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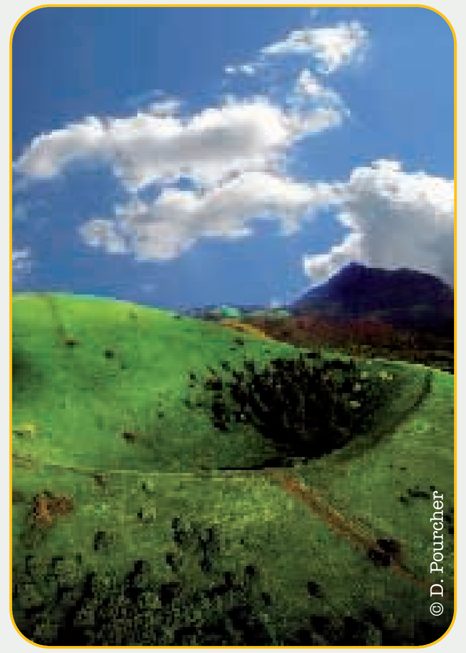

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Gérard COLLIN,
and Christopher WOOD.

WORLD HERITAGE

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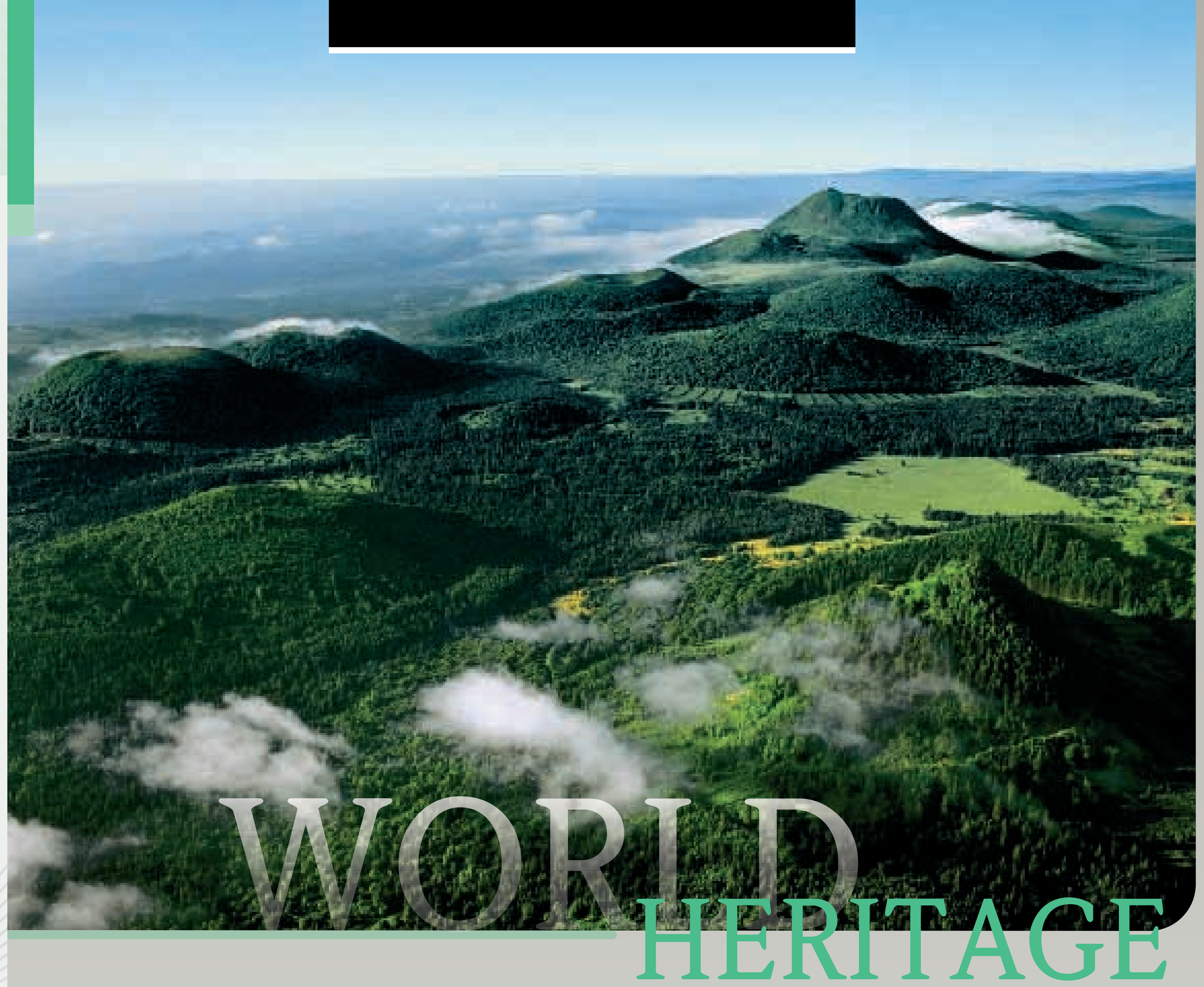

WORLD HERITAGE

Chaîne des Puys Limagne fault

PUY-DE-DÔME
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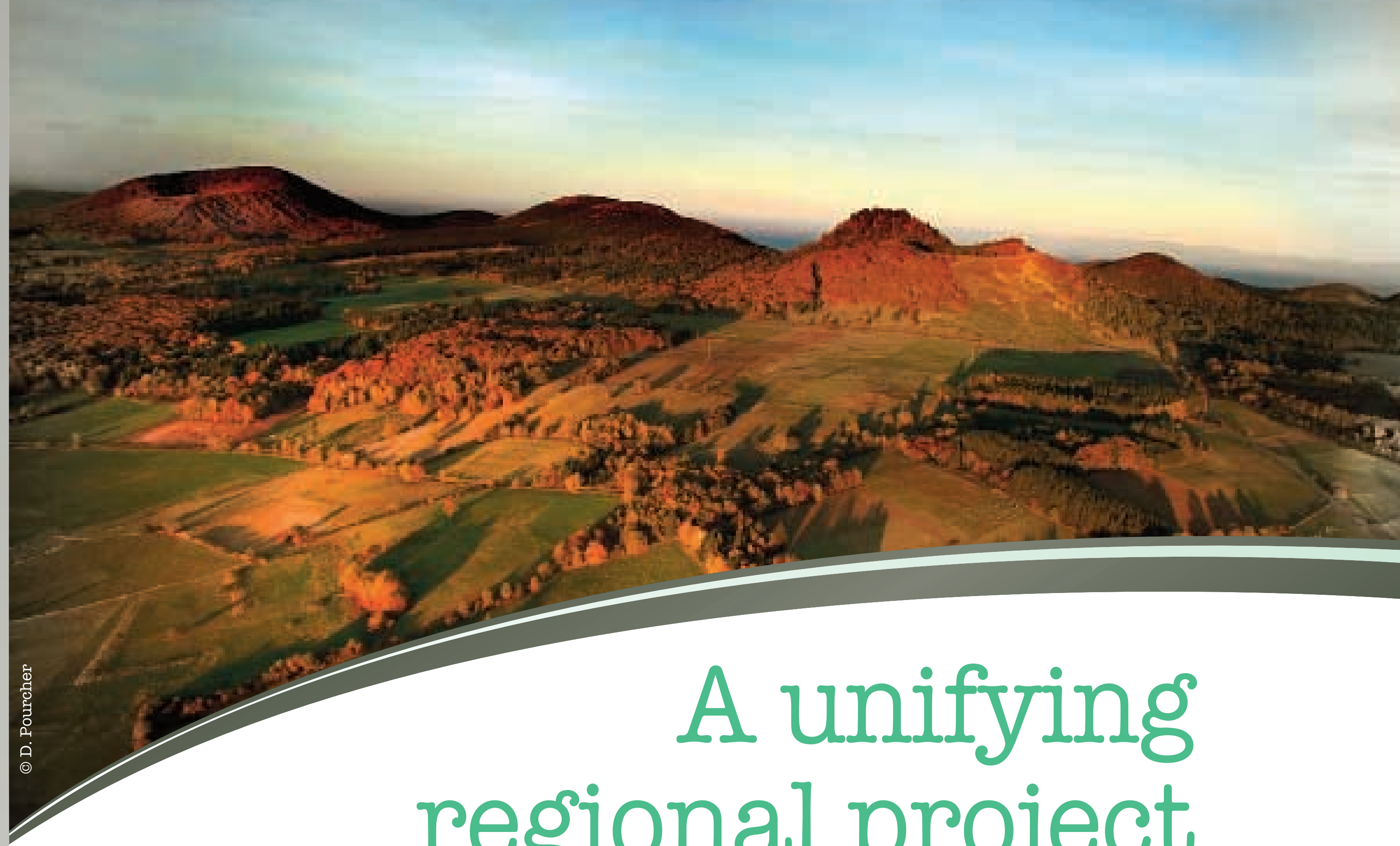

A unifying regional project

This application proposal for the magmato-tectonic ensemble of the Chaîne des Puys and the Limagne Fault to be accepted onto the World Heritage List has been jointly compiled by the local council of the Puy-de-Dôme, the Regional Natural Park of the Volcanoes of the Auvergne (PNRVA), the University of Clermont-Ferrand and the local government of the Auvergne region, with support from the regional government and the town of Clermont-Ferrand.

The application is part of an ongoing process to protect and highlight the value of this area, which began in 1977 with the creation of the PNRVA. In 2000 the Chaîne des Puys was added to the national list of Natural Monuments and Sites (following a law established in 1930), then in 2008 it achieved the status of Grand site de France®.

These thirty years of sustainable, collaborative management of this outstanding geological landscape have enabled it to preserve its integrity. This application proposal to the World Heritage List aims to unite all the interested parties and the local population in order to:

- make the universal excellence of this site more widely known;
- allow for social and economic development within the legal framework set up in 1930 for the protection of classified landscapes;
- favour sustainable local development based on carefully planned tourism;
- develop national and international scientific research on this major volcanological and geological site.

