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Abstract: In sprawling urban areas, geoheritage is suppressed into limited niches. Potential geosites are highly vulnerable and could disappear completely during construction, or their integrity could be irreversibly modified. Here, we create an inventory of urban geoheritage for Clermont-Ferrand in France, recording more than 50 sites using the French national workflow. The results of the quantitative assessment have been used to differentiate between geosites (high scientific value) and geodiversity sites (limited scientific significance, important additional values). Finally, we discuss some important considerations on urban geoconservation, such as geotouristic itineraries or customized management strategies for each site and the whole city.

Key words: geosite inventory, urban geoheritage, geoconservation, geodiversity action plan, Clermont-Ferrand, France

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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. 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. 2). The city is located next to a UNESCO World Heritage site, the *Chaîne des Puys – Limagne Fault* Tectonic Arena, and shares

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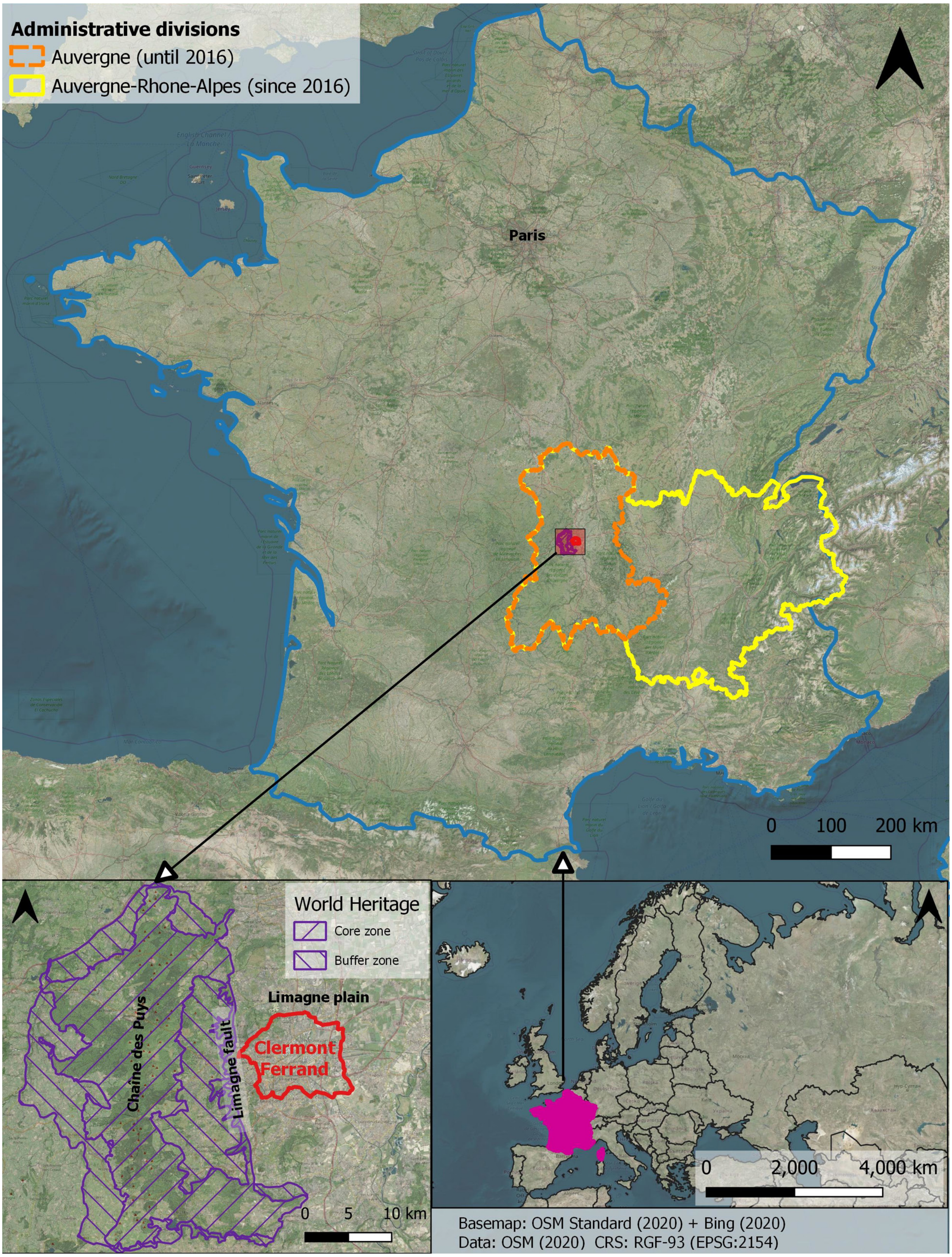

