Justification for inscription

Fig 1. The nominated property within the West European Rift
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3.1.a Brief synthesis

A product of alpine folding, the West European Rift lies concentrically around this mountain arc, to which it is temporally and spatially connected. An emblematic segment of this rift, the Chaîne des Puys - Limagne fault tectonic arena, is located in central France, in the heart of the Auvergne-Rhône-Alpes region, and covers an area of 242 km^2. (Fig. 1)

Set in a natural theatre, it is an exceptional illustration of a major phenomenon of the Earth's history: continental break-up. An integral part of the plate tectonics cycle proposed by Tuzo Wilson, this rifting phenomena is remarkably manifested in the landscape by an unparalleled concentration of its main components: faulting, downthrow and sedimentation, alkaline volcanism and uplift. Each of these essential stages is present and is clearly represented by the major attributes of the nominated property (from oldest to youngest) (Fig. 2):

The Plateau des Dômes, remnant of the ancient Hercynian mountain chain. This mountainous relief, linked to the formation of the Pangean supercontinent, was completely planed down by 350 million years of erosion, before being faulted, uplifted and tilted during the formation of the West European Rift.

The Limagne fault escarpment. This 30-km-long feature is a testament to the continental break-up, subsidence and sedimentation which took place between 37 and 25 Ma (million years ago). The fault separates the Plateau des Dômes, raised to a height of 700 m, from the adjacent broad subsidence basin (the Limagne graben). During this period, the continental basement to the East subsided progressively by nearly 3 km, thus forming the Limagne graben. During its formation, the graben was infilled with sediments, which maintained a similar surface height to the plateau. A portion of the sediments was then removed following uplift, exposing the surface trace of the fault, and revealing the characteristic sedimentary sequence which catalogues the rifting history.

Inverted relief of the Montagne de la Serre. This Pliocene (~ 3.4± 0.3 Ma) volcanic lava flow of around 9 km in length was initially emplaced on the valley floor, straddling ancient basement material and the graben sediments. The regional uplift brought about erosion of the softer sedimentary rocks on either side of the lava flow. This long basaltic ribbon thus ultimately became a ridge feature (1 000 m in height at its origin, and 600 m at its furthest point), making it an important testament to the uplift phase.

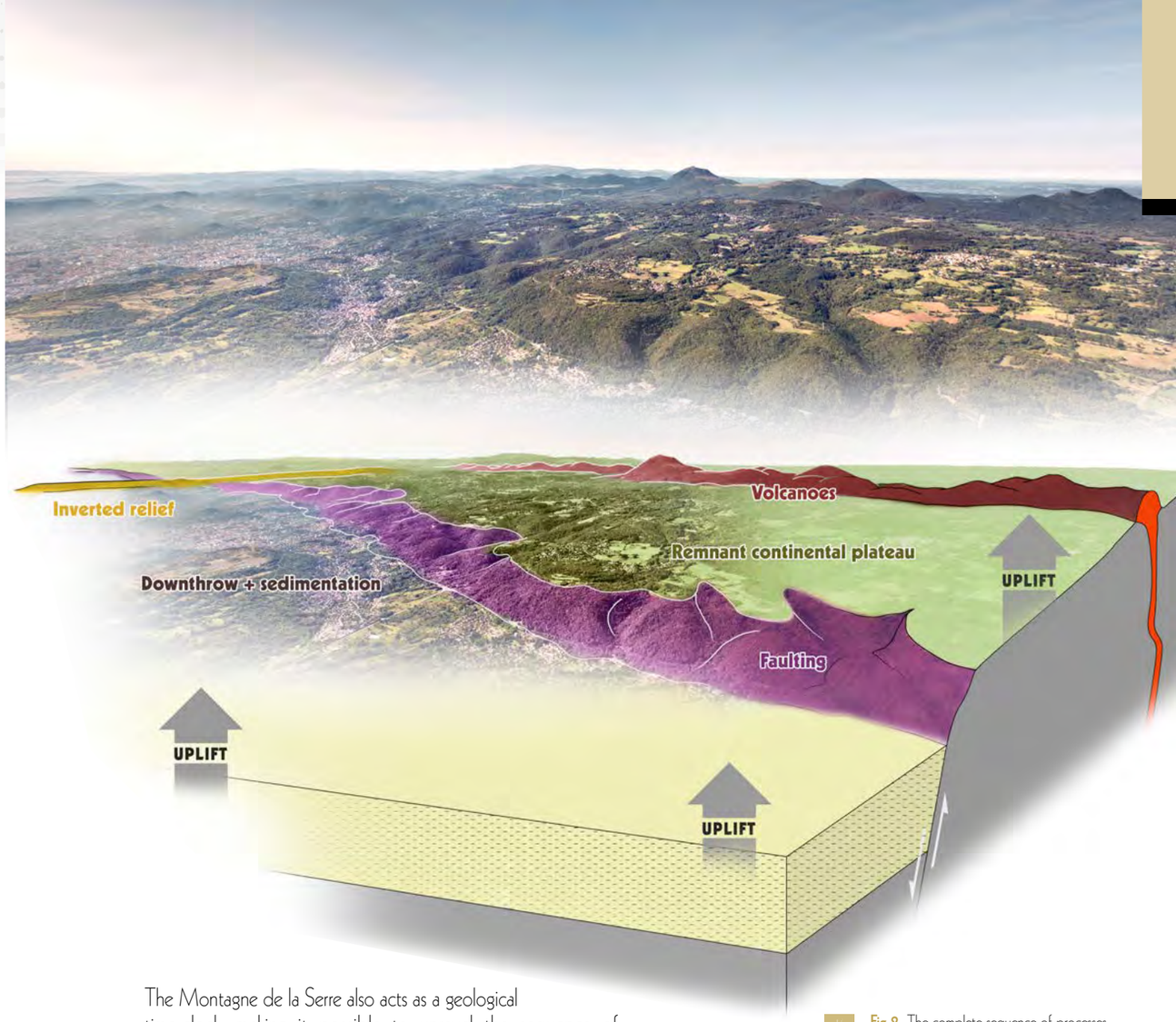

Fig 2. The complete sequence of processes which give rise to continental break-up. All the features are clustered in the Chaîne des Puys - Limagne fault tectonic arena.
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The Montagne de la Serre also acts as a geological time-clock, making it possible to unravel the sequence of geological processes. Thus the fact that the lava flow is not cut by the fault, as well as its being preserved as inverted relief, confirms that the faulting and subsidence took place prior to its emplacement. It also signifies that the height of the sediments in the graben was similar to that of the surface of the Plateau des Dômes at the time of the lava flow formation. Finally, it shows that uplift and erosion followed its formation, and that these were generalised throughout the Massif Central.