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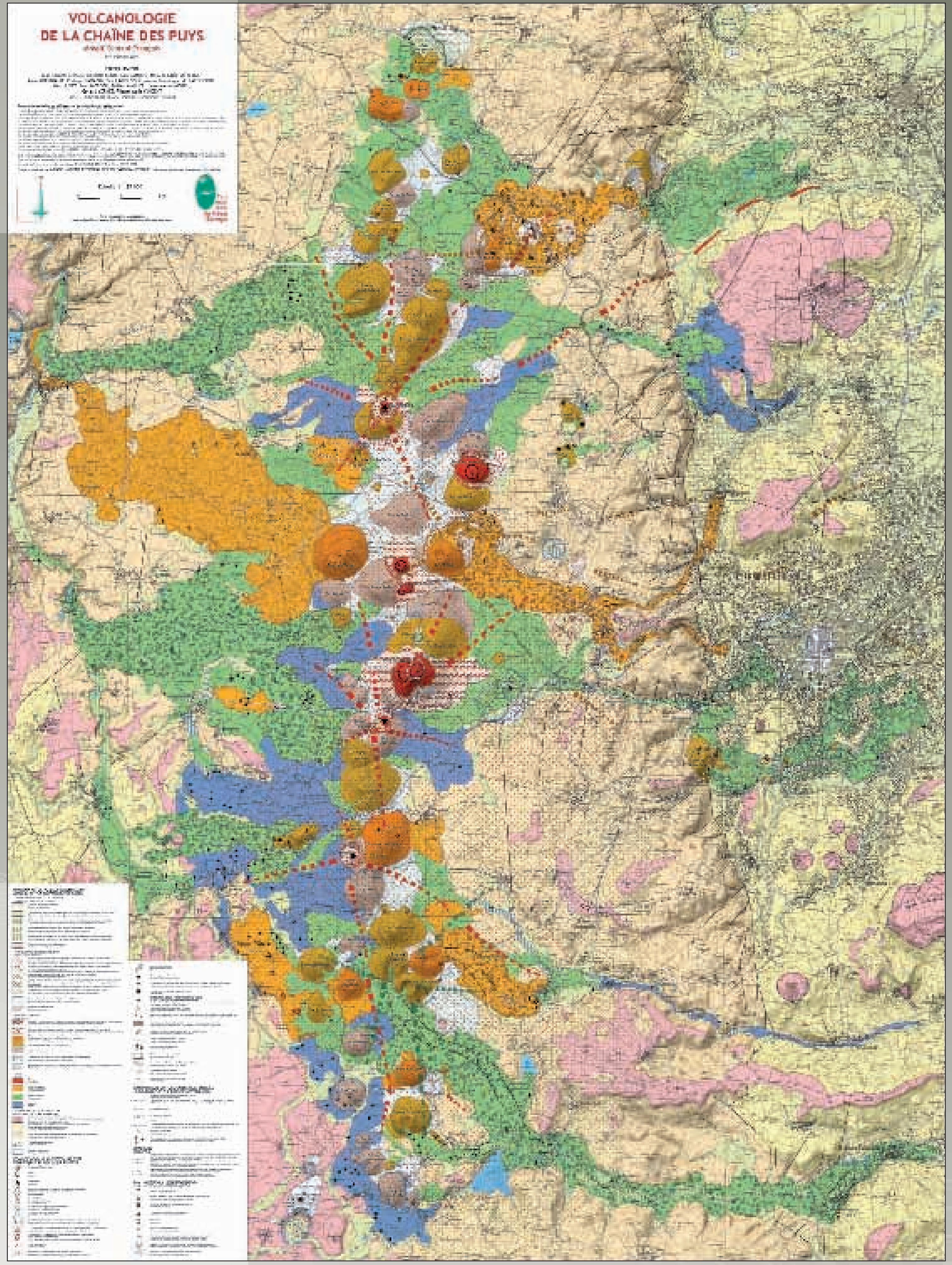
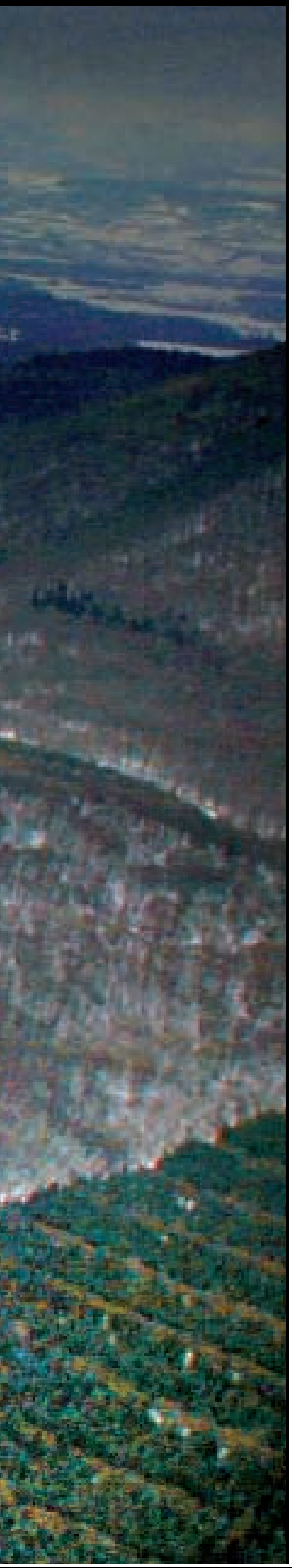


Volcanological map of the Chaîne des Puys
(Source: © EAVUC 2009)



Application for the magmato-tectonic ensemble of the Chaîne des Puys and Limagne Fault

1 Identification of the Property

1.a Country: France

1.b Region:

Auvergne Region, Department of the Puy-de-Dôme

1.c Name of Property:

Magmato-tectonic ensemble of the Chaîne des Puys and the Limagne Fault

1.d Geographical coordinates to the nearest second:

X = 0° 43' 49,2852'' - Y = 45° 42' 4,2012''

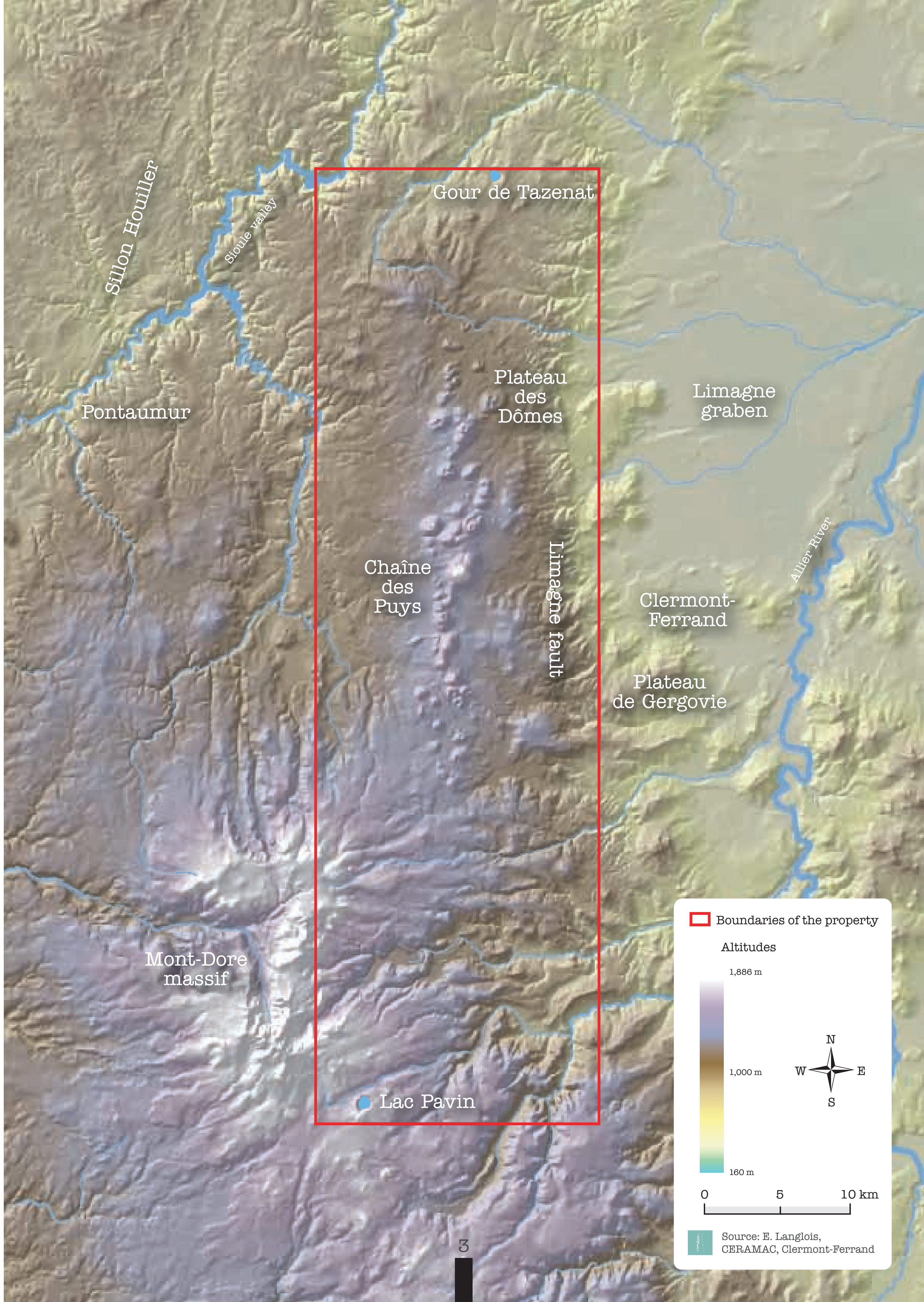
1.e Maps and plans, showing the boundaries of the nominated property:

Written description of the boundary of the proposed Property:
The magmato-tectonic ensemble of the Chaîne des Puys and the Limagne Fault is around sixty kilometres from north to south, and around ten kilometres from west to east. The outline is delimited morphologically:

- to the north by the gour de Tazenat, which is the most northerly basaltic maar of the Chaîne des Puys;
- to the east by the fault escarpment which separates the plateau des Dômes, a crystalline horst, from the sediments of the Limagne Plain;
- to the south-east by the Monts Dore massif, a stratovolcano dating from the end of the Tertiary period which is cut by glacial valleys;
- to the south by the Pavin-Montchal-Montcineyre volcanic complex, which is the most recent manifestation of volcanic activity in the Chaîne des Puys;
- to the north-west by the Sioule river which initially runs northwards, then turns towards the north-west at the Pont-de-Menat.

1.f Area of nominated property:

508,55 km²



2 Description

2.a Description of Property

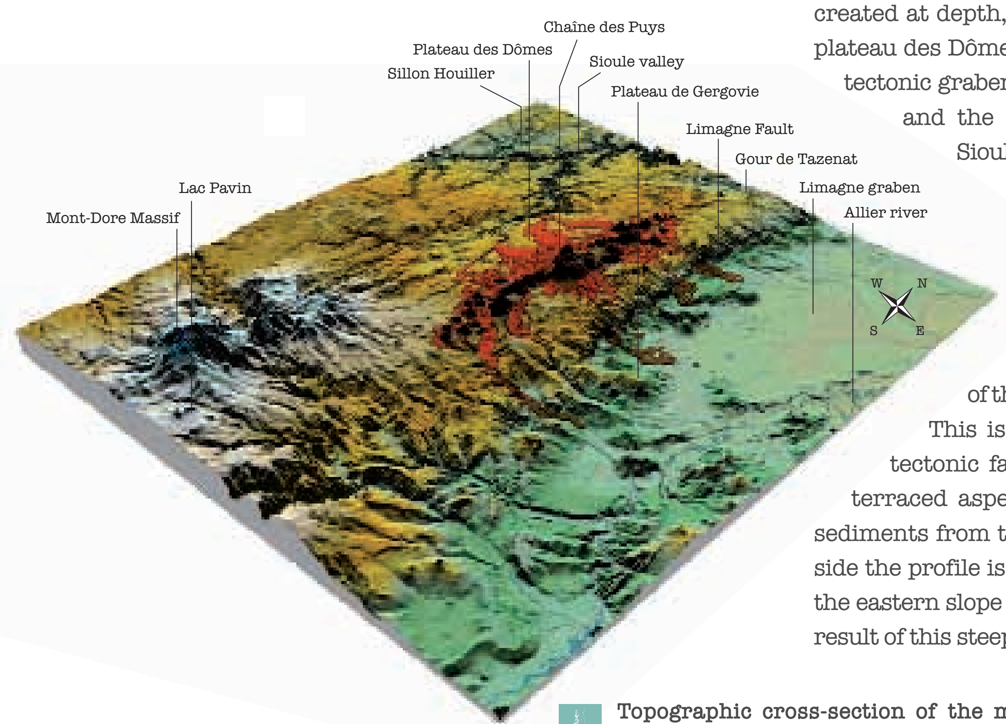
The structural-morphological framework of the magmato-tectonic ensemble

