELBISZ T., **VEREB V.**, QUIDELLEUR X., DRUITT T., NOMIKOU P., KÓSIK SZ. (2018) Reconstructing the Late Bronze Age intra-caldera island of Santorini, Greece. In: Mattoni S. (ed.) Abstracts Volume of the International meeting ‘Cities on Volcanoes 10’: Millenia of Stratification between Human Life and Volcanoes: strategies for coexistence. Istituto Nazionale di Geofisica e Vulcanologia, p.661.

VEREB V., MEIRINHO P., LIMA E., NUNES J.C. (2018) Digitally based monitoring process of geosites in Azores UNESCO Global Geopark: An open-source solution with ODK Collect, XLSForm and Enketo framework. Abstracts Book, 8th International Conference on UNESCO Global Geoparks, p. 245.

VEREB V., VAN WYK DE VRIES B., HAGOTS M. (2019) Remote sensing monitoring and geosite assessment of Dallol, Ethiopia. Putting an isolated and deserted area on map with geoheritage and resilience. *Geophysical Research Abstracts 21*: EGU2019-5640

VAN WYK DE VRIES B., **VEREB V.**, KARÁTSÓN D. (2019) Geosite inventories in World Heritage sites: essential for protection and management. *Geophysical Research Abstracts 21*: EGU2019-3604

DELAGE E., RÉGIS É., **VEREB V.**, VAN WYK, DE VRIES B. (2019) 3DTelC: Réalité Virtuelle pour les risques naturels (2019)

VEREB V., VAN WYK DE VRIES B. (2019) Urban geosite assessment: the example of Clermont-Ferrand. Abstracts Book, 15th European Geoparks Conference, p. 108.

VEREB V., VAN WYK DE VRIES B., GUILBAUD M.N. (2020) Urban geosites : special context, unique interpretation, increased vulnerability. Oxford Geoheritage Virtual Conference Abstract Volume, p.87-88.

GUILBAUD M.N., VAN WYK DE VRIES B., NÉMETH K., **VEREB V.**, HAGOS M., MANRIQUE N., FERMET-QUINET N., IRAPTA P.N.S., VALLEJO VARGAS S., CORTÉS G.P., NAVARRO M., LEVEN C.L. (2020) UNESCO IGCP project 692. Geoheritage for geohazard resilience: A global geoheritage initiative to share knowledge, raise awareness and communicate about natural hazards. Oxford Geoheritage Virtual Conference Abstract Volume, p.67-68.

LEVEN C.L., NAVARRO M., VAN WYK DE VRIES B., **VEREB V.** (2020) La Isla de Ometepe: a potential global geopark. Oxford Geoheritage Virtual Conference Abstract Volume, p.18

IRAPTA P.N.S., **VEREB V.**, VAN WYK DE VRIES B. (2020) A tale of Taal churches: The Taal church ruins and the new Taal basilica as geoeeducation sites to highlight geohazard risk in an area of active volcanism and tectonics. Oxford Geoheritage Virtual Conference Abstract Volume, p.76-77.

ζ/C Educational activity (in ELTE, Hungary)

- 2016/2017 autumn semester
 - lh1c2370 Külső erők földrajza gyakorlat (*Geography of external forces practice*)
- 2016/2017 spring semester
 - lh1c2783 Természetföldrajzi szintézis gyakorlat (*Synthesis of physical geography practice*)
 - lh1c6391 Természetföldrajz - évközi terepgyakorlat (*Physical geography – mid-semester fieldtrip*)
- 2017/2018 spring semester
 - tg1c3K39GG Geoinformatika 2. (*GIS 2 for Earth Sciences BSc Geography specialization*)
 - lh1c437 Számítógépes prezentációs technikák (*Presentation techniques with computers*)
 - ntermftgyl17ta Természet- és környezetföldrajz – nyári terepgyakorlat (*Physical and environmental geography – summer field trip*)
- 2018/2019 autumn semester
 - BMVD-200.924/EC Földtudományi örökségvédelem és geoturizmus (*Geoheritage and geotourism*)

ζ/D Outreach, other activities

- 29/04/2017 Felfedezők napja (*Explorers' Day*), Budapest – participation at the Dept. of Physical Geography stand
- 05/09 – 09/09/2017 14th European Geoparks Conference, Ponta Delgada, Portugal - volunteer
- 20/05/2019 Pint of Science, Clermont-Ferrand – presenter (*'Sous vos pieds'*)
- 06/09/2019 'A könyvtáraknak is megvan a maguk sorsa...' (*'Libraries have their destiny'*) Eötvös József, College, Budapest – main organizer and presenter at the workshop on historical geographical libraries
- VEREB V. (2019) Azori-szigetek: Vulkáni paradicsom az Atlanti-óceán szívében. *A Földgömb*, 37 (336): 46-59 (article in the popular outreach journal of the Hungarian Geographical Society)
- Website administrator or research-related domains:
 - tef.elte.hu (ELTE Department of Physical Geography, Budapest) – 2016-2018
 - mendolmuhely.elte.hu (Mendöl Tibor Workshop on Geography, Earth and Environmental Sciences, Eötvös József College, Budapest) – 2016-2018
 - 3dtelc.lmv.uca.fr (3DTELC Erasmus+ project) – 2018-2020

ADATLAP

a doktori értekezés nyilvánosságra hozatalához*

I. A doktori értekezés adatai

A szerző neve: *Vereb Viktor*.....

MTMT-azonosító: *10060018*

A doktori értekezés címe és alcíme: *Geoheritage and Resilience. Selected studies of volcanic geoheritage areas from different geographical environments and different levels of protection*

DOI-azonosító: *10.15476/ELTE.2020.154*

A doktori iskola neve: *Földtudományi Doktori Iskola*.....

A doktori iskolán belüli doktori program neve: *Földrajz-Meteorológia Program*

A témavezető neve és tudományos fokozata: *Dr. Karátson Dávid; Dr. Benjamin van Wyk de Vries*

A témavezető munkahelye: *ELTE-TTK-FFI Természetföldrajzi Tanszék; Université Clermont Auvergne, Observatoire du Physique du Globe de Clermont, Laboratoire Magmas et Volcans*.....

II. Nyilatkozatok

1. A doktori értekezés szerzőjeként

a) hozzájárulok, hogy a doktori fokozat megszerzését követően a doktori értekezésem és a tézisek nyilvánosságra kerüljenek az ELTE Digitális Intézményi Tudástárban. Felhatalmazom a Természettudományi kar Dékáni Hivatal Doktori, Habilitációs és Nemzetközi Ügyek Csoportjának ügyintézőjét, hogy az értekezést és a téziseket feltöltse az ELTE Digitális Intézményi Tudástárba, és ennek során kitöltse a feltöltéshez szükséges nyilatkozatokat.

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2. A doktori értekezés szerzőjeként kijelentem, hogy

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b) a doktori értekezés és a tézisek nyomtatott változatai és az elektronikus adathordozón benyújtott tartalmak (szöveg és ábrák) mindenben megegyeznek.

3. A doktori értekezés szerzőjeként hozzájárulok a doktori értekezés és a tézisek szövegének plágiumkereső adatbázisba helyezéséhez és plágiumellenőrző vizsgálatok lefuttatásához.

Kelt: Pásztó, 2020.09.25.....



.....
a doktori értekezés szerzőjének aláírása