Fig. 1. The location of Clermont-Ferrand in France and in Auvergne.

the same basic geological framework. The *scale* is that of the administrative unit of Clermont-Ferrand, a clearly-defined 43 km^2 area (Fig. 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 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

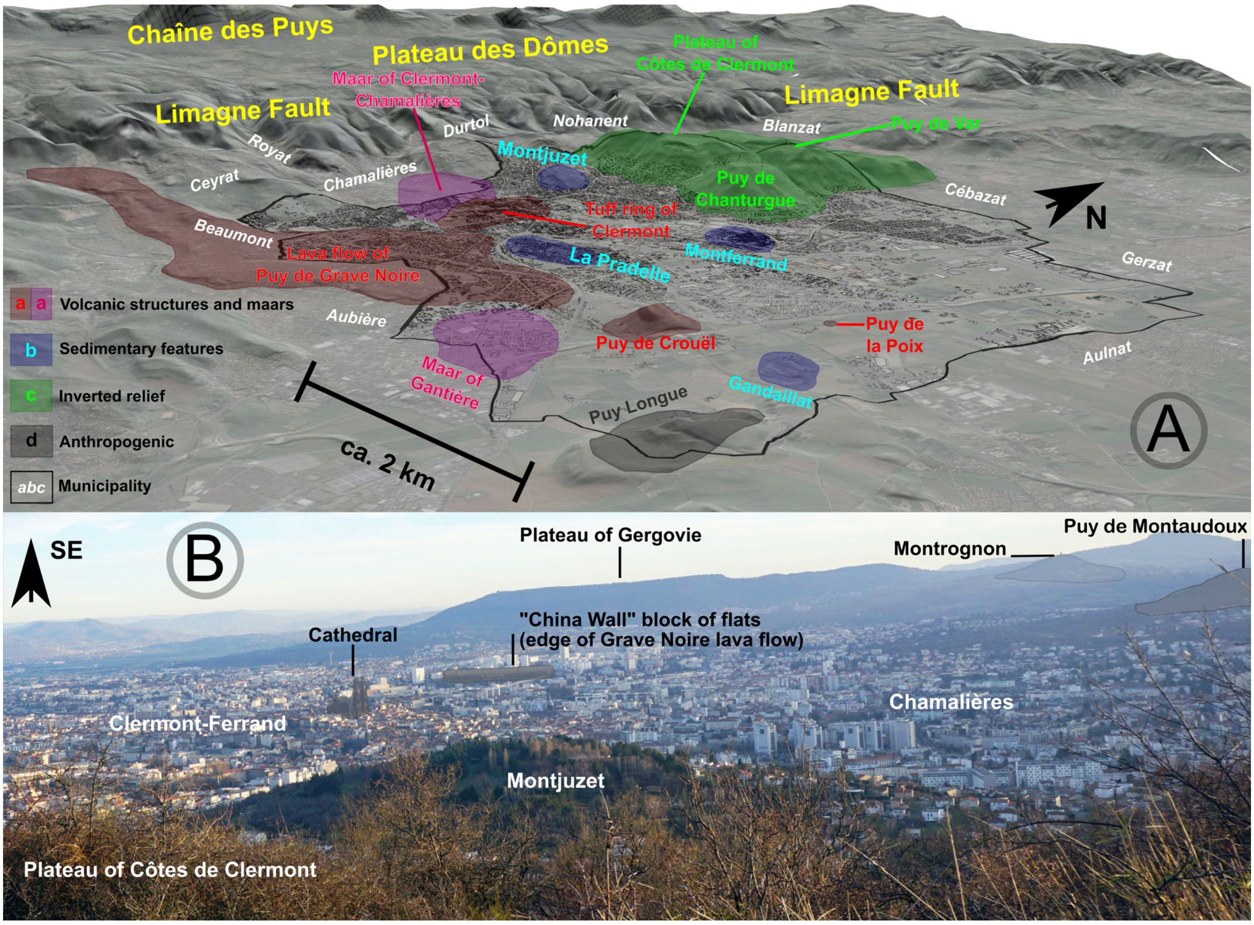

Fig. 2. The main geological – geomorphological features of Clermont-Ferrand.
A – A DEM (CRAIG 2013) view from southeast, indicating the extension of built-up areas as well (OSM 2020).
B – the view of the city from its highest point, the Plateau of Côtes du Clermont. The Plateau of Gergovie in the background is an inverted relief feature as well, but outside the city limits.

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.

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 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:

- contribute to the landscape, the cityscape,
- be a constraint, but also an advantage to urban development,
- provide resources, such as exploitable stone or an aquifer
- cause or be affected by natural hazards,
- 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.

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. 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. 2). 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 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. 2). 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.