The magmato-tectonic ensemble of the Chaîne des Puys and the Limagne Fault is the result of successive geological events dating back to Palaeozoic times. These events include major dynamic processes such as orogenesis (mountain building), erosion, faulting and magmatism, and the end product we see today is an impressive scaled-down model of the following structural geological features, all found within a limited area:

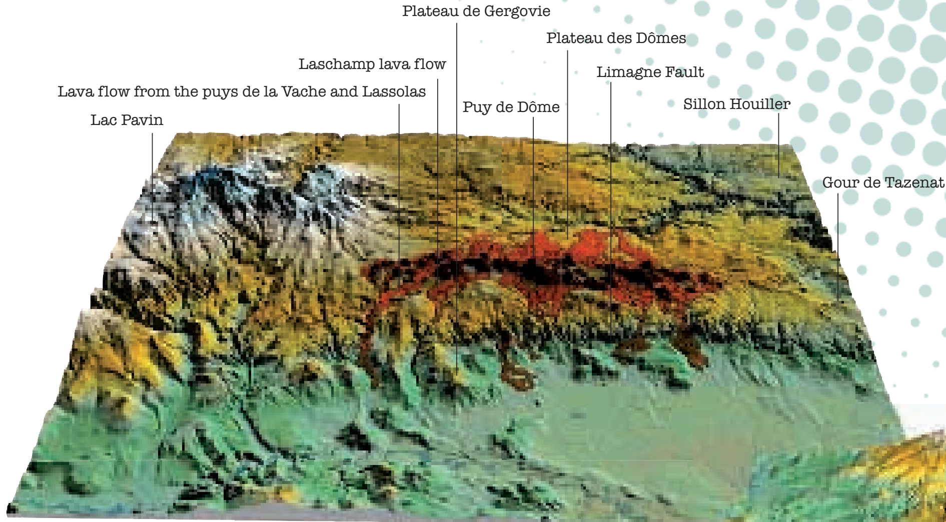
- an eroded horst – the plateau des Dômes –;
- a Carboniferous strike-slip fault – the Sillon Houiller –;
- a continental rift – the Limagne Fault –;
- a rift graben – the sedimentary Limagne graben –;
- a monogenetic volcanic field – the Chaîne des Puys –.

The plateau des Dômes

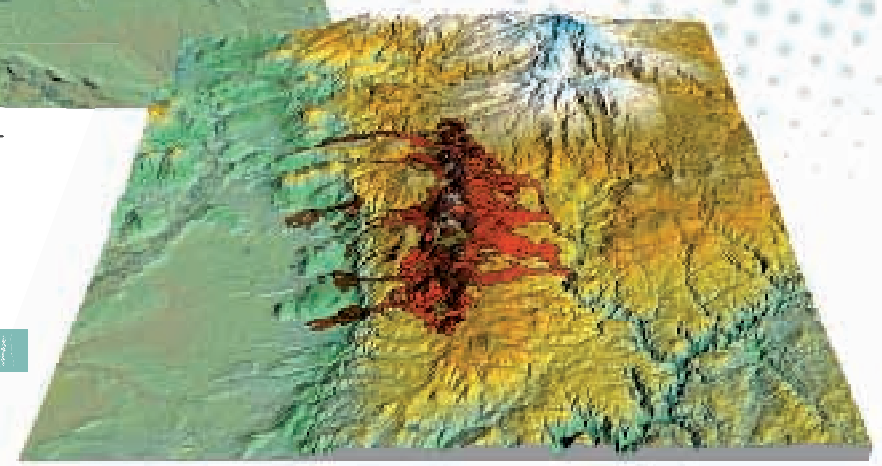
The plateau is composed of a basement whose complex evolution covered the period from the Palaeozoic to the Cenozoic (see also the section on the Background and development). In the Carboniferous, around 350 Ma, the sedimentary rocks were metamorphosed to form gneisses and schists during the Variscan orogeny, which was accompanied by thrust faulting. At the same time intense magmatic activity led to the intrusion of large granitic bodies. A second wave of granitic intrusions took place in the Clermont-Ferrand area between 330-280 Ma (the Royat granite body dates from this event) which represented the final wave of Variscan activity. From the Permian period, around 250 Ma, the Variscan topography underwent erosion for around 200 Ma to form the peneplain onto which the Chaîne des Puys edifices and their associated deposits were erupted. The substratum outcrops at a number of locations around Clermont-Ferrand, and the planar surface of the horst exposes structures which were initially created at depth, such as the granitic plutons. The plateau des Dômes is an uplifted horst between two tectonic grabens: the Limagne graben to the east, and the Olby graben, which includes the Sioule valley, to the west. The horst is up to 1,030 m high whereas the Limagne plain lies at an altitude of around 300 m. An E-W cross-section shows that the profile is asymmetric, with a steeper gradient on the eastern side of the horst, facing the Limagne graben. This is due to a series of closely-spaced tectonic faults on this side giving a steeply terraced aspect, combined with erosion of the sediments from the Limagne plain. On the western side the profile is much gentler. Thus the valleys on the eastern slope are both deeper and narrower as a result of this steeper gradient.



Topographic cross-section of the magmato-tectonic ensemble viewed from the southeast (Source: E. Langlois, CERAMAC, Clermont-Ferrand)



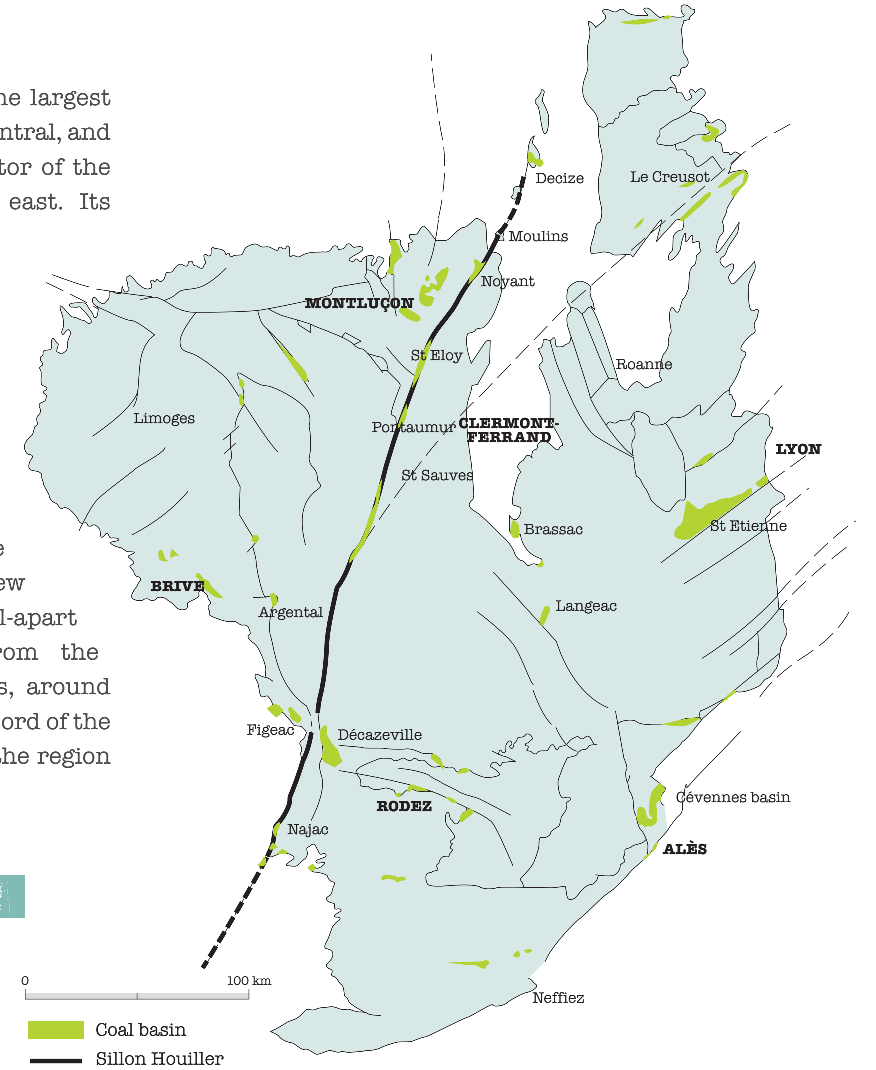
Topographic cross-section of the magmato-tectonic ensemble viewed from the east
(Source: E. Langlois, CERAMAC, Clermont-Ferrand)



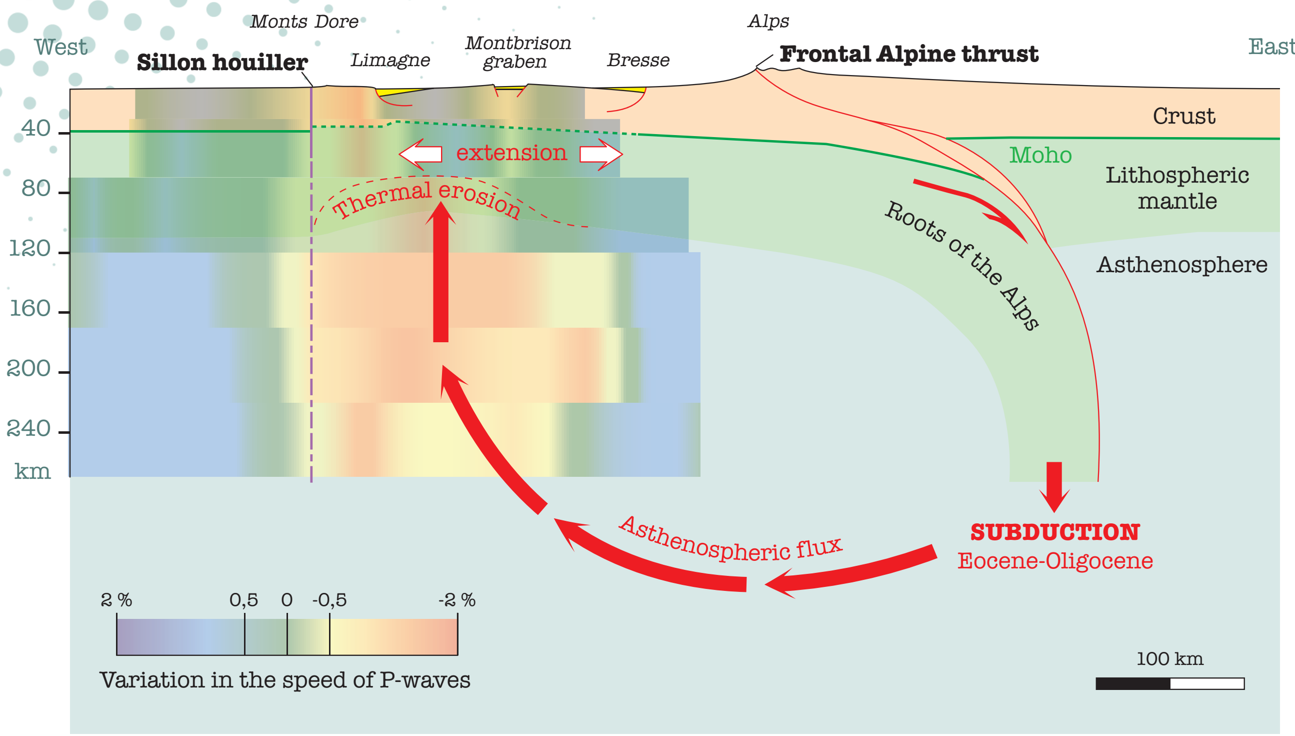
Topographic cross-section of the magmato-tectonic ensemble viewed from the north
(Source: E. Langlois, CERAMAC, Clermont-Fd)

The Sillon Houiller

The 250 km-long Sillon Houiller fault is the largest tectonic feature which crosses the Massif Central, and it separates the non-volcanic western sector of the massif from the volcanic sector to the east. Its presence at the surface is marked by the NNE-SSW alignment of discontinuous Carboniferous pull-apart basins. The Sillon Houiller formed as the uplift associated with the Variscan collision gave way to collapse structures, creating a huge strike-slip fault which can be traced from Moulins in the north to Décazeville in the south, passing close to Saint-Eloy-les-Mines and Pontaumur in the Puy de Dôme. The fault can be detected down to a depth of a few hundred kilometres, and the associated pull-apart basins are infilled with vegetation from the Stephanian (the end of the Carboniferous, around 300 Ma). This sedimentary infill bears a record of the various deformations which have affected the region over the last 300 Ma.