The volcanic alignment of the Chaîne des Puys. These eighty Quaternary (95,000 – 8,400 ya) edifices are direct proof of alkaline magmatism, an integral stage of continental break-up. They constitute both the most northerly and the youngest of the major volcanic bodies of the French Massif Central. They are aligned along a North-South axis 32 km in length and 4 km wide, parallel to the Limagne border fault, which they reproduce visually. This link between volcanism and tectonics is a universal aspect of the rifting process. It is found elsewhere in the world, but never with such clarity. In addition, the diversity of the magmas, shown by the range of edifices formed, demonstrates the great upheaval inflicted on the continental basement by the rifting process.

In conclusion, the Chaîne des Puys - Limagne fault tectonic arena presents a complete sequence of the processes which give rise to continental break-up: faulting of ancient continental basement and formation of a subsidence graben, melting of rocks at depth to generate alkaline volcanism along faults at the surface, and large-scale thermal uplift (Fig. 2 and 3). The concentration and distribution of the site's attributes within a single area provide an overview of the whole rifting process. They also clarify the intrinsic links between the features, as well as their chronology.

While typical graben morphologies are found on the World Heritage List, such as the imposing landscape of the East African Rift, none of them illustrate the overall continental break-up process.

The Chaîne des Puys - Limagne fault tectonic arena is unequalled globally in terms of its completeness, density, and clarity of topographic expression, providing unique evidence of the genetic and chronological links between the rift features, making it an eminently representative site to illustrate continental break-up.

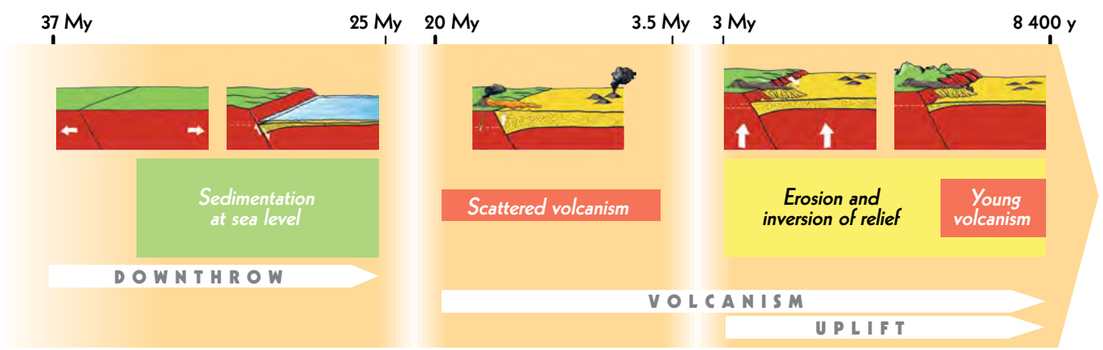


Fig 3. The timing of graben, sedimentation, volcanism and uplift in the Limagne rift
© From Michon and Merle 2001, modified - Drawings by Denis Poughon

3.1.b Justification for inscription under criterion (viii)

Continental break-up: a tectonic phenomenon which amply fulfills criterion (viii)

Plate tectonics is the major paradigm of Earth Sciences. This fundamental theory explains continental drift, the current make-up of the continents, as well as their past and future upheavals. The **complete plate tectonics cycle** was proposed by Tuzo Wilson (Fig. 4). It consists of the movement of continents, from their beginning as one large plate, called supercontinent, which broke up into several fragments that drifted apart from each other. Because this plate movement takes place around a sphere, the plates firstly split apart (**divergent phase**) then collide (**convergent phase**).

The divergent phase of the Wilson cycle involves initial thinning and faulting of the continent into two fragments which start to move apart (**continental rifting phase**). The definitive separation of these two continental fragments, which results in the opening of a new ocean, takes place after a transition period (**ocean-formation phase**) of several million years. During this latter phase, the two continental fragments are still united by remnants of the continental crust, which become increasingly eroded by oceanic magma. The resulting split, through which arises an inexhaustible supply of magma, eventually forms an oceanic ridge, covered by an ocean which separates the two newly created continents (**ocean-ridge phase**).

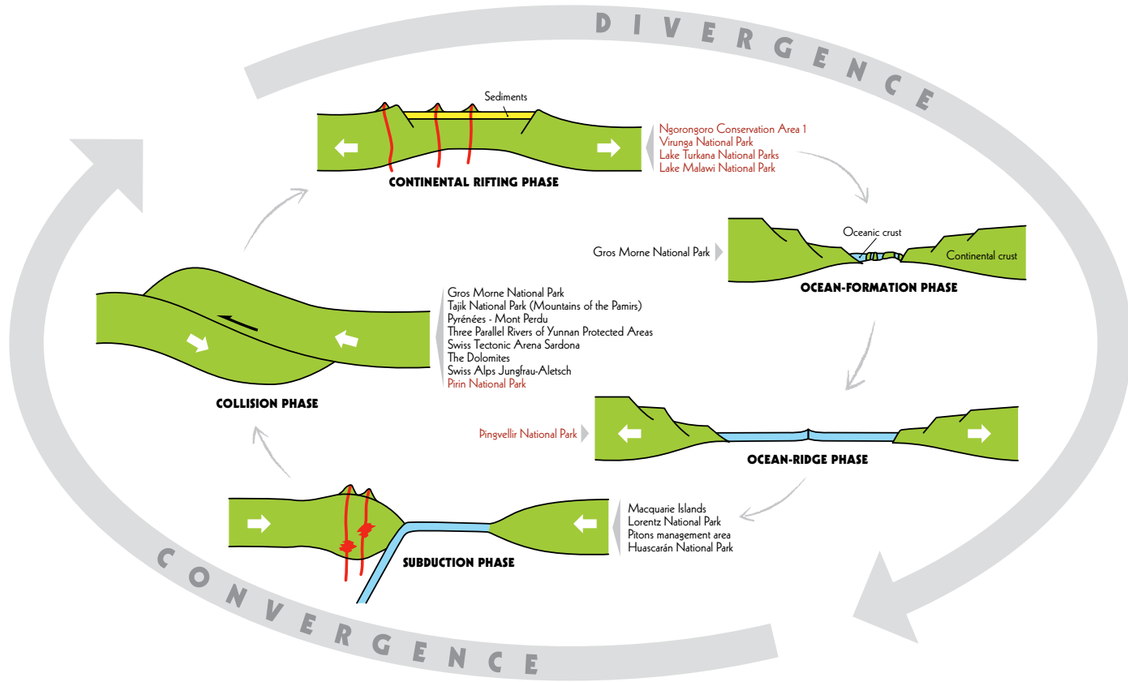


Fig 4. The complete plate tectonics cycle as proposed by Tuzo Wilson.