Northwards, the hill and park of *Montjuzet* conserves the remnants of Oligocene rift sedimentation, with reported stromatolites, and is covered by Quaternary tephra layers from the *Chaîne des Puys* 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. 2). 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. 2).

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. 2).

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). 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 1:50,000 (BRGM 2019), and the topographic maps of IGN (2019).

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.

Inventory and assessment

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 described below.

The *Inventaire National de Patrimoine Géologique* (INPG), which we followed, is the comprehensive framework that controls and guides the assessment of geoheritage, as well as the collection, processing and publication of geoheritage data in

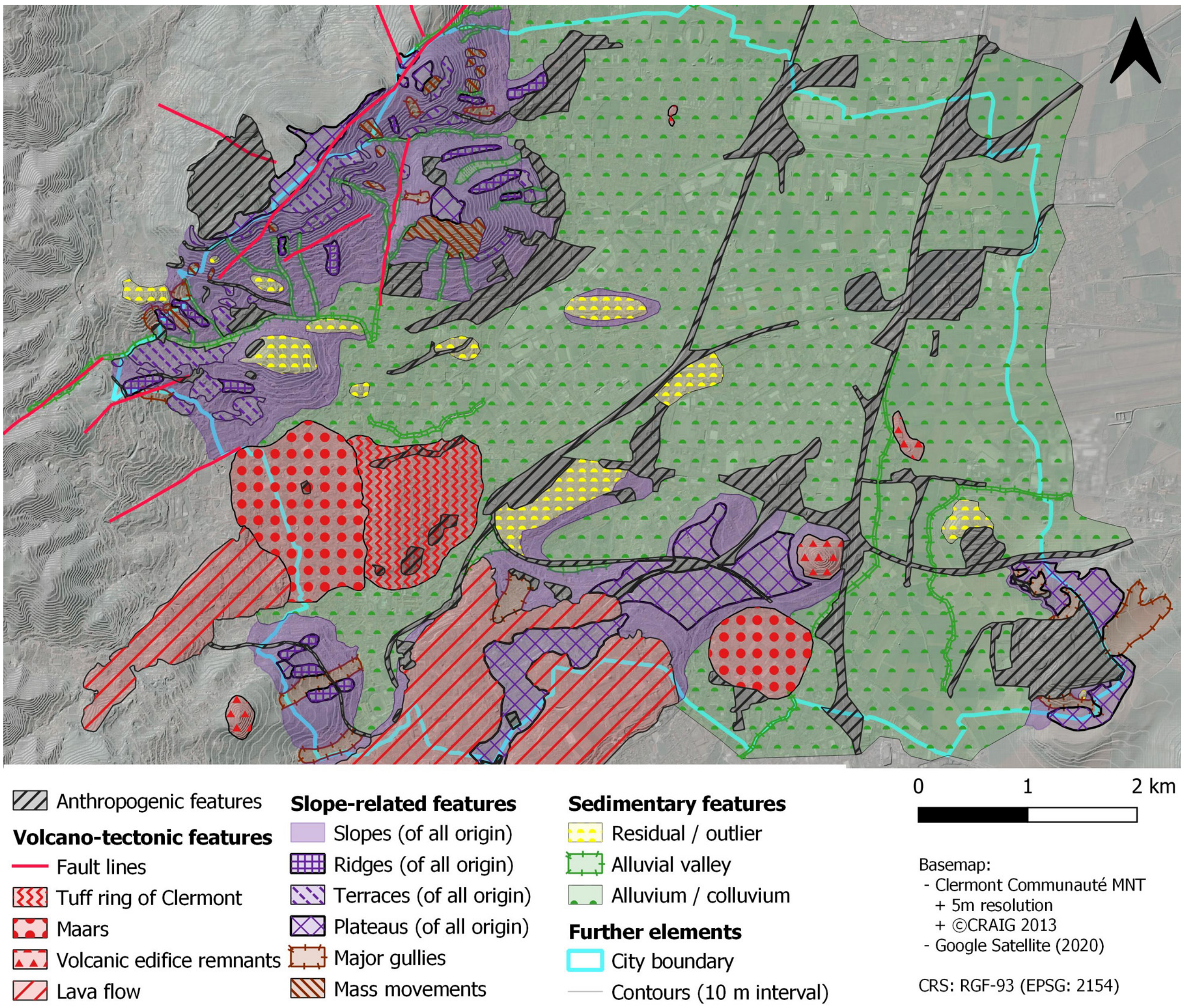

Fig. 3. The simplified geomorphological map of Clermont-Ferrand.

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 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). 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*. 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). *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.

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.