Silllon Houiller strike-slip fault in the Massif Central
(Source: P. Boivin, Laboratoire Magmas et Volcans, Clermont-Ferrand)



Tectonic model
(Source: EAVUC, adapted from O. Merle, L. Michon and M. Granet)

This major strike-slip fault has influenced the volcanism of the Massif Central, in particular acting as a barrier to the zone of thinned crust which, according to the "passive rifting" tectonic model of Olivier Merle and Laurent Michon (2001), determined the location of the Chaîne des Puys volcanics.

In this model the formation of the Alpine mountain chain, resulting from the subduction of the European lithospheric plate, was the prime cause of the tectonic evolution and volcanism in the Massif Central over the last 65 Ma, culminating in the formation of the Chaîne des Puys.

Modelled simulations of the tectonics of the region indicate the necessity of a vertical discontinuity down to a depth of a few hundred kilometres. This appears to match well with seismic surveys which show a discontinuity down to about 250 km beneath the Sillon Houiller fault, but as yet there is no confirmation of its presence (O. Merle, pers. com.).

Limagne Fault and graben

The Limagne Fault separates the crystalline horst from the graben, and represents one of the three major segments of the West-European Rift which flank the Alpine mountain chain. The three sectors are, from east to west, the Eger graben (oriented ENE-WSW), the Rhine graben (oriented NNE-SSW) and the grabens of the Massif Central (oriented N-S). Sedimentary infill in these three sets of grabens is mainly Oligocene in age (35-25 Ma), which shows that the extension throughout this area was synchronous during the Tertiary. The extension was directly related to the formation of the Alps, and this crustal collision led to tectonic disruption at a distance from the heart of the mountain chain, resulting in the faulting in the granitic peneplain. In the Massif Central region, the effects of the Alpine collision were manifested by generalised uplift accompanied by faulting. The faults led to the uplift of a crustal block, or horst, now known as the plateau des Dômes, with simultaneous downthrow on either side of up to 2,000 m to create the Limagne graben and the Olby-Sioule basin. The sedimentary deposits in these basins

are predominantly lacustrine, but the presence of thin layers containing coccoliths (unicellular calcereous plates formed in marine conditions) shows that there were at least brief marine transgressions in the Limagne area.

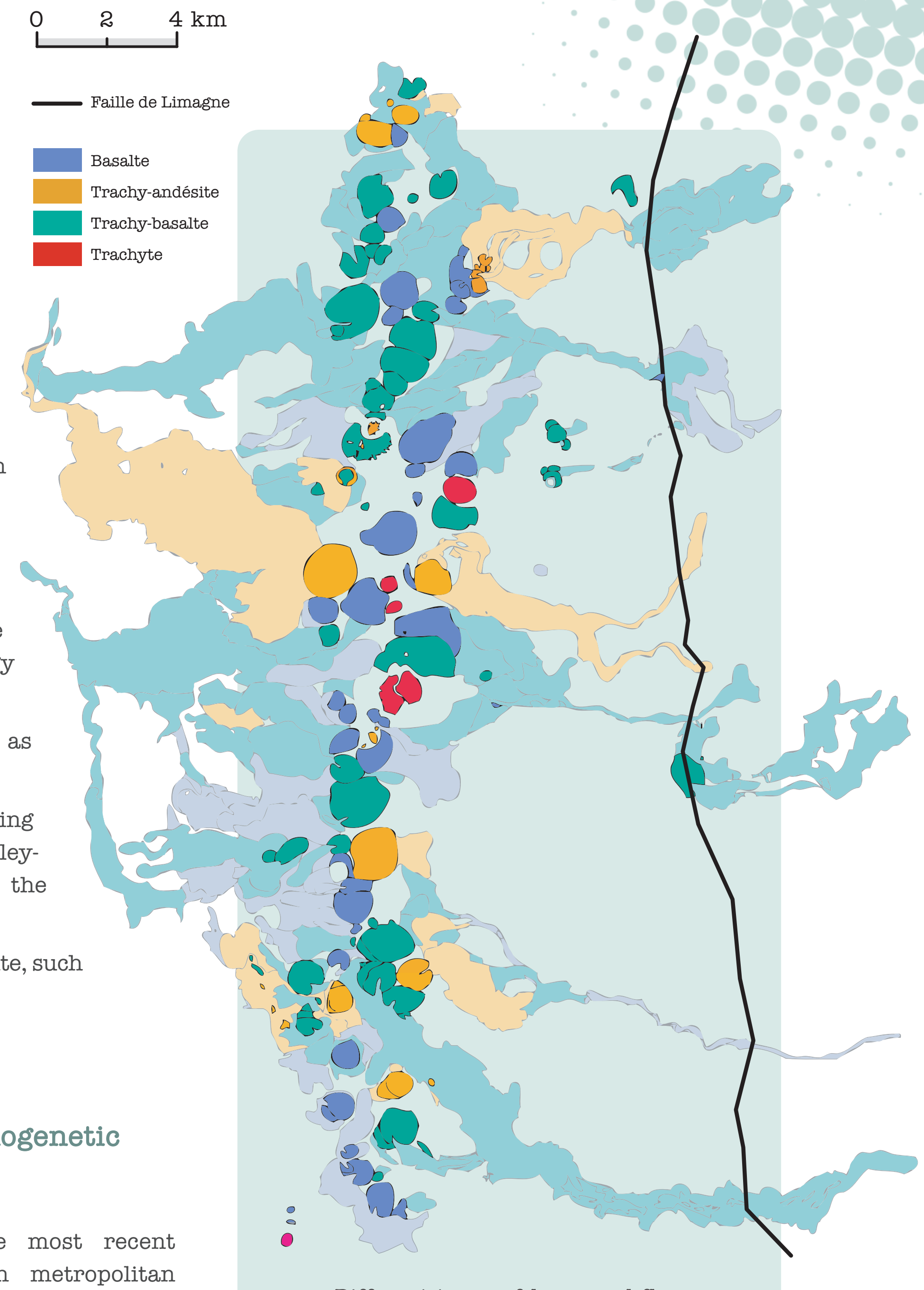
This graben, where the continental crust had been thinned, was the site of intense volcanism, mainly basaltic, over a period of 30 Ma (from the Oligocene to the Quaternary). There are three main types of geomorphology present:

- exposed volcanic necks, such as Mount Rognon;
- flat-topped hills, representing inverted relief of former valley-confined lava flows, such as the plateau of Gergovie;
- rounded hills made up of peperite, such as the puy de Bane.

The Chaîne des Puys, An intracontinental monogenetic volcanic field

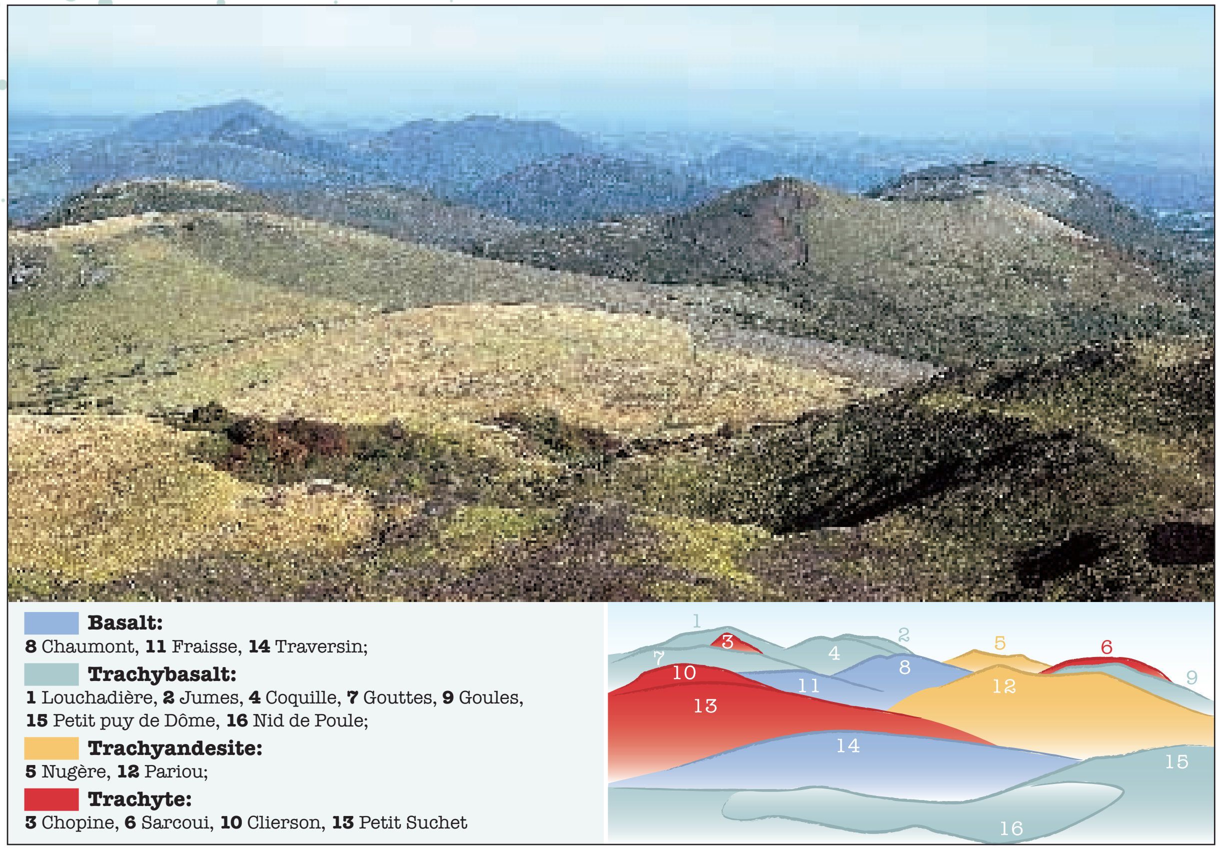
The Chaîne des Puys is the most recent manifestation of volcanism in metropolitan France. Its activity spanned 95,000 – 7,000 ya (Pleistocene to Holocene in age), which is brief in geological terms. According to the classification of the Smithsonian Institution's Global Volcanism Program the Chaîne des Puys is considered to be dormant, and thus still potentially active, as the most recent volcanic activity occurred within the last 10,000 years. The volcanic field is relatively small (32 x 4 km in the central part), consisting of around 90 well-preserved edifices in a compact alignment from the maar de Beanit in the north to the puy de Montenard in the south.