In black: properties specifically nominated on the World Heritage List for their tectonic values

In red: properties nominated on the World Heritage with a tectonic backdrop, but listed for other values

© CD63 from T. Wilson

Due to the spherical nature of the Earth, this divergence which began progressively at different parts of the globe, brought about the convergence of continental plates elsewhere. When two continental plates approach each other, the oceanic crust disappears gradually beneath the continental crust (**subduction phase**), progressively closing the intervening ocean. When the latter has completely disappeared, the continents collide and form a mountain chain (**collision phase**), thus **bringing the process full cycle to recreate a single plate or supercontinent**.

The most recent supercontinent to form was Pangea (~350 – 300 Ma) (Fig. 5), but scientists have established that there were at least two full cycles leading to the creation of a single large continent prior to this, each lasting several hundred million years: Rodinia (1 100 Ma) and Pannotia (600 Ma).

Fig 5. From Pangea to our seven continents.
© CD63

The World Heritage List recognises the importance of these tectonic processes linked to continental drift; it has chosen to illustrate the various stages of the Wilson Cycle via diverse sites inscribed under criterion (viii), focussing particularly on different aspects of continental collision (for example Pirin National Park, Bulgaria; Three Parallel Rivers of Yunnan Protected Areas, China; The Dolomites, Italy; Pyrénées - Mont Perdu, France; Swiss Alps Jungfrau-Aletsch, Switzerland; Swiss Tectonic Arena Sardona, Switzerland; and Tajik National Park (Mountains of the Pamirs), Tajikistan, etc.) (Fig. 4).

The IUCN's thematic study *Geological World Heritage: a global framework* (2005) also identified "tectonic and structural features" as one of the thirteen pertinent themes for inscription under criterion (viii), citing as examples "elements of global-scale crustal dynamics including continental drift" and "rift valley systems".

Exceptional illustrations of continental break-up fully correspond to criterion (viii). This stage of the Wilson Cycle is currently not represented on the World Heritage List, while collision is illustrated by numerous sites. The nominated property belongs to this category and can contribute to fill this gap.

The trinity of faulting, volcanism and uplift in the Chaîne des Puys - Limagne fault tectonic arena
© A. Ith

Description of the process of continental break-up

Continental break-up is characterised by a linked sequence of events whose end-result is the progressive separation of two continental segments. Although the sequence can vary according to the tectonic context of the incipient rift, the following characteristic features are always present (Fig. 6):

- **Extension** of the continental crust, which leads to **faulting** at depth and the formation of a collapse structure (graben). The boundary between the ancient basement and the graben is marked by one or more large-scale **bounding faults**. Often the graben is asymmetric and then the bounding fault is only present on one side. This is actually the most frequent case in the world. The graben is progressively filled by **sediments** following a typical sequence (detrital sediments – sandstones linked to erosion, then marly limestones formed in a lacustrine environment);

- **Melting of rocks** at depth generates **volcanism** along the fault traces at the surface. This volcanism is alkaline and can occur equally in the centre of the rift or on the rift shoulders. Increased complexity in the basement induced by the faulting also results in the production of **differentiated magmas** (through the creation of intermediate magma chambers);

- Broad-scale **uplift**. This thermal uplift results in **raised topography** (including the formation of **plateaus**) which in turn **increases erosion** and thus exposes structures testifying to this phenomenon, such as **inverted relief** and **groups of peaks at the same height**. **Marine sediments** found at high altitude and **plateaus tilted** away from the rift can also be indicators of this thermal uplift.

These three major phenomena (faulting, volcanism and uplift), together comprise a single unique process (continental break-up). They follow sequentially and are fully interlinked and interdependent. The scale of the rift system affects the proximity of the resultant features, but this interdependence can be seen in a number of characteristics of the site, notably alignments, differentiated magmas linked to faulting at depth, preferential erosion of sedimentary strata and inverted relief linked to volcanism and uplift.

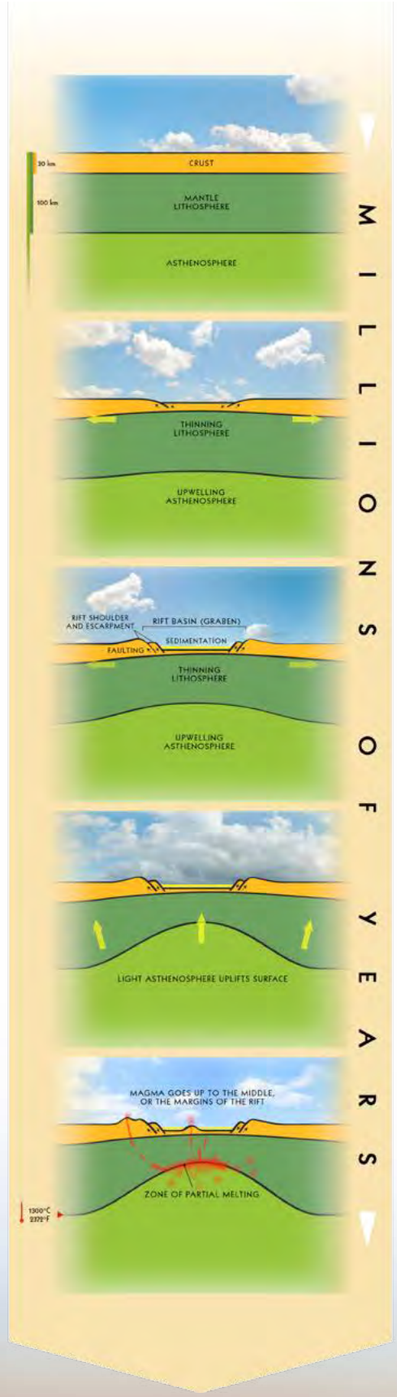


Fig 6. Continental break-up linked sequence of events.
© CD63

The Chaîne des Puys - Limagne fault tectonic arena: an exceptionally representative example of the process of continental break-up

Less that **ten major rift systems** are visible on the Earth's surface: the East African rift (EAR), the Dead Sea rift, the Baikal rift, the Basin and Range province, the Rio Grande rift, the Central American rift (CAR), and the Western European rift (WER), to which the Chaîne des Puys - Limagne fault tectonic arena belongs. The West Antarctic Rift, which is entirely covered in ice, can also be added to the list (Fig. 7).

Due to the scale of tectonic systems, which are often several thousand kilometers in length, it is **impossible to inscribe an entire rift system on the World Heritage List**. The strategy commonly followed for continental collision sites involves inscribing a selection of smaller, representative areas. Recognition of the heritage of continental break-up could use this same approach.

Each of the eight major rift systems can easily be divided into segments of an appropriate size, which can be taken as a basis for comparison with the Chaîne des Puys - Limagne fault tectonic arena.