Table 1. 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	20-11	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			**Total score**	**12 points in maximum**
Preservation status	0 (poor) – 3 (good)	2				
Total score	**48 points in maximum (scale × coefficient)**					

Results

The simplified geomorphological map of Clermont-Ferrand

The majority of the city area is a widespread alluvial and colluvial plain as noted in the geological description (Fig. 3). 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 Crouël*) landforms.

In contrast, a high diversity of geomorphological and geological features is observable in the western part of the city area (Fig. 3). 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.

The urban geoheritage inventory of Clermont-Ferrand

A total of 53 sites were recorded and assessed with the INPG methodology as of 2019 (Fig. 4, Table 2).

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. 4).

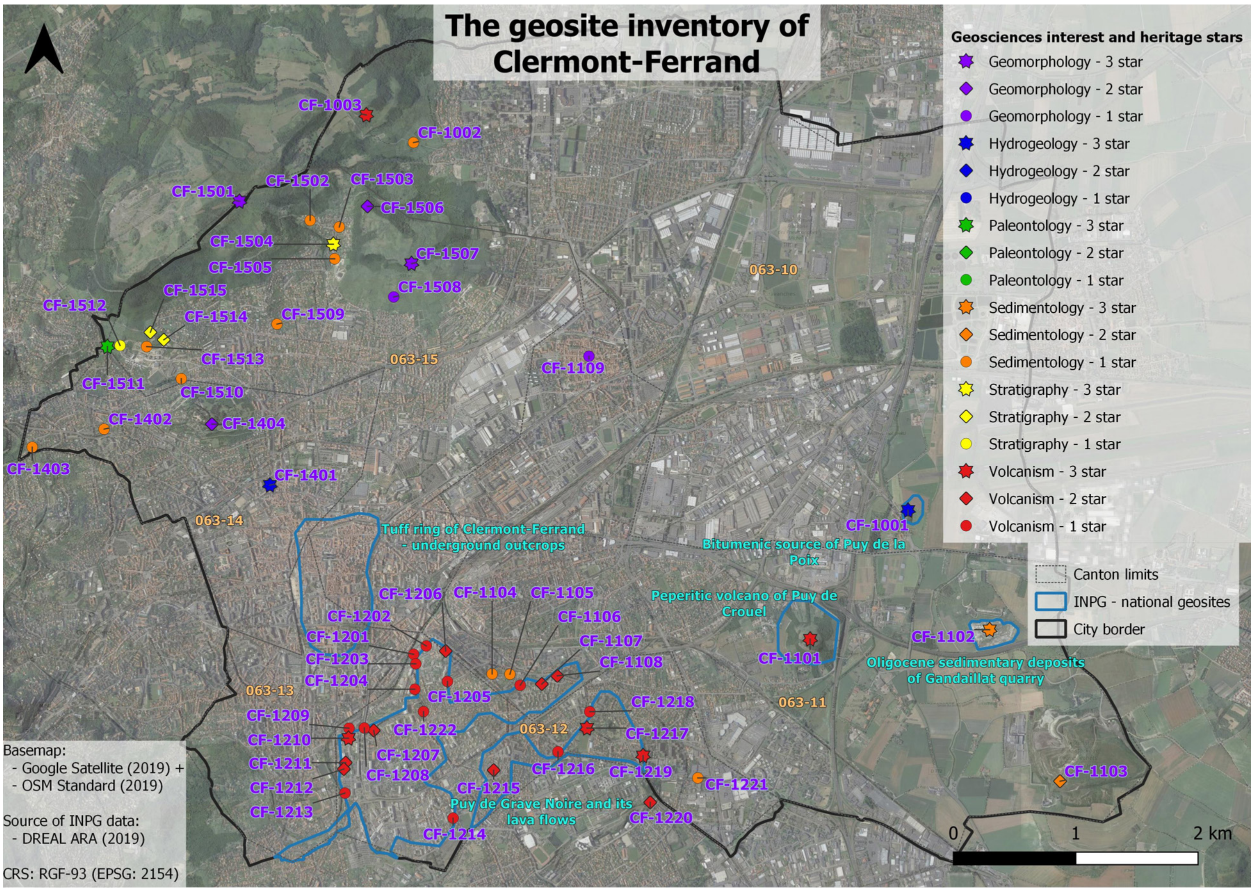

Fig. 4. Geographical distribution of geosites and geodiversity sites in Clermont-Ferrand according to the local inventory.