There are two peripheral groups which lie 10-20 km away to the north and south: the gour de Tazenat and the Pavin group, respectively. The Pavin group



Different types of lavas and flows, Central part of the Chaîne des Puys
(Source: E. Langlois, CERAMAC, Clermont-Fd)

Monogenetic volcanic fields rarely exhibit the full chemical range of magma types, from basic to evolved, via intermediate compositions. This is because their tectonic setting generally precludes the formation of shallow level magma chambers in which magma can undergo differentiation. However, geophysical (seismic and aeromagnetic surveys) and petrological data for the Chaîne des Puys volcanics indicate the existence in this region of two superposed levels of magma chambers. The deeper level lies towards the base of the crust (between 25-30 km in depth), while the upper level is at a depth of around 5-15 km.



The Chaîne des Puys range, looking north from the puy de Dôme,
(Source: © EAVUC 2009)

has the youngest deposits of the Chaîne des Puys, dated at around 7,000 ya. The majority of edifices are classed as monogenetic, following the terminology of Alfred Rittman (1962), as they are the product of a single, generally 'short' eruption (a few days to a few months duration). They represent an exceptional grouping of varied volcanic forms, showing very little erosion due to their young age in geological terms.

Using the international nomenclature (I.U.G.S., Le Maitre, 2002), the Chaîne des Puys volcanics have been grouped into four principal types which are recognisable in the field: basalts, trachybasalts, trachyandesites and rhyolites. The chemistry of the rocks is alkaline and weakly potassic, and overall there are almost no breaks in the differentiation series from alkali basalt to quartz-bearing trachyte, passing through hawaiites, mugearites and benmoreites. These different compositions give rise to characteristic edifice profiles, making it possible to distinguish and recognise different lava types through the landscape, as shown in the figure above. Thus this volcanic chain, whose human scale allows it to be observed without difficulty, contains in miniature an exceptional range of all the major volcanic phenomena:

- 'primary' edifices: cones, domes, protrusions, tuff rings, maars, crater lakes;
- eruption structures: nested craters, breached craters, twinned craters, collapse craters, feeder pipes, dykes;
- specific volcanic features: fissure volcanism, valley-confined lavas, inverted lava plateaus, small flood basalts, lava tumuli, emptied volcanic necks;
- volcanic deposits: ash, lava flows, pyroclastic deposits.

Educational and Scientific Aspect

The study of the Chaîne des Puys in the 18th century laid the foundations for a new scientific discipline, now known as volcanology. In addition to this, a number of internationally renowned experiments and scientific discoveries have taken place in this region, which still remains an important educational site.

The birthplace of volcanology

The foundations for the scientific study of volcanoes were laid down in the Auvergne during the 18th and 19th centuries, making this region a historical centre for the emergence of the new discipline of volcanology.

Jean-Étienne Guettard (1715–1786)

Jean-Etienne Guettard, curator of the Natural History collection of the Duke of Orléans, was the first to publicise the volcanic nature of the Chaîne des Puys. In 1752 he published a Memoir on the various mountains of France which he interpreted as having been volcanoes, based on the association of form and process. This was the first geomorphological approach to landscape. In addition he proposed that these mountains were potentially dormant rather than extinct, which provoked perhaps the greatest controversy in the history of geology.

Abraham Werner (1749-1817) & James Hutton (1726-1797)

In the second half of the 18th century the scientists allied themselves to one of two opposing groups, the Neptunists and the Plutonists. The Neptunists were led by the German, Abraham Werner, who argued for a sedimentary origin (either marine or lacustrine) for basalt, while the Scot, James Hutton, led the Plutonists and interpreted the lavas as having initially been molten basement material which was subsequently thrown out of volcanic craters and solidified as it cooled.

Nicolas Desmarest (1725-1815)

The naturalist, Nicolas Desmarest, spent time in the Chaîne des Puys at the end of the 18th century, and increased the number of volcanic edifices recorded from the three identified by Guettard to over sixty. He drew up the first geological map of the Chaîne des Puys and Monts Dore Massif, which was published in 1780. He belonged to the Plutonist camp, and he succeeded in demonstrating that the basaltic features observed were not marine in origin, but primary lava features. He identified three volcanic 'epochs': recent, older, and oldest volcanoes. His application of stratigraphic and geomorphologic principles to the study of a volcanic terrain was very innovative.

Déodat de Dolomieu (1750-1801)

Dolomieu was a geologist and mineralogist who compared the volcanic activity of the Chaîne des Puys to molehills in which the mole "*works away underground and pushes earth, taken from a layer underneath, out onto the fields at the surface*" (1798). During his trips around the region he showed that the different volcanic rocks came from different sources, which he placed beneath the granite layer, rather than being a direct result of granitic fusion as had previously been postulated. This represents the first coherent model for the composition of the Earth.

Léopold von Buch (1774-1853)

"Would you like to see volcanoes? Go to Clermont rather than Vesuvius or Etna". Thus spoke the German geologist, Leopold von Buch, who justified his statement by explaining that the products of these active Italian eruptions hid what lay underneath, whereas at Clermont the volcanic products flowed/fell onto the adjacent plain. Von Buch travelled widely, his destinations including Vesuvius, the Alps, the German mountains, the Scandinavian islands, the Hebrides and the Canary Islands. He came up with a theory in 1802 to explain the origin of domes and other craterless volcanoes after visiting the Auvergne. He broadened this hypothesis by introducing the notion of the structures being 'uplift craters' (1819), and publication of this work proved contentious enough, once again, to divide the European geological community.

George Poulett Scrope (1797-1876)

The Englishman, Scrope, after studying the volcanic rocks of Vesuvius, Etna and the Eiffel region, visited the the Auvergne several times in the 1820's, culminating in the publication of his classic *Memoir on the geology of Central France, including the Volcanic formations of Auvergne, the Velay and the Vivarais* (1827), illustrated with his own maps and engravings. The revised edition was published under the title *The Geology and extinct Volcanoes of Central France* in 1858, and became very popular.

Maurice and Katia Krafft (1946-1991 and 1942-1991)

In the 1980's it was the dream of the famous volcanologists, Maurice and Katia Krafft to create a European volcanology museum in the heart of the Chaîne des Puys. This became a reality in 2002 with the opening of Vulcania, a European centre for Volcanology, which houses a large part of their private collections.

Ongoing research

Throughout its long history, the Chaîne des Puys has continued to be the focus of numerous research projects, mainly under the guidance of the Laboratoire Magmas et Volcans at Clermont-Ferrand, of which the Volcanology group has taken the lead in most of the recent work on the region, and coordinates the projects deriving from around ten international collaborations.

University	Country of origin	Topic
Edinburgh / Reykjavik	United Kingdom / Iceland	Lavas from the puy de Côme: study of the structure and texture of the lava flows
Edinburgh	United Kingdom	Inverted relief, erosion and uplift around the Chaîne des Puys
New Mexico Highlands	United States	Dyke intrusions and lava flows at Royat and Lemptégy
Uppsala / Durham	Sweden / United Kingdom	Incorporation and dissolution of xenoliths at Beaunit and Lemptégy
Arizona	United States	Evolution of basaltic scoria cones: relationship between the emplacement of lava flows and the growth of scoria cones
Tucuman	Argentina	Morphometry of the Chaîne des Puys
Prague	Czech Republic	Comparison of the volcanoes of the Chaîne des Puys with those of the Bohemian Massif
Gant	Belgium	Structure of the tephras deriving from the scoria cones of the Chaîne des Puys

Left: **acid maar, lac Pavin.** Right: **dome of the puy Chopine enclosed by the cresent-shaped cone of the puy des Gouttes** (Source: © EAVUC 2009)

Aerial view of the Chaîne des Puys seen from the north, with the Limagne Fault hidden by clouds
(Source: J. Way)

An important site for other natural and physical sciences

In addition to the volcanoes, numerous scientific discoveries and experiments have been carried out in the Chaîne des Puys and Limagne Fault region, and it remains a reference site for scientific monitoring and teaching purposes.

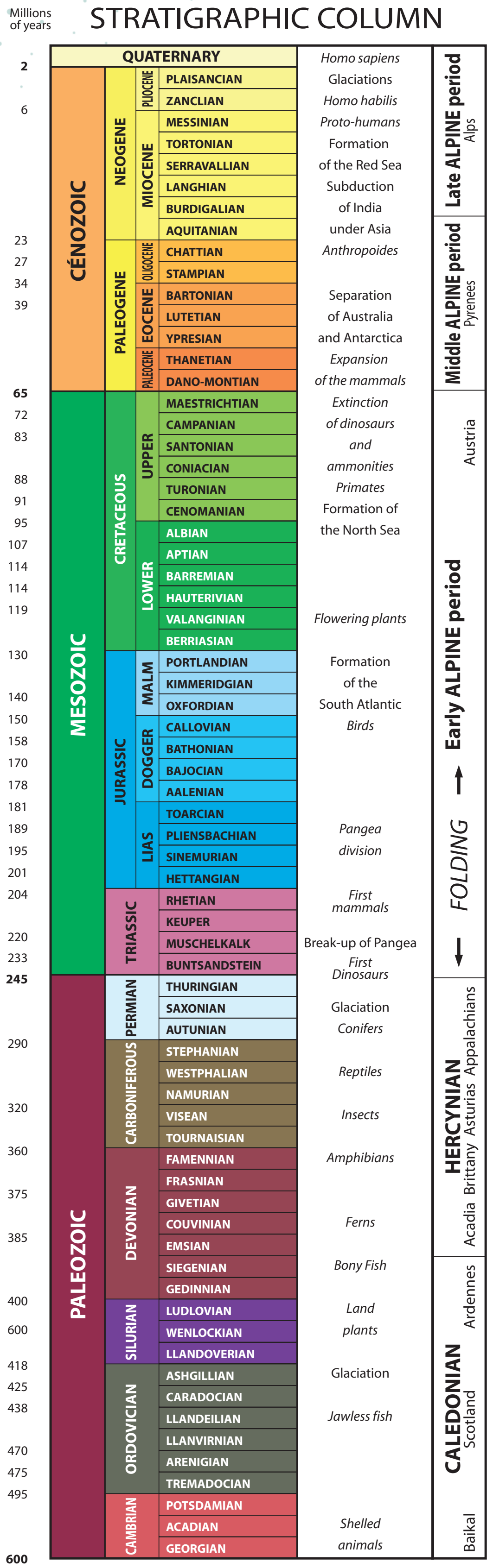
Pascal and atmospheric pressure:
One century before Guettard's discovery of the dormant volcanoes, the French mathematician, doctor, philosopher and theologian, Blaise Pascal, carried out his famous vacuum experiment between the summit of the puy de Dôme and the town of Clermont-Ferrand. This experiment aimed to shed light on the concepts of pressure and a vacuum, and was based on the work of Torricelli on atmospheric pressure.

Recording station for absolute gravity and the Observatory on the summit of the Puy de Dôme:
The measurement of 'absolute gravity' is vital in the detection of movements of the Earth's crust and its internal structure. The puy de Dôme is a site for the recording of reference measurements due to its central location within France, its distance from the ocean and the important gravimetric difference between the base station (Cézeau) and the summit, where there is a difference in altitude of over 1,000 m for a horizontal distance of 10 km.