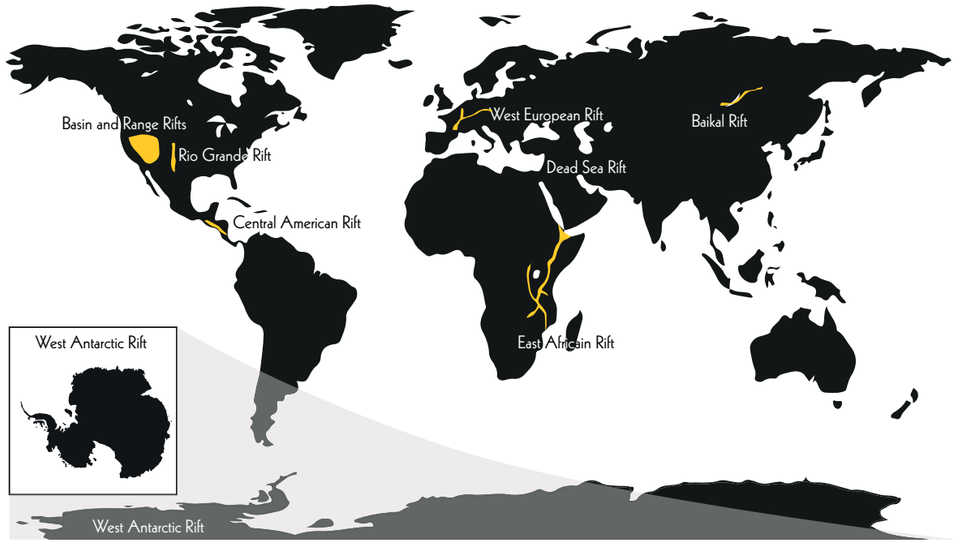


Fig 7. Map of the eight main continental rift systems
© CD63

A comparative analysis, presented in section 3.2 (p. 29), based on the expertise of specialists for each of the world's rifts, provides an overview of all the rift systems in order to select the most complete and representative segments and to compare them.

The Chaîne des Puys - Limagne fault tectonic arena, an emblematic segment of the Western European Rift, stands out on an international level because **it encompasses within a single perspective the entirety of the characteristic features of the vast and complex process of continental break-up**. Because of the scale of the mechanisms involved in this process, the

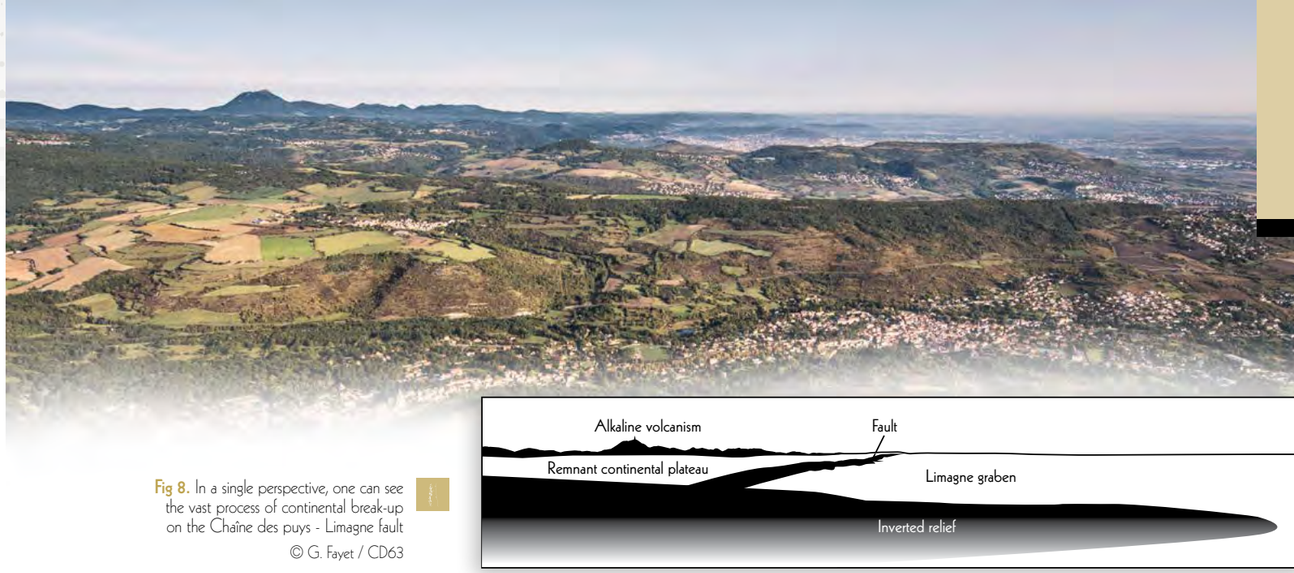


Fig 8. In a single perspective, one can see the vast process of continental break-up on the Chaîne des puys - Limagne fault
© G. Fayet / CD63

related landforms are often widespread and not visible at the same time. However, while being of equivalent size as other sites, the nominated property is exceptionnaly compact. It displays in a single perspective how the continental basement has been faulted, has undergone subsidence, provided a passage for uprising magma, and how the overall surface has been significantly uplifted (Fig. 8).

The site contains a marked fault scarp which forms a sharp boundary between the ancient continental plateau and the subsidence graben, the latter being almost completely filled with sediments. Alkaline volcanics formed inverted relief lava flows then the Chaîne des Puys at different stages during the rifting process, all of which are clearly visible in the landscape. The perfect alignment between the volcanic chain and the Limagne fault testifies to the intrinsic link which exists between magmatism and tectonics, in the same way that the broad diversity of the lavas at this site is a direct result of the upheaval in the basement caused by faulting. The large-scale uplift and subsequent erosion of sediments is clearly illustrated by the significant inverted relief features and the exposure of representative sedimentary sequences. The Montagne de la Serre, which straddles the basement and the sediment-filled graben, acts as a geological time-clock, making it possible to interpret the chronology of the features present within the context of the continental break-up.

Most of the rift segments are made of a **half-graben**, which is the most common subsidence structure. Few of them contain, within a single area, all of the landforms characteristic of the continental break-up process. It is rare to find the combination of faulting, volcanism and uplift as net as in the Chaîne des Puys - Limagne fault tectonic arena. The concentration, clear chronology and obvious interdependence of the nominated property's geological features are unparalleled in the world.

This complete rift sequence is imprinted on the landscape of the nominated property, which congregates in a unique way the distinctive and characteristic geomorphological elements that illustrate the whole process of continental break-up. This is one of the reasons why this site has served as a scientific reference from the 18th century for the study of the fundamental geological processes.

The Chaîne des Puys - Limagne fault tectonic arena is thus **an eminently representative example of the process of continental break-up**, which justifies its inscription onto the World Heritage List under criterion (viii).