Table 2. 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 Crouël – peperitic volcanic neck	46	3	6	geosite	volcanism
CF–1102	Quarry of Gandaillat – 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. Desdevises 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

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–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	Margeride 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. Nohanent 184 – stromatolithes	35	3	10	geosite	paleontology
CF–1512	R. Victor Charreton 18 – Oligocene sediments	16	1	9	geodiversity site	stratigraphy
CF–1513	Rue V. Charreton x – Oligocene sediments	20	1	8	geodiversity site	sedimentology
CF–1514	Rue V. Charreton y – Oligocene sediments	23	2	9	GS / GDS (GDS)	stratigraphy
CF–1515	R. de Trémonteix – Oligocene sediments	27	2	8	GS / GDS (GDS)	stratigraphy

Individual, isolated sites include the Petrified Source of *Saint-Alyre* (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 5 and 6 according to the two main criteria of INPG: 1) the *geoheritage interest*, and 2) *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.

Figure 5A 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. 5A):

- 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. 5B). 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. 5B). The group of 3-star

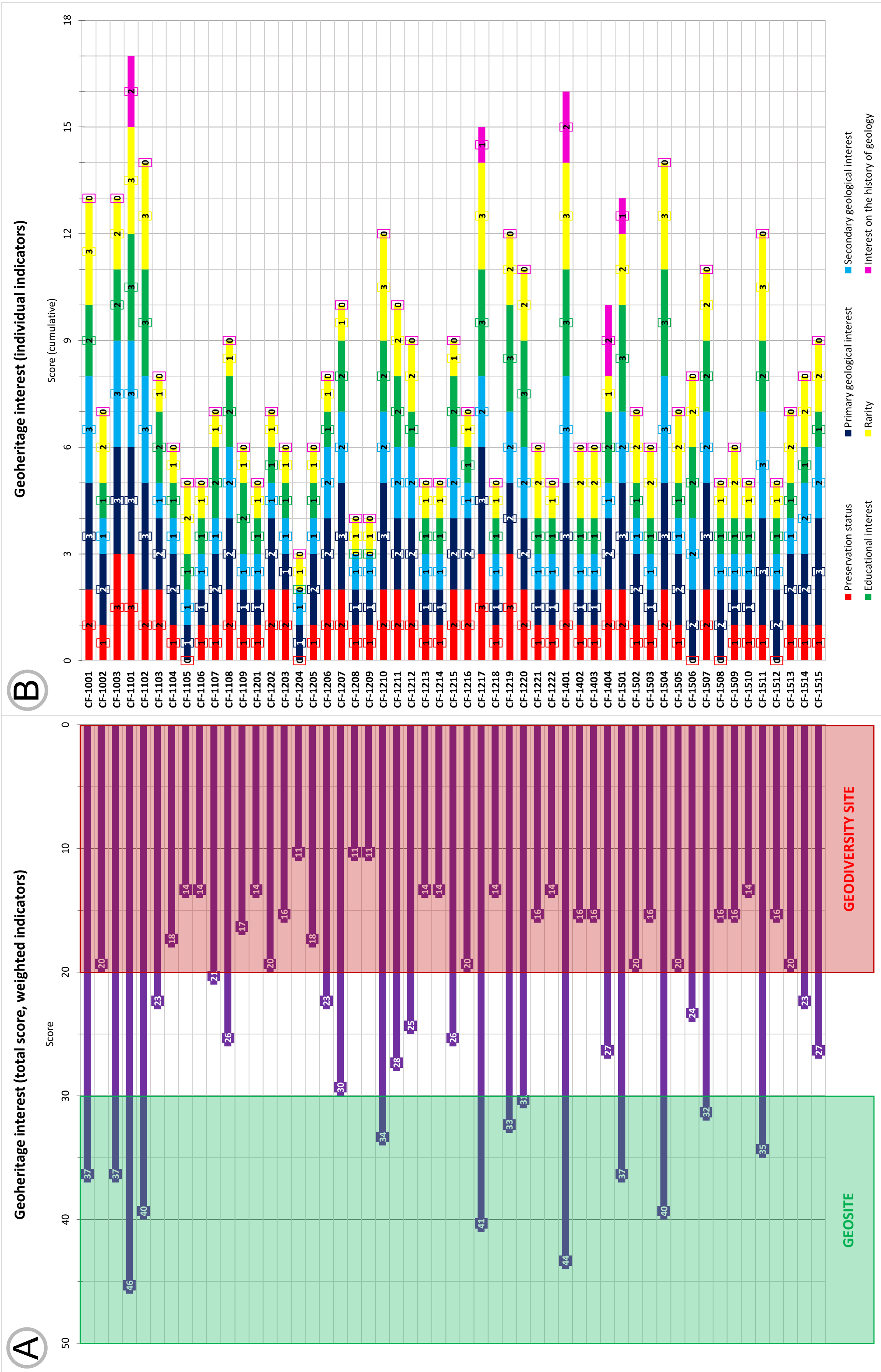

Fig. 5. Quantitative assessment of geoheritage interest of the local geosites and geodiversity sites of Clermont-Ferrand with INPG.