Meteorology:
This discipline has an ongoing link with the summit of the puy de Dôme, whose altitude makes it an ideal place from which to observe clouds. The clouds derive from two main weather systems: one from the maritime westerly winds originating in the Atlantic, the other from north/northeasterly winds originating in the relatively more polluted north and central Europe. These contrasting weather systems give rise to varied meteorological and environmental conditions. The importance of this site was emphasised in 2008 by the purchase of a wind tunnel for research purposes, which allows clouds (water droplets and ice crystals) to be sampled in small quantities under natural conditions.

Magnetic reversals:
The head of the Observatory of the puy de Dôme from 1900 – 1909, professor Bernard Bruhnes, discovered the presence of magnetic reversals preserved in the Earth's rocks. In 1905 Bruhnes carried out observations on local volcanic rocks which enabled him to prove that lava was capable of recording the Earth's magnetic field. He was thus able to show that the polarity of the magnetic field had reversed several times in the past. The current polarity is towards the north, and carries the international term of the 'Bruhnes period'. In 1967 N. Bonhommet and J. Babkine discovered that the lava flows of Olby and Laschamp in the Chaîne des Puys had retained the record of a recent magnetic anomaly in which there was a partial reversal of the magnetic field, which had not previously been recognised elsewhere. This unusual phenomenon is now known as the 'Laschamp event', and has since been identified at five other points in the world in sediments of marine or lacustrine origin.

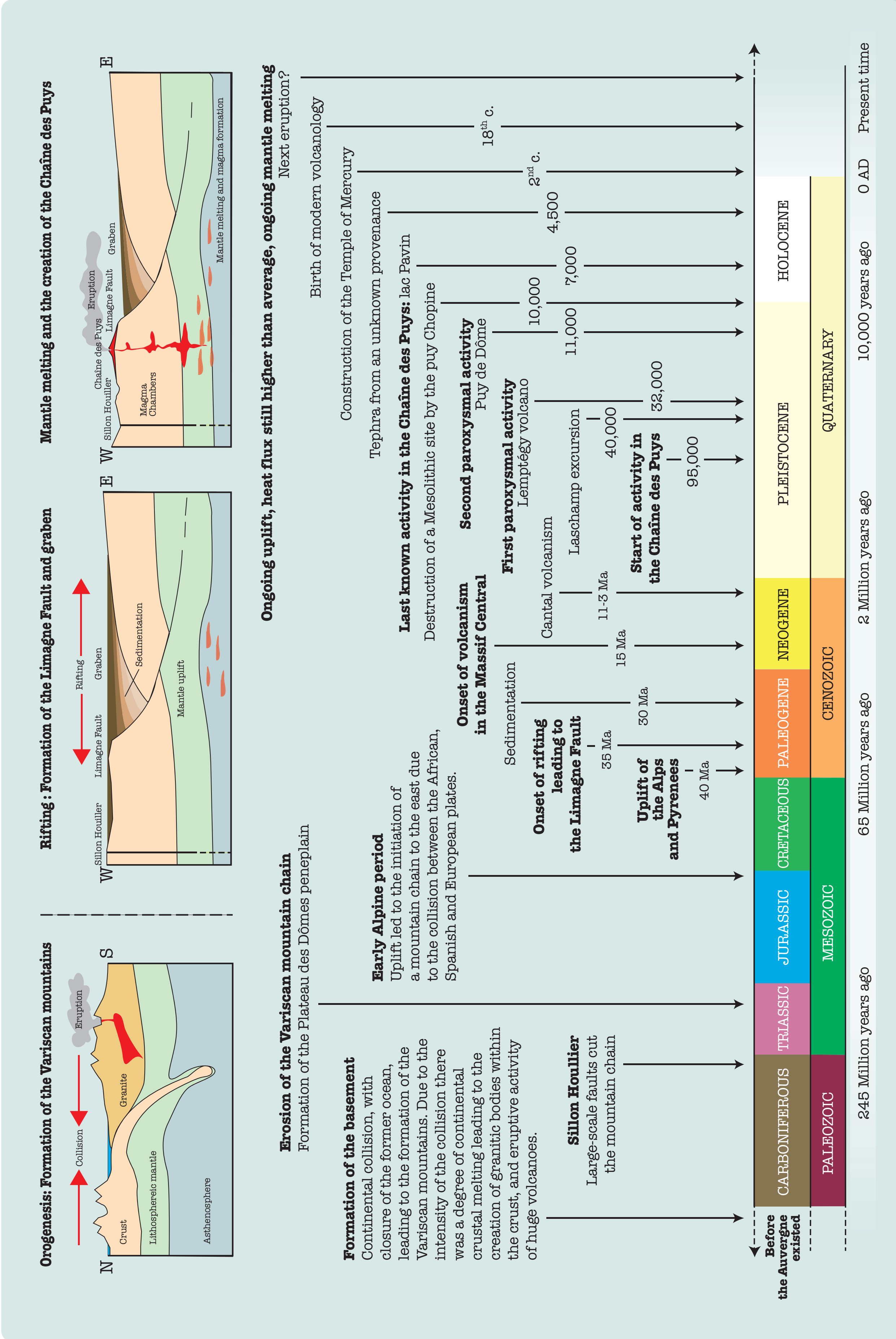
2.b History and development



The geomorphological variety present within the magmato-tectonic ensemble of the Chaîne des Puys and Limagne Fault results from the combined effects of the main structural processes which interact on the Earth, namely orogenesis, erosion, rifting and volcanism. The major stages in this region are as follows:

- Continental collision in the Palaeozoic which created the Variscan rocks (metamorphic and granitic rocks of Carboniferous and Permian age, 350-250 Ma) which now form the basement to the Chaîne des Puys;
- Formation of the Sillon Houiller fault, after the Variscan folding, which cuts across the Massif Central from north to south, passing close to Pontaumur. Basins along the fault were infilled with vegetation-rich sediment at the end of the Carboniferous (Stephanian, 300 Ma);
- 200 Ma of erosion starting from the Permian and continuing through the Mesozoic period, which completely modified the Variscan topography. By the end of the Mesozoic there was a peneplain which forms the current Plateau des Dômes;
- Uplift and rejuvenation of this plateau in the south due to the formation of the Pyrenees mountains, and to the east due to the formation of the Alps (Palaeocene – Eocene – Oligocene);
- Period of extension and crustal thinning related to subduction beneath the Alps (West European rifting), leading to the break-up of the granitic basement and the formation of the Limagne graben (Oligocene, 35-25 Ma);
- Sedimentation and marine incursions into the Limagne graben, with the region lying close to sea level;
- End of rifting (25 Ma), thereby avoiding full continental break-up and the installation of a new sea;
- Chaîne des Puys volcanism, which is located outside the zone of crustal thinning (Pleistocene to Holocene, 95,000 – 7,000 years ago).

Geological timescale
(Source: International Commission on stratigraphy, UISG)



Geological history of the Auvergne (Source: B. Van Wyk de Vries, Laboratory Magmas et Volcans, Clermont-Ferrand)

3 Justification for Inscription

3.a Criteria under which inscription is proposed

The proposed property corresponds to several aspects of criteria (vii) and (viii) of the Operational Guidelines for the Implementation of the World Heritage Convention:

The perfect crater of the puy Pariou, a strombolian cone
(Source: P. Soisson)

Criterion vii:
Areas of exceptional natural beauty
The numerous individual, vegetated edifices of the Chaîne des Puys together form a harmonious and picturesque landscape, their linear alignment highlighted by the Limagne fault which runs parallel, and means that they dominate the adjacent plain.

Criterion viii:
Significant on-going geological processes in the development of landforms
The Chaîne des Puys represent a type of landform which is unusual in western Europe. In addition they display almost the entire range of lava compositions, which is rare given the geodynamic setting, and constitute overall an exceptional example of the major volcanic phenomena.

Criterion viii:
Significant geomorphic or physiographic features
This magmato-tectonic ensemble is effectively a scale-model for structural geology, enabling the fundamental geomorphological principals involved in the development of topographic forms (morphogenesis), as well as the make-up of continents, to be observed in a small area, covering a period of 350 Ma.

Criterion viii:
Major stages of earth's history
Historically important site in the development of scientific research, where the experiments and observations carried out have enabled the discipline of volcanology to be defined and progress through the intensive work on volcanic forms and terrestrial processes. There is still vigorous research and educational work centred on this property.

3.b Proposed Statement of Outstanding Universal Value

The serene beauty of the landscape of the Chaîne des Puys is composed of around 90 small volcanic edifices whose diversity contrasts with that normally associated with a monogenetic, aligned volcanic field. There are three factors which are used to define a volcanic province: age, chemistry and structural context. The Chaîne des Puys presents a unique combination of these three characteristics.

The Chaîne des Puys ensemble is distinguished by an unusual and paradoxical association of a boundary fault, the Limagne Fault, with an alignment of volcanic edifices which appear to parallel it, despite the fact that classic tectonic scenarios have the magma rising where the crust has been preferentially thinned. In addition, all the basic volcanic forms are represented in the Chaîne des Puys, this uniqueness being due to the differentiated nature of the lava which has given rise to the visual variation in the shapes of the volcanoes. This chemistry, which is outstandingly rich given the geodynamic continental rift context, results from a complex system of magma chambers. However, it is the arrangement of the edifices within the Chaîne des Puys which qualifies it for international status: numerous volcanic fields exist world-wide, but they are either made up of randomly dispersed edifices, or, if there is an alignment, then the edifices are almost exclusively strombolian cones, which are the most widespread volcanic forms in the world. Such volcanic fields are found in Mexico, China, Madagascar and Spain, but none of them comprise such a regular alignment, nor show such variety, density or freshness as that of the Chaîne des Puys. This volcanic chain, which is on a human scale, in effect demonstrates in miniature an outstanding range of all the classic volcanic phenomena and their associated products. Taken individually these phenomena are not exceptional, but it is their concentration into one volcanic episode which makes this property exceptional.

The Chaîne des Puys is also rich in terms of geodynamics. The major processes which explain the structure and nature of the earth's crust are combined within a relatively small area (around 508 km^2): orogenesis, erosion, rifting and volcanism.

Thus the site comprises an eroded mountain basement, a Carboniferous strike-slip fault, a normal fault and a monogenetic volcanic field.

The geological eminence of this magmato-tectonic ensemble of the Chaîne des Puys and the Limagne Fault has been recognised since the 18th century. It has subsequently aroused interest in the scientific community on an international scale, and is one of the birthplaces for modern volcanology and historical science. Far from having exhausted subject matters for research, the complex geology of the Chaîne des Puys continues to attract researchers from around the world, and is also a valuable learning ground for school children and the general public. In addition to the volcanism, numerous scientific discoveries and experiments have taken place in this region.

Conclusion

The Chaine des Puys, which comprises a large number of volcanic edifices grouped together within a relatively restricted geographical area, aligned parallel to the Limagne Fault, is an impressive example of intra-continental fissure volcanism, all the more outstanding for the intact nature of the volcanoes and the freshness of the rocks. It also serves as a model in which the large-scale dynamic processes of continental formation and break-up can be seen, and due to its easily accessible and observable 'human scale' the Chaine des Puys is not just a beautiful landscape, but provides a first class magmato-tectonic, educational and epistemologic site. The geological qualities of the proposed site, linked to ongoing scientific research and educational development, correspond to criterion (viii), which calls on sites '*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*'. In addition the notable natural beauty of the landscape has inspired writers and artists, and has attracted famous visitors from the 18th century onwards (criterion vii).