3.1.c Statement of integrity

The nominated property contains all the elements necessary to express its potential universal value

As described earlier, the large scale of the rift segments makes it necessary to select the most pertinent zones to provide a **complete representation of this phenomenon**. The boundaries of the site thus encompass all the elements necessary to illustrate the characteristic manifestations of the process of continental break-up (cf. 3.1.b), as well as geological elements which testify to their fundamental interdependence. The perimeter thus contains:

The Limagne fault makes a major linear border with the sedimentary graben
© J. Damase

- A major linear border fault which clearly separates the old continental basement (Plateau des Dômes) from the large sedimentary graben at lower relief. It constitutes the characteristic sign of continental faulting and the formation of a large-scale subsidence basin which was progressively filled by sediments. The site also includes smaller-scale evidence of this process: tectonic striations, an outcrop of the fault plane, and sedimentary sequences characteristic of a rift edge (detrital sediments and sandstones followed by lacustrine marly limestones);

- The entire Chaîne des Puys volcanic alignment, with its fresh outlines, as well as Pliocene volcanic features such as the Montagne de la Serre. The eighty differentiated edifices and their associated flows provide a complete range of the alkaline lavas characteristic of rift volcanism. The Chaîne des Puys, and the earlier Pliocene volcanism, testify to the upheaval caused by the faulting of the continental crust at depth and the differential melting and fractionation of the ensuing rocks;

- A completely planed-off plateau, a relic of the old continental basement (ancient Hercynian Mountain Chain). The Plateau des Dômes forms the rift shoulder, and acts as a base for the volcanics. Its altitude of around 900 m demonstrates the regional uplift to which the whole area has been subjected. It is also tilted towards the exterior of the graben, providing further evidence for this uplift;

- A large-scale inverted relief feature 9 km in length: the Montagne de la Serre. The presence of inverted relief is a classic sign of regional uplift, and the subsequent erosion led to a progressive wearing away of the sedimentary basin. The Montagne de la Serre provides essential information as it straddles both the Plateau des Dômes and the Limagne graben, thus demonstrating the differential erosion between the old basement block and the subsidence basin. There is no perceptible difference in height in this lava flow as it crosses the Limagne fault, clearly indicating the chronology of the continental break-up: faulting preceded the Pliocene volcanism, and the uplift occurred afterwards.

The Montagne de la Serre, a text-book exemple of inverted relief
© H. Monestier

These fundamental attributes, as well as their intrinsic relationships (volcanic alignment paralleling the fault scarp, inverted relief straddling the fault but unaffected by vertical movement, and a continuous sedimentary sequence sealed in place by the lava flows) are all entirely contained within the site's perimeter.

The property thus comprises all the attributes necessary for a complete presentation of the phenomenon of continental break-up: it makes it possible to fully understand the diverse features that are linked to it, as well as their relationships and their chronology.

The ensemble proposed for inscription illustrates the effects the effects of the rifting on **Earth's surface and the landscape** on a large scale (marked faulting and subsidence of the continental crust, aligned and differentiated volcanics, distinct uplift) as well as on a smaller scale (sediments, differentiated lavas, outcrops, tectonic striations).

The fresh volcanic alignment on the Hercynian plateau
© G. Fayet

The dimensions of the site are such as to encompass the distinctive geological processes representative of continental break-up on a scale which makes it possible both to perceive and to preserve them

The perimeter of the nominated property has been chosen in order to represent the entire range of continental break-up processes while still respecting **conservation issues**. It provides **an unbroken line** encompassing only the geological elements of outstanding universal value, leaving those features which are less significant, altered or affected by development in the immediate environment or the buffer zone.

Like other rift segments studied in the comparative analysis, this site is obviously set in a broader tectonic environment (Fig. 9). This tectonic environment includes, in particular, other volcanic massifs affected by glacial erosion, at a distance of a few tens of kilometres, as well as a huge sedimentary basin. It was not suitable to include these, according to the *Operational Guidelines*, because:

- The intrinsic relationships with the more distant volcanics are not perceptible or scientifically proven. Further, due to their greater age, these volcanic massifs have been altered by glacial erosion and are thus less impressive than the Chaîne des Puys. Finally, they do not have the same rich diversity of lavas;

- In terms of the sedimentary basin, large sections do not comply with conservation regulations. Besides, the scale of the sedimentary basin is much greater (45 km wide), making it out-of-proportion with respect to the nominated property (14 km wide);

- The geological attributes of these volcanic massifs and the sedimentary basin are not highly significant, and cannot be designated as being of outstanding universal value.

The nominated property seen from the Massif du Sancy, 10 km away. The Limagne fault is barely visible, justifying a more restricted perimeter
© A. Ith

However, the sedimentary basin is clearly visible from the nominated property, which it adjoins, and the fault scarp (which lies entirely within the perimeter) is the most impressive illustration of the subsidence. In the same way, the other, more distant, volcanic massifs are visible from the site, providing broader insight into the overall magmatism.

In conclusion, the dimensions of a phenomenon such as continental break-up make it necessary to define a perimeter that is at the same time coherent, well-preserved and highly relevant to a World Heritage inscription. The zone proposed for inscription includes **all the archetypal expressions of the rifting process**. Located in the heart of a major segment of the West European Rift, it includes the most exceptional geological features, while also illustrating the major visual impact of this process on the landscape. Finally, the proximity and density of all the site's attributes facilitate understanding of their interactions and chronology.