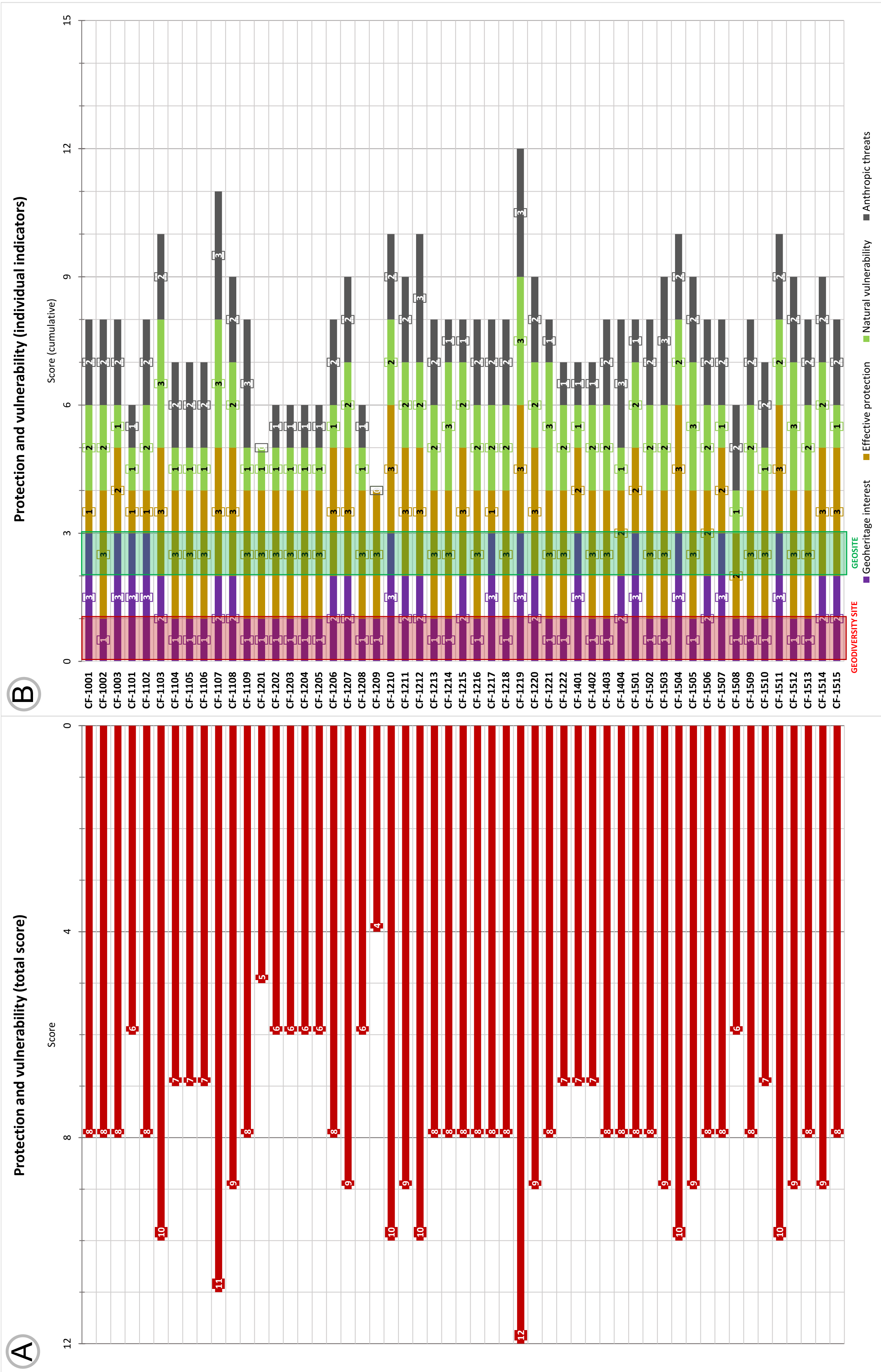

Fig 6. Quantitative assessment of vulnerability and protection of the local geosites and geodiversity sites of Clermont-Ferrand with INPG.

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. 5B). 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.

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 Crouël* (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 Desdevies 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 *need for protection* and *vulnerability* values are moderate to high, underlining the fragility of geological outcrops and geomorphological landforms in an urban context (Fig. 6). However, *geoheritage interest* directly affects the *need for protection* and *vulnerability* 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 *need for protection and vulnerability* 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*).

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.

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:

1. biodiversity importance (e.g., habitat for flora and fauna elements),
2. relevance to cultural heritage, by inviting experts to record the potential connotations of each site in that respect,
3. 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.

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. 7). 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. 8).