3.c Comparative analysis

The unique Chaîne des Puys site, set in a geodynamic context which is itself unique, is outstanding in terms of:

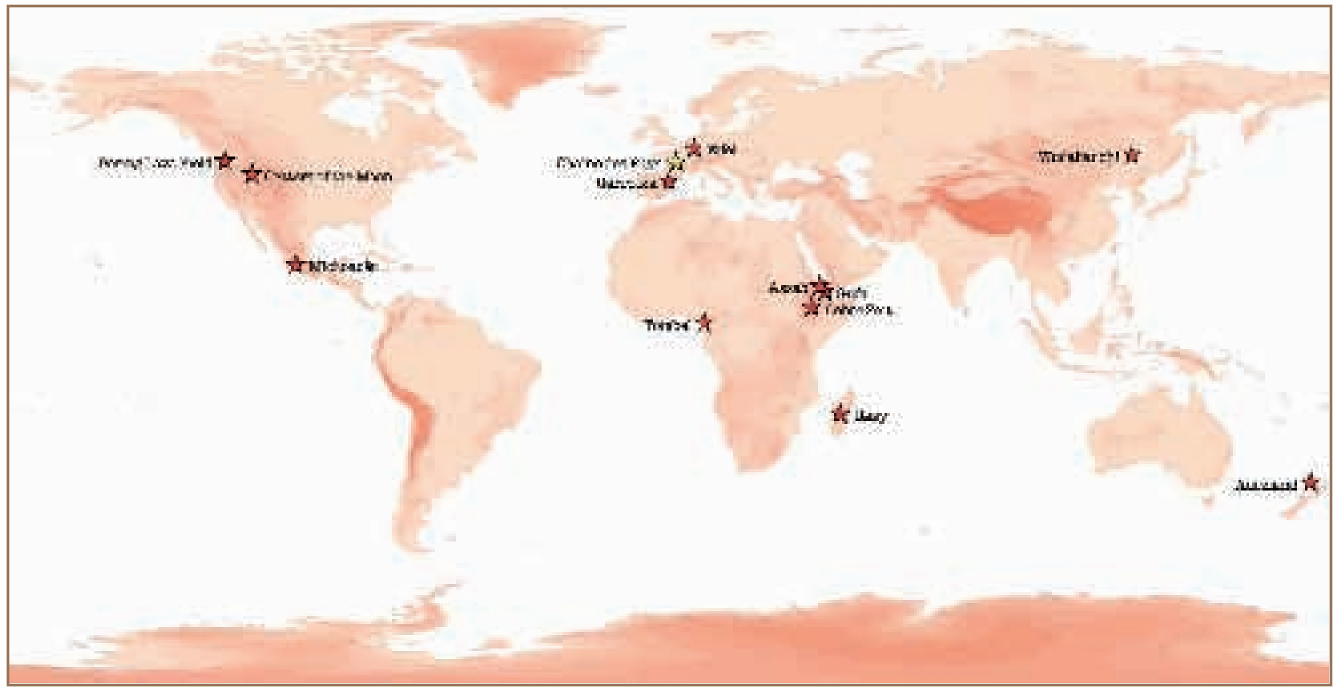
- volcanology;
- structural setting;
- scientific research.

The IUCN thematic study (World Heritage Volcanoes: A Thematic Study, 2009, n°8), which aims to guide future inscriptions on the volcanic sites list, distinguishes several volcanic classifications, mainly based on the nature and eruptive style of the volcanic provinces (polygenetic/stratovolcano or monogenetic), the lava chemistry and resulting flow reliefs, as well as the geotectonic environment and geostructural context. On the basis of these characteristics a large number of volcanoes can be eliminated from this comparative study, notably those which:

- are at the edge of tectonic plates rather than being in an intra-continental setting;
- are polygenetic or centred around a large, main edifice rather than in a monogenetic field like the Chaîne des Puys.

There are rare examples of individual monogenetic edifices, but the majority of this type of structure occurs in 'fields'. Monogenetic fields are often found as secondary structures on the flanks of stratovolcanoes:

- large-scale shield volcanoes such as Mount Halla on the island of Jeju in the Republic of Korea;
- strombolian cones such as Mount Etna in Sicily, on which there are 250 small monogenetic cones;
- in the centre of calderas where there is a 'rift zone' formed of a series of linear faults, such as on Teide volcano, Tenerife, Spain.



Map of the intracontinental monogenetic volcanic fields
(Source: Conseil général du Puy-de-Dôme)

Comparison with the Quaternary sites already inscribed on the World Heritage List

	Virunga National Park (In danger since 1994) Democratic Republic of Congo	Hawaii Volcanoes National Park United States	Tongariro National Park New Zealand	Shiretoko Japan	Volcanoes of Kamchatka Russia	Air and Ténéré Natural Reserves (In danger since 1992) Niger	Aeolian Islands Italy	Pitons Management Area Saint Lucia	Teide National Park Spain	Jeju Volcanic Island and Lava Tunnels Republic of Korea
Outstanding Volcanic qualities	Intra-continental volcanic ensemble, but composed of 9 active stratovolcanoes	2 most active stratovolcanoes in the world: changing landscape Emblematic of hotspot volcanism	Large active volcanic chain over a length of 2,500 km, essentially andesitic stratovolcanoes	Typical island arc chain of stratovolcanoes: subduction volcano systematics	Huge volcanic peninsular resulting from subduction, wide variety of volcanoes and forms. Active stratovolcanoes and seismicity	Cenozoic volcanism notable for its intrusive complexes and erosion features	Volcanic archipelago: subduction volcanism Stratovolcanoes	Volcanic landscape island arc, subduction zone	Vocanic landscape island arc, stratovolcano, subduction zone	Network of lava tunnels and shield stratovolcano and parasitic scoria cones built above a hotspot
Outstanding structures	Associated with the East African Rift, an example of a major fault, but located directly on the fault, following the classic tectonic model									
Exceptional science and educational value		Type volcanic site: birthplace of classic research methods and volcanological terminology					Reference site for volcanology, gave its name to 2 eruptive styles, highly important site for volcano surveying		Accessible volcanic ensemble located within a relatively limited geographical area, volcanological history of the 19th century	

Comparison with other intra-continental monogenetic volcanic fields worldwide

Name	Number of edifices	Diversity	Age & integrity	Area	Statovolcano
Wudalianchi China (Tentative List)	Fourteen cones	Limited : basaltic scoria cones, lava flows, dammed lakes	12 Pleistocene volcanoes + 2 very well preserved 300 years old volcanoes		
Auckland New Zealand (Tentative List)	Around fifty edifices	Maars, shield volcanoes and scoria cones (no domes)	Pleistocene (140,000 years) to Holocene (600 years) Altered site: the majority of the cones have been partially or entirely exploited for extraction of their products	29 km in length	Rangitoto
East Eifel Volcanic Field Germany	240 edifices spread over three volcanic provinces: East, West and High Eifel	Phonolitic domes, scoria cones, lava flows, tuff rings, caldera (Laacher See), maars	Pliocene - Pléistocene - Holocene The majority of the volcanoes in the Eifel field are old and very eroded Protection and management: Geopark and National Park Nature Reserve	2,000 km²	Polygenetic edifices
Garrotxa Spain	Around fourty edifices	Limited: scoria cones, lava flows	Pleistocene – Holocene Unaltered morphology, minor exploitation through quarrying, but limited by the establishment of the Garrotxa National Park	120 km²	
Michoacán Mexico	More than 1,400 lava exit points (edifices and flows without cones)	Mainly scoria cones and lava flows, but there are also small shield volcanoes, lava domes, maars and ring cones scattered within the province	From the Pleistocene to historic eruptions (eg. Paracutin 1943-1952): unequal integrity of site preservation	200 km x 250 km, 50,000 km²	Tancitaro and polygenetic edifices
Boring Lava Field United States	Around thirty edifices	Limited: scoria cones and small shield volcanoes	Pliocene – Pleistocene: ancient and eroded volcanoes	21 km in length	
Craters of the Moon United States	Around twenty five edifices	Limited: basaltic scoria cones and lava flows	Holocene Young volcanism, fresh morphology	45 x 2-8 km	
Gufa Eritrea/Djibouti	Around thirty cones (from satellite photos – little precise information as the site has not been well studied)	Limited: basaltic scoria cones and lava flows	Holocene, date of last eruption unknown Integrity not known		Mousa Alli
Assab Eritrea	Several tens of cones (from satellite photos – little precise information as the site has not been well studied)	Limited: basaltic scoria cones and lava flows	Holocene, date of last eruption unknown Integrity not known	90 x 55 km	Polygenetic edifices
Debre Zeit Ethiopia	Tens of scoria cones and maars	Limited: scoria cones and maars, the latter mostly filled by lakes	Holocene Integrity not known		Bishoftu
Tombel Cameroon	Tens of scoria cones and 3 maars	Limited: scoria cones and maars, the latter mostly filled by lakes	Holocene Young, non-vegetated morphology		
Itasy Madagascar	Around ninety edifices	Scoria cones with flows, trachytic domes, explosion craters	Oligocene – Pliocene Well preserved morphology despite their age	30 km in length 400 km²	Ankara

The only site which is really comparable on a worldwide scale is Itasy on the island of Madagascar. Itasy is a much older massif (Oligocene to Pliocene, 27.9 – 2.86 Ma), whose geodynamic context remains unclear (possibly intra-continental) and poorly studied (J. CHOROWICZ, J.M. BARDINTZEFF, G. RASAMIMANANA, P. CHOTIN, C. THOUIN, J.R. RUDANT: *An approach using SARS ERS images to relate extension fractures to volcanic vents: examples from Iceland and Madagascar*, Tectonophysics, 1997). There are striking similarities between the two sites, such that Itasy has been nicknamed 'The Chaîne des Puys of the Indian Ocean' (R. BATTISTINI: Le massif volcanique de l'Itasy, Annales de Géographie, 1962; S. MONTAGNAN and E. PONS, *Le Massif Central de l'Itasy*, Réunion University, 2008). Over a length of around 30 km, and covering an area of around 400 km², the equivalent of the central part of the Chaîne des Puys, there are some 90 edifices, comprising scoria cones and their lava flows, trachytic domes and explosion craters varying in age from the Oligocene to the Pliocene. As in the Chaîne des Puys, the pelean domes are concentrated in the central zone. Another similarity is that the explosion craters are the last physical expression of volcanic activity (cf. Pavin lake in the Chaîne des Puys). However, even though the morphology is representative of similar activity, the Itasy volcanics are much older, and therefore relatively more eroded, and have been the subject of very few publications.

An impressive ability to fill several of the existing gaps in the World Heritage Volcanoes List

The thematic study carried out by the IUCN, entitled '*World Heritage Volcanoes: A Thematic Study* (IUCN World Heritage Studies, 2009, n°8), highlights (p.32) the gaps which should ideally be filled in order to achieve a balanced Volcanoes List.

The Chaîne des Puys contains several of the features signalled as important but missing from the World Heritage Volcanoes List, which aims to represent the full range of volcanic phenomena in areas which are accessible to the general public.