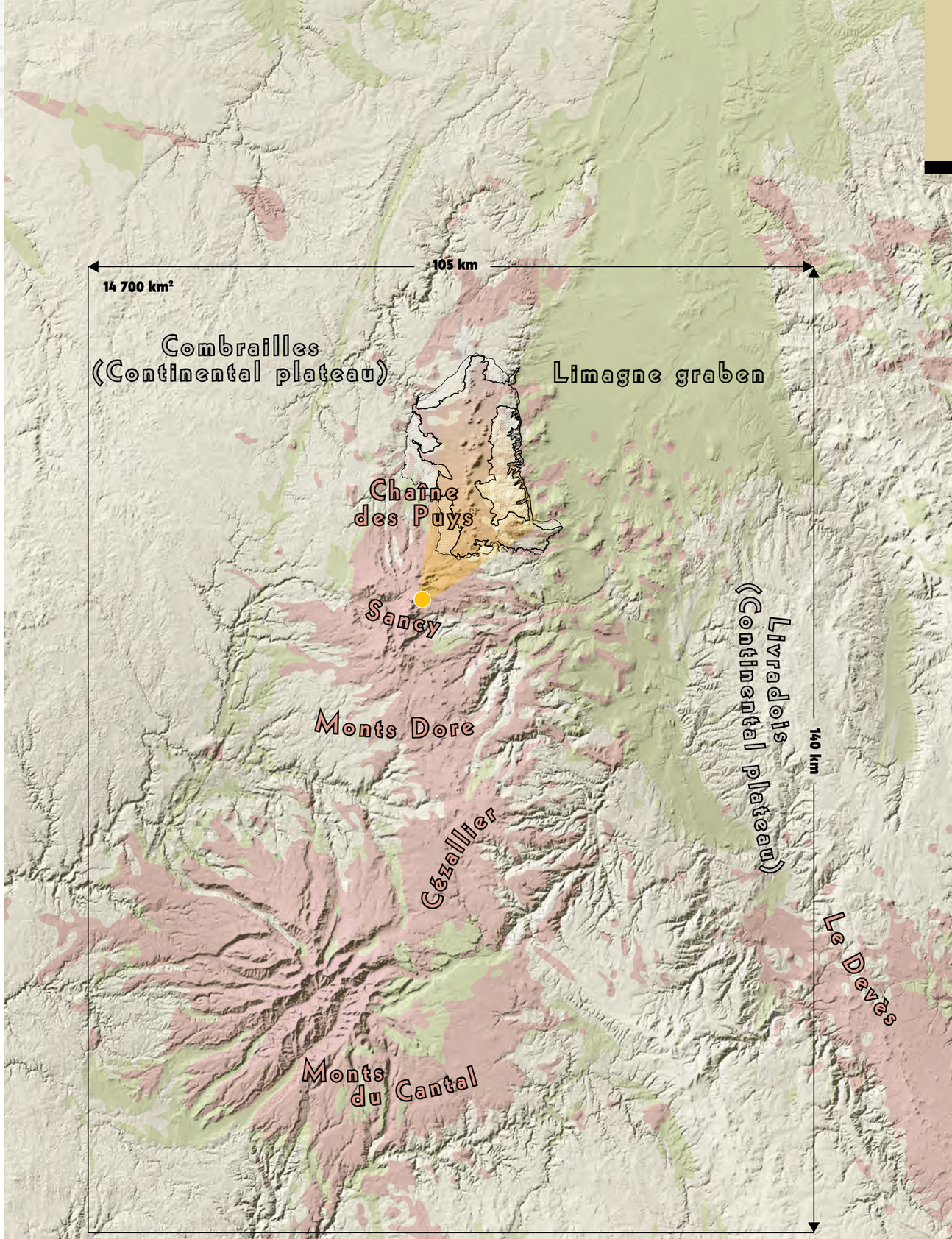


Fig 9. The broader tectonic environment of the nominated property. In Yellow, the picture perspective from the Massif du Sancy.
© CD63 from BRGM

The state of conservation of the nominated property meets the Operational Guidelines' requirements and the degradation mechanisms have been identified and are under control

The geological features included within the site's perimeter are **almost all intact**; they are protected from urbanisation; the erosion is very superficial and has not altered the structures themselves; quarrying activities concern only a very minor part of the nominated property. More generally, human impact has been very limited, and has in no way compromised the geological value of the Chaîne des Puys - Limagne fault tectonic arena.

The well-conserved nature of the site, despite its proximity to the urban area of Clermont-Ferrand, is linked to more than forty years of management measures and protection of the site by the State and local actors. This long-standing recognition of the heritage value of this region and the desire to preserve it constitute the major guarantees in maintaining the site's integrity over the long-term.

Four major threats have been identified within the site, which have all been made the object of preventative and corrective procedures for the last few years, both through national legislation and by the measures defined and implemented by the management plan which is part of the inscription process:

Quarries

National legislation prohibits the opening of any new quarrying activity within the classified site of the Chaîne des Puys. The two pouzzolane quarries which are still active, **corresponding to a surface area equivalent to 0.1% of the site, have been temporarily excluded from the proposed perimeter**, until their definitive closure and complete rehabilitation. An official commitment was made by the Minister of Ecology on 9 October 2015 to prevent the renewal of the quarries' extraction permits, which expire in 2018 and 2030.

Urbanisation and the communication network

The site is only very modestly urbanised: 4 000 inhabitants in the central zone, equivalent to 16 inhabitants per km², and less than 21 000 inhabitants in the buffer zone. Its geography and climate make it less attractive than the more residential Limagne plain. Effective and suitably-adapted protection measures are currently in place: there are **building restrictions on the site's attributes**, and **limits on construction around existing villages in the buffer zone**. Urbanisation is thus controlled now and the latest demographic figures indicate a slight reduction in population within the site and a low percentage of second homes (8.7%).

The Toupe quarry at the South extremity of the property. It represents less than 0,1% of the site
© A. Ith

The urbanisation is very limited on the nominated property
© A. Ith

Afforestation and covering of the geological features

Forest covers certain areas of the nominated property, in particular along the fault and on the lava flows. While there is certain ecological, educational and climatic interest to this, which also serves to protect the features from erosion, the vegetation cover can mask certain morphologies if it is not properly managed. Although the geological features are easily identifiable in the landscape, the management plan aims to reinforce their clarity. To achieve this it envisages preserving pasturing on those summits which are currently used for this purpose, and the return to pasture-land of ten others, thanks to a close collaboration with farmers and the land owners. It also intends to carry out specific forestry work involving new logging methods, and enhancement of certain volcanoes through diversification of forestry species.

In terms of the Limagne fault, the forest plays an essential protective role in limiting urbanisation from the town of Clermont-Ferrand at its foot. This forested area, which in no way detracts from the visibility of the tectonic structure, has been identified in various urbanisation documents as **high priority and to be preserved**. As far as the Plateau des Dômes and the Montagne de la Serre are concerned, they are relatively clear of woodland.

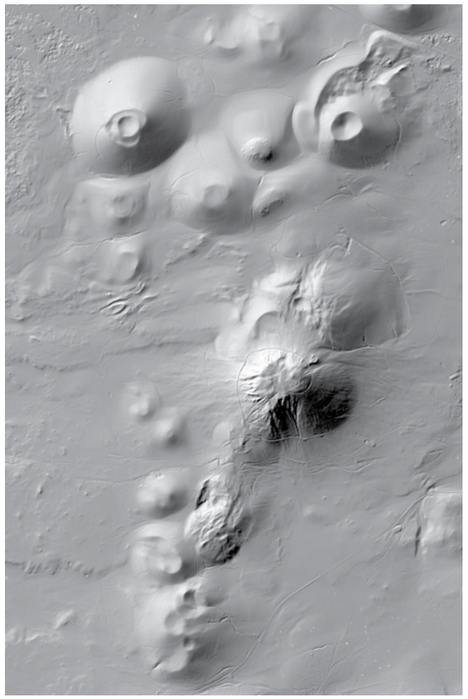


Fig 10. Altimeter data for the central sector of the Chaîne des Puys.

This image confirms that the erosion is essentially superficial, and should not be confused with geological folds and faults.

Erosion of the soil linked to visitor numbers

Natural erosion is limited by the vegetation and has little effect on the site. Anthropogenic erosion, related to visitor numbers on hiking trails as well as sporting practices, affects four of the eighty volcanic edifices of the Chaîne des Puys. The Limagne fault and Montagne de la Serre sectors of the site, which have a less fragile soil cover, are unaffected by this problem. The factors affecting erosion are closely examined and measures taken to reduce their effects. A number of preventative and corrective procedures have thus been set in place: awareness-raising campaigns to inform the public; limitation of certain uses (logging, tourism); integrated development and restoration work on certain paths.