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.

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

Fig. 7. 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.

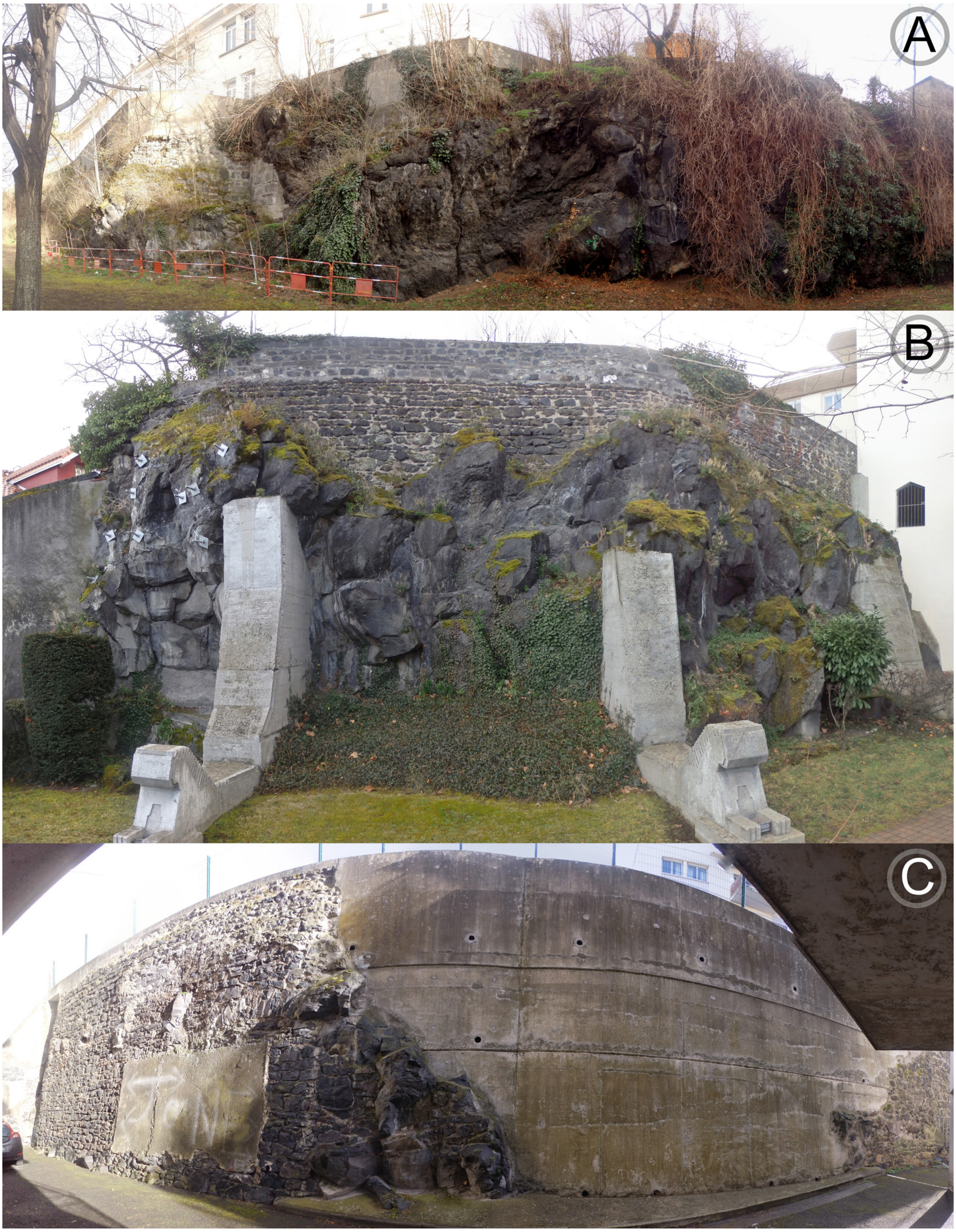

Fig. 8. Three examples of slope stabilization of outcrops of *Grave Noire* lava flow.
A – a still unconsolidated site at Rue Henry Arnaud 21 – CF1207. The temporary fence suggests an acknowledgement of some hazard, the danger is that poorly thought out remediation may destroy the sites values.
B – a 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.

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.

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. Cohendy*) 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. 8C). 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. 9).

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.

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*

Fig. 9. The outcrop of *Grave Noire* lava flow at *Impasse Dr. Cohendy* (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.

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 n.d.). 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 Mourlevat*, 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.

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 n.d.). 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 1988), also features local building materials, such as the arkose of the *Plateau des Dômes*. In addition, modern 20th century buildings, such as the *Galeries 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.