Pelean dome (puy de Dôme) in the background, with a scoria cone with nested craters in the foreground (puy de Côme)
(Source: D. Pourcher)

Volcanic features identified as poorly represented or missing by the IUCN	Characteristics of the Chaîne des Puys and Limagne Fault site
Fissure volcanoes	Alexander McBirney and Jacques-Marie Bardintzeff, in the 2nd edition of their work, Volcanology (2000) cite the Chaîne des Puys as a type example of a fissure system
Tuyas, hyaloclastic rocks (hills which are volcanic in origin, formed during sub-glacial eruptions)	In the region of the Pavin group there are pillow basalts formed under the ice of the Sancy and Mont Dore volcanoes, a perfect example of a passage zone Many hydrovolcanic characteristics associated with frozen soil, such as the collapse of the Gravenoire, the hyaloclastites of Roca Neyra, the pepperite intrusions at Châteaugay (rootless cones)
Continental Flood Basalts	The Chaîne des Puys, the Cézalier and the pre-Mont Dore can be considered as a small-scale flood basalt province: all the characteristics are united here, with a reduced volume
Large ash flows and ignimbrite sheets/plateaus	The pyroclastic flow deposits originating from the puy Chopine, Killian and the trachy-andesitic maar of Pavin, and the ash-fall deposits from the puy de Nugère, have covered several thousand hectares in the Limagne basin, as well as creating small pyroclastic flow plateaus in the Chaîne des Puys
Intrusive landforms (exposed in relief due to erosion)	Intrusive landforms: inverted relief of Gergovie, exposed chimneys and dykes at Lemptégy, eroded lava flows from the puy de la Vache at St-Amande-Tallende
Basaltic plains Silicic volcanic field	The Chaîne des Puys is an elevated basaltic plain with silicics (trachytic domes), and shows a complex intermingling of compositions and morphologies. Provides a geological model with numerous and varied characteristics including plateaus, volcanic fields and a rift
Continental rifts	The Chaîne des Puys magmato-tectonic ensemble is aligned parallel to the Limagne boundary fault, which it appears to follow despite the former not being in the zone of crustal thinning
Iconic sites	Historically and internationally renowned for its aesthetic, scientific and educational qualities, the Chaîne des Puys has all the requirements for an iconic volcanic site
Monogenetic volcanic fields	Intra-continental monogenetic field which is outstanding in the number of edifices (more than 90), their variety (all the classic volcanic forms are represented), their good state of preservation, and their alignment, located in an overall rich geological setting

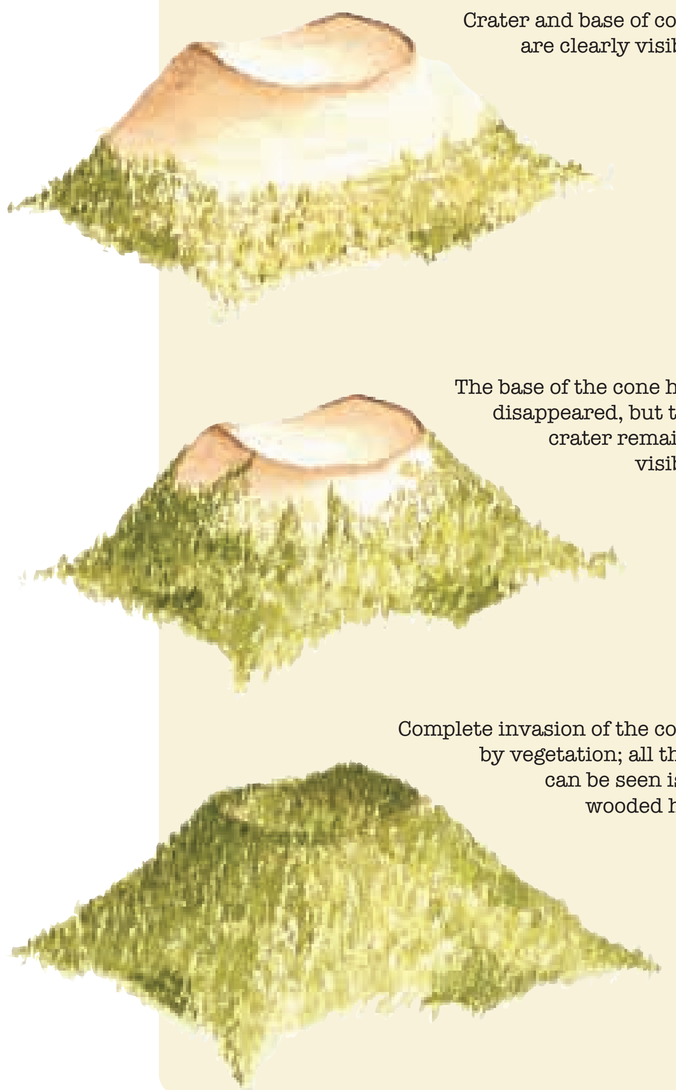
3.d Integrity and authenticity

This region has been the object of long-term, united management, and its preservation is ensured through the limitation of housing and control of erosion. This has enabled the original forms of the volcanoes to be conserved. Nevertheless, the many activities practiced within the property need to be reconciled with the protection of this potentially vulnerable landscape in order for it to retain its beauty.

4 Protection and management

4.a Factors affecting the Property

Since the property already carries a national classification, there are strict rules in place to prevent any major change to the landscape. However, as for all landscapes, it is not possible to guarantee the permanence of the natural equilibrium. For this site there are three main threats which need to be guarded against: the loss of its visual identity, physical degradation and risks inherent to the nature of the geology.



Process by which the inherent landscape is masked by vegetation
(Source: PNRVA)

Preservation of the landscape

The value of the Chaîne des Puys lies in the fact that the shapes of the volcanoes are manifestly clear thanks to being located in a relatively open landscape, and the views are magnificent either from the summits of the puys themselves, or from more distant viewpoints. The upkeep of these open areas, which are threatened with falling into disuse due to the decline of agriculture/pasturage in the region, is strategically important for the overall beauty of the property.

Upkeep of the physical integrity

During the 19th and 20th centuries the Chaîne des Puys was industrially exploited for its volcanological deposits, which has impacted on the physical integrity of certain of the smaller puys. There are still three active pouzzolane quarries in the Chaîne des Puys, spread over two sites:

- one quarry in the puy de la Toupe, in the commune of Aurières;
- two quarries in the puy de Tenusset, in the commune of Saint-Ours-les-Roches.

Erosion

Due to the strongly porous nature of the volcanic soils, and the material of which they are made up, these soils are very susceptible to wind erosion when they dry out, or to liquefaction when they become too wet. They are also degraded by the tourists who pass over them, and those whose sports or hobbies take them into the Chaîne des Puys. A widespread publicity campaign has been launched to inform people of the threats from erosion, and extensive work has been underway since 2006 to stabilise paths and endangered areas, carried out by the Regional Natural Park of the Volcanoes of the Auvergne.

4.b Protection and management of the Property

Ever since the end of the 19th century, with the discovery of the ruins of the Temple of Mercury on the summit of the puy de Dôme during the building work associated with the construction of the meteorological observatory, increasingly extensive protections have been put in place for the Chaîne des Puys and Limagne Fault region.

- **1889:** Classification of the remains of the Temple of Mercury as a historic monument;
- **1933:** Classification of the summit of the puy de Dôme (following the law of 1930);
- **Ministerial orders of 1959 and 1962:** Classification of the puys de Lassolas and de la Vache;
- **Ministerial order of 1972:** Inscription of the Chaîne des Puys onto the List of Classified Sites;
- **October 1977:** Official creation of the Regional Natural Park of the Volcanoes of the Auvergne;
- **26 September 2000:** classification of the Chaîne des Puys as a Natural Monument by ministerial decree (following the law of 1930);
- **Since 2005:** Campaign to promote the value of the Chaîne des Puys;
- **2003-2008:** Campaign to achieve the designation of Grand Site for the puy de Dôme;
- **15 January 2008:** attribution of the title Grand site de France® to the puy de Dôme.

4.c Management plan and key indicators for measuring state conservation

In the framework of this World Heritage Property project the people involved with the planning and science of the site at various institutions, as well as those representing users of the site, have contributed to the setting up of a strategic management plan for the Chaîne des Puys and Limagne Fault ensemble. Almost the entire property is contained within the Regional Natural Park, and it is additionally protected by a Forestry Charter, by the fact that it coincides with a Natura 2000 zone, and because it contains classified or inscribed sites. The management plan which covers the whole of the proposed property focuses on four main themes: governance, landscape, tourist potential and knowledge of the property, incorporating in addition various projects launched by different project managers.

The basaltic maar of Tazenat, on the northern margin of the Chaîne des Puys
(Source: D. Pourcher)

Type of monitoring	Means of evaluation	Objectives	Sources	Groups involved	Frequency of checks
1. Governance of the property					
Evaluating countryside usage	Evolution of the urban planning document; agricultural, pastural and forestry matters; elimination of black spots in the countryside	Meet regulations for the management of the region; fight excessive reforestation of the landscape; preservation and improvement of the quality of the landscape	Local government of the Auvergne region (State services); body responsible for agricultural interests in the department; groups working with/on the land	Local government of the Auvergne; property manager	Annual
Reconciliation of the varied land usages	Number of meetings with those involved	Maintaining traditional practices and the cohabitation of land usages in the property	Regional Natural Park of the Volcanoes of the Auvergne (PNRVA)	Property manager	Annual
2. Knowledge of the property					
Scientific activity related to the property	Number of theses, published articles and conferences	Improve and bring up-to-date the scientific findings and data for the property	Universities; laboratories; Regional Natural Park of the Volcanoes of the Auvergne (PNRVA)	Property manager	Annual
Overseeing the evolution of the landscape	Photo referencing; satellite photos; monitoring the urban occupation and land use; supervising quarries; monitoring vegetation cover	Preserve and improve the landscaped qualities of the property	Regional Natural Park of the Volcanoes of the Auvergne (PNRVA)	Property manager	Annual
Sharing information with the general public	Number of publications aimed at the general public; number of exhibitions, conferences and classes for the public	Encourage the sharing of information with the general public, and improve their understanding of the processes involved in the preservation of the patrimony	National body for education; Regional Natural Park of the Volcanoes of the Auvergne (PNRVA)	Property manager	Annual
3. Ensuring durable tourism					
Management of tourist information points and individual information boards in the property	Number of information points, signed pathways, information boards and multilingual information leaflets	Direct the majority of people to managed areas of the property, thereby protecting more vulnerable areas	Local Council (Conseil général), PNRVA, Regional Delegation for Tourism, Regional Committee for the Development of Tourism and the departmental tourist agency	Property manager	Annual
Evolution of the number of tourists visiting the property	Managing the entry-points to the property and counting the throughflow of people	Monitoring the number of tourists, and evaluating their impact on the integrity of the property	Local Council, PNRVA, Regional Delegation for Tourism, Regional Committee for the Development of Tourism and the departmental tourist agency	Property manager	Annual
4. Evolution of the landscape					
Management of the sign-boards	Defining the number of locations which require sign-boards; emplacement and integration of sign-boards into the landscape	Inform the general public while respecting the integrity of the landscape	Local Council; Regional Natural Park of the Volcanoes of the Auvergne (PNRVA)	Property manager	Annual
Evolution of slope profiles	Number of landslips, and erosion channels	Fight against erosion, channel formation and soil degradation: drain emplacement, re-vegetation, elimination of off-path detours, improved understanding of countryside-users	Regional Natural Park of the Volcanoes of the Auvergne (PNRVA)	Property manager	Annual