To conclude, the nominated property has long benefited from protection and management measures. It is subject to strict legislation, amongst the strongest available in the French legal arsenal in terms of landscape and environment (Cf. 3.1.e). It is also subject to measures concerning the identified threats thanks to a management plan that has been in operation for the last five years, and which is backed by adequate human and financial resources. This geological site is sparsely urbanised, the geological features are very little altered (Fig. 10), and **its state of conservation fulfils the Operational Guidelines' integrity requirements under criteria (viii)**.

3.1.d Statement of Authenticity (not applicable for natural criteria)

3.1.e Protection and management requirements

The site has been the object of management and protection measures for more than 80 years[1], which were boosted 40 years ago with the creation of the Auvergne Volcanoes Natural Park in 1977, the extension of the "classified site" in 2000, the Grand Site operation in 2008[2], and the setting up in 2012 of a specific management plan within the context of the application process for inscription on the World Heritage List. These management measures have largely been driven by local actors, in collaboration with the State, which demonstrates and guarantees the desire of the region and the French State to preserve this exceptional site.

1 - Classification of the puy de Dôme volcano in 1933 in the domain of landscape and sites.

2 - Sixth site to be listed in France.

The Chaîne des Puys - Limagne fault ensemble is preserved by strict national and local regulations

Thus the preservation of the outstanding universal value of the Chaîne des Puys - Limagne fault tectonic arena, and of the geological features of which it is composed, relies on a solid and long-existing legislative base; an operational management plan; and specific governance to ensure its correct application, together with adequate human and financial resources.

A solid and long-existing legislative base applicable to both public and private land

In accordance with paragraphs 97 and 98 of the *Operational Guidelines for the implementation of the World Heritage Convention*, the protection and enhancement of the Chaîne des Puys - Limagne fault ensemble are guaranteed by national legislation measures and regulatory documents concerning the development of the region.

Three national regulatory measures allow the State direct control over the main threats identified (urbanisation, quarries, and construction), which are applicable to both private and public land:

- The whole of the site is covered by the **Montagne Act** (passed on 9 January 1985), which prevents construction that is not adjacent to existing buildings;
- The **quarries plan**, backed by the State, prevents the opening of any new quarry within the Chaîne des Puys. For the purposes of this dossier, the French State has also committed to not renew the existing work permits of the two currently active pouzzolane quarries, which will be incorporated into the revised plan which is currently being drawn up;
- 82% of the site, including the most sensitive parts, are covered by a "classified site" or "listed site" status, two of the strongest regulatory measures in France[3]. As a classified site, any modification to the state or aspect of the site on public or private land has to apply for special authorisation from the Ministry of Ecology. This classification also involves restrictions to land use (construction, camp sites and caravan parks are all prohibited).

Other national and local measures provide significant complementary protection, both to the main zone and the buffer zone:

- The site is covered by local measures (**Park Charter, schemes for territorial coherence and local urban planning documents**) which concern construction and land use. The site's principal attributes (the Chaîne des Puys, the Limagne fault and the Montagne de la Serre) are specifically identified as natural zones to be preserved;
- National and local measures provide specific protection for the exceptional ecological zones (**Natura 2000, Sensitive Natural Areas**);
- Lastly, **forestry regulations** allow for the implementation of strategies to share land-use between forest and pasture.

3 - UICN Category III protected area.

More generally, in the spirit encouraged by the IUCN, the French Environment Code provides for **impact studies and environmental evaluations** of certain planning documents as well as for major projects. In the case of a World Heritage Site, the specifications for these studies always contain a section relating to the preservation of the OUV of the inscribed site.

These measures thus ensure:

- That the World Heritage Site is taken into account in the policy documents involving the site, notably the quarries plan, the Natural Park Charter, the regional energy plan…;
- Powerful protection against any large-scale project that might pose a threat to the site, the heritage value being fully taken into account in the impact study imposed as a pre-requirement to authorisation of the said project.

The management plan draws on all these protections, uniting and directing them towards the preservation of the outstanding universal value.

A shared management plan which can respond to the threats identified

Operational since 2012, the management plan dedicated to the preservation of the outstanding universal value has been designed to respond in an operational way to the site's main issues and threats (quarries, erosion, conflicts of land use, loss of landscape visibility, and construction). Based on both the regulatory measures described above and on a proactive contractual framework, it has three main points:

Point 1: The preservation of the visibility and integrity of the geological features;

Point 2: The management of tourist numbers and the preservation of traditional local activities;

Point 3: Awareness-raising and diffusion of knowledge and information about the site and its fragilities.

This is an operational and programmatic document which has been **adopted by all the application's institutional partners, and which is binding both politically and financially**. Particular attention has been given to establishing **coherence in terms of the politics of the different local authorities**. It covers both inter-disciplinary action concerning the site as a whole (awareness-raising, monitoring, communication, visitor-related material, agricultural and forestry support, and transport management) and **integrated management** measures applicable to certain buildings or specific sectors. These integrated management acts combine enhancement of the geological features in the landscape, fight against erosion regulation of visitors, and farm and forestry management which is biodiversity-friendly.

Strong leadership and specific governance linked to local actors

The Department of the Puy-de-Dôme and the Auvergne Volcanoes Natural Park, in association with the French State, are in charge of the direction and operational implementation of the management plan. Given the **broad range of competences** covered by the legislation (natural areas, hiking trails, tourism, agriculture, forest, circulation, development strategy for the region) they have all the means necessary to intervene in the main issues that might confront the nominated property.

The management plan also allows for **specific governance** combining all the site's institutional partners and stake-holders: the State, the Department, the Regional Park, the Region, the local communes and their associations, scientists, environmental organisations, economic actors (including representatives of the farmers, forestry workers and quarry workers), tourists, land/house owners, and users of the site.

The implementation of the management plan as operational projects also makes it possible to associate the local communities directly concerned, either geographically, when the project concerns a specific object (for example a building), or thematically.

Example of the public commitment for the preservation of the site: a voluntary work to way-mark the path of the puy Pariou, March 2014
© J. Way

Adequate human and financial resources for the issues concerned

Sixty six people are involved in the management of the site, **twenty nine** of whom work full time using their varied expertise. The team includes people on the ground (Park guards) and others whose role is to monitor and implement the different projects. The number of employees relative to the surface area of the Chaîne des Puys - Limagne fault is equal to the density that you would find in a French National Park.

Mounted guard of the National Forestry Office patrolling the Chaîne des Puys
© J. Way

In addition, the management team benefits from help from scientists in the domains of management and the geological sciences via an international scientific committee, as well as from researchers at the local universities.

In terms of financial resources, a contractual agreement signed by partners, of more than **18 million euros over a five year period**, covers the requirements of personnel, running costs and investment.