Geoeducation

The *Chaîne des Puys-Limagne Fault* Tectonic Arena encompasses two world-renowned examples of geosciences education, the *Vulcania* theme and adventure park on volcanism, and *Lemptégy*, 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 Crouël* 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 Crouël* (CF1101) for Miocene volcanoes (offering a wide panorama for the Quaternary volcanism of the *Chaîne des Puys* 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.

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.

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 19^{th} 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. 10) 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

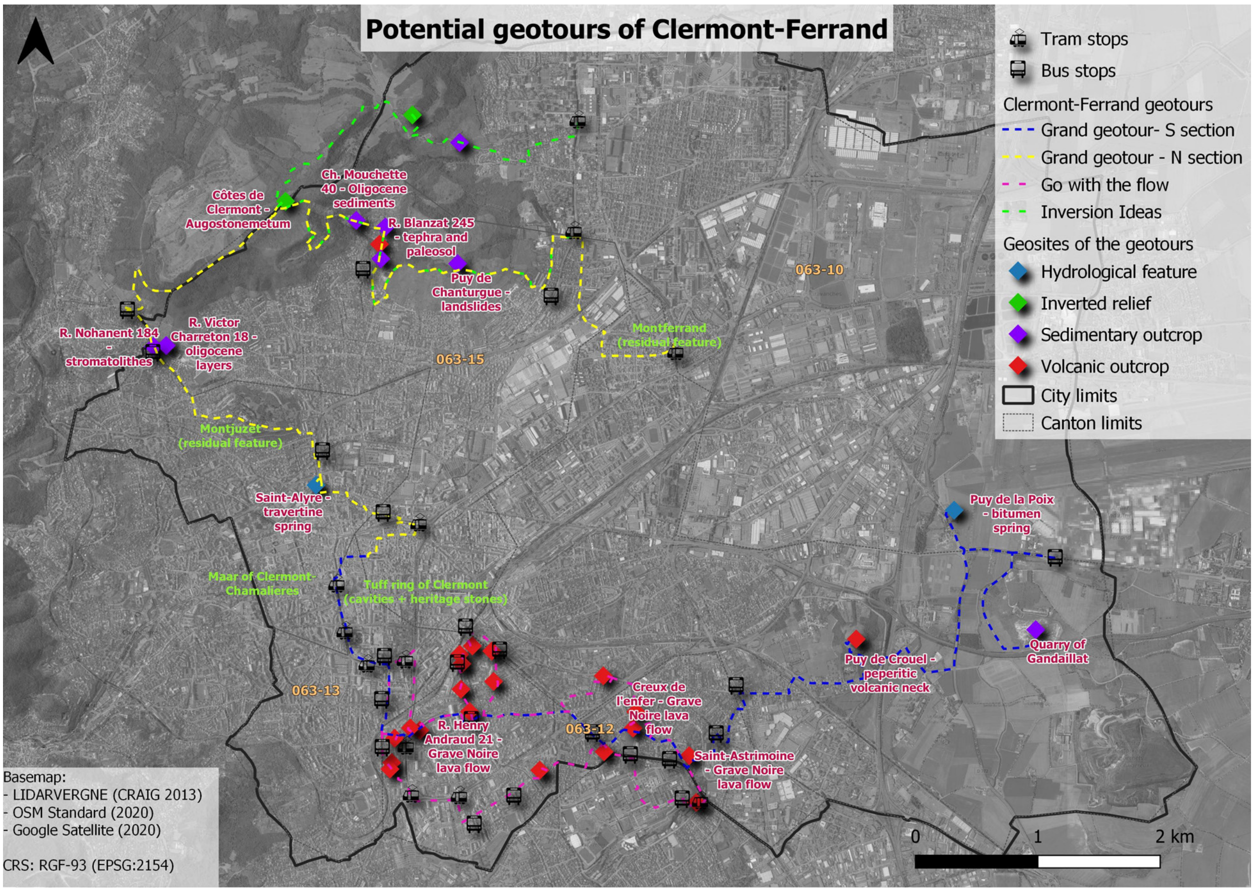

Fig. 10. The proposed geotouristic routes in Clermont-Ferrand with the names of the most important geosites along the tracks.

Aubière. It contains almost all of the visible outcrops of this unit, ranging from the most representative larger sites (*Rue Desdevies du Dézert 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.

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. 10) 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).

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.

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. Cohendy* (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.

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Author contributions

The compilation of the simplified geomorphological map, the database structure of the inventory, and the field work was carried out principally by Viktor Vereb. Marie-Noëlle Guilbaud and Benjamin van Wyk de Vries prepared the detailed physical and geological description of the sites, and provided ideas and feedback for this work. Dávid Karátson contributed significantly to the conceptual and textual coherence of the paper.

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