The management of the site resides with the principal backer (the Departmental Council of the Puy-de-Dôme), which has high and sustainable finances thanks to its annual budget of more than 700 M€, of which 46.5 M€ are devoted to issues concerning the management of the site.

Other funding, public and private, adds to these resources, while the main paying tourist attractions on the site balance their running costs with the income gained from their visitors.

It should be noted that a number of companies based in the region have engaged in a sponsorship agreement to support the protection and enhancement of the Chaîne des Puys - Limagne fault tectonic arena which provides an **additional 700 000 € over five years** towards the management of the nominated property.

Local commission uniting all the actors involved in the management of the Chaîne des Puys - Limagne fault
© J. Way

3.2 Comparative analysis

The Chaîne des Puys - Limagne fault is applying to World Heritage as a continental break-up representative, which is an exceptionally complete, diverse and eloquent expression of this process.

Continental break-up combines three phenomena that are intrinsically linked[1]: downthrow, volcanism and uplift. If this combination is inherent to the continental break-up process, its order may change depending on the origin of the rifting[2] and its passive or active nature[3]. So there is no single classical sequence with one feature appears first, then is overlain, destroyed, or juxtaposed by another one. Also each of these phenomena is associated with characteristic morphologies[4]. Downthrow, volcanism and uplift strongly interact with each other as shown, for example, by the diversity of magmas induced by structural modifications, or by the alignment of volcanoes with faults. Along with grabens, these are the most visible expressions of the rifting process.

Virunga
© Yvette Kaboza

At present, there are sites on the World Heritage List in a rifting environment, but no candidacy has yet been put forward **to illustrate the continental rifting process in itself**. In each case, the rift is but a **backdrop** (Virunga, Kenya Lake system, Ngorongoro, Lake Malawi, Lake Turkana, Kondoa Rock-Art Sites), the properties were nominated either for their aesthetic values, the biodiversity, or their cultural assets. As a matter of fact, their boundaries do not incorporate the major rifting features as their perimeters were not designed to illustrate continental break-up.

Kenya lake system in the great rift valley
© National Museums of Kenya

The reason of this absence can be related to:

- The size of the continental break-up process (aerial / satellite view can be needed to appreciate the process in its entirety like in the Dead Sea);
- Its time scale (millions of years, so that the early features eroded away or covered by water or sediments like in Baikal);
- Its lack of accessibility for non-specialists (dramatic landscapes but very widespread, or with one dominant feature so the intrinsic connectivity between the three phenomena is hard to perceive, like in the Virunga).

Ngorongoro
© Kishore Rao

For non-specialists, the perception of a rift is quite often limited to its faulting and subsidence aspect. A long linear valley is the most popular perception,

1 - Pagli, C., Mazzarini, F., Keir, D., Rivalta, E., & Rooney, T. O., 2015. *Introduction: Anatomy of rifting: Tectonics and magmatism in continental rifts, oceanic spreading centers, and transforms*. Geosphere, 11(5), 1256-1261
Sengor, C., and Natal'in, A.L., 2011. *Rifts of the World* GSA Special Papers 2001, 352 : 389-482

2 - Foulger, G.R., 2010 *Plates and Plumes: a geological controversy*, Wiley-Blackwell 328 pp.

3 - Turcotte DL and Emmerman SH (1983) *Mechanisms of Active and Passive Rifting*, Tectonophysics 94(1):39-50 · May 1983

4 - Downthrow: faulting and graben / basin; magmatism: volcanoes; uplift: relief inversion and raised surfaces.

but this does not reflect the process in its entirety. This is partly due to the fact that in many cases, the features are scattered over large areas **without visual connection**, so that it is difficult to see in one single view and understand **that it is one single process**. Sites that get round these obstacles are rare. In a **heritage perspective, we are looking for sites where all the features are present, understandable, articulated all together, conveying a clear and complete view of the entire process**.

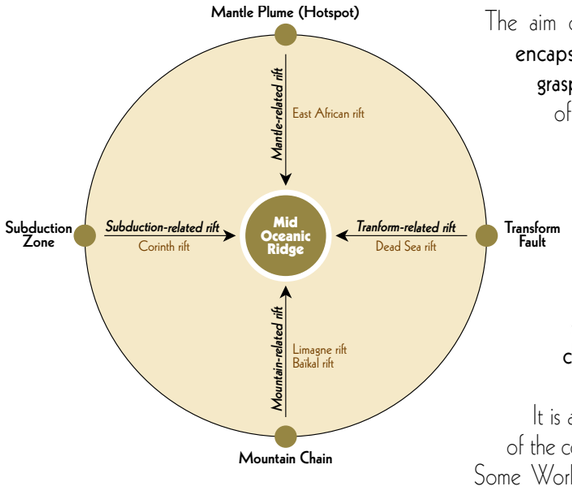


Fig 11. Simple model for rift classification
© Cd63 from O. Merle, 2011.

The aim of this comparative analysis is to determine which site(s) **best encapsulate(s) the fundamental elements of continental break-up in a graspable landscape** and in doing so, can stand as an outstanding example of this fundamental geological process.

It has to be made clear that what will be examined is the **process of continental rifting in its entirety**, and not only its most common geomorphological expressions, which are escarpment and graben. **Volcanic and uplift features are inherent parts of the continental break-up process** and will stand along with tectonic structures. A special attention will be paid to their **connectivity, diversity and clarity of expression**.

It is also to be stated that continental break-up is one of the major stages of the continental drift, characterized by divergence and convergence phases. Some World Heritage properties already illustrate plate tectonic movement as theorized in the Wilson cycle, such as the collisional and subduction stages. But **continental break-up, oceanisation and oceanic ridge** are not yet represented per se on the List.

Importantly, inside each of those stages, **various sites could be eligible in the future** to cover the full spectrum of plate tectonics. Collisional zones are already represented by about ten UNESCO WH sites (Cf. 3.1.b, pages 13-14). The same logic can be applied for the rifting process, based on the diversity of tectonic contexts that generate continental break-up (mountain chain, transform, hotspot and subduction) (Fig. 11). More than one site would then be needed to fully represent their variety of expressions, and this comparative analysis helps to identify some of the major candidates that could be considered as universal expressions of divergent tectonics.

Methodology applied: prerequisites, indicators and experts elicitation

To set up a right and proper comparative analysis methodology, the examples of Stevns Klint (Denmark) and Sardona (Switzerland) nominations have been followed with the use of prerequisites and peer review for the appropriate selection of sites and their in-depth comparison. Throughout all this analysis, a thorough expert elicitation was also solicited to discuss and certify our results.

Prerequistes – coming up with the best selection of segments out of a complete overview of world rifts.

The first step was to review the eight major continental rift systems in the world and for each of them, **identify distinct segments**. This was facilitated by the fact that each of these rift systems is well studied with good maps of tectonic and volcanic features (Fig. 12).

Then, a selection of the most interesting segments was made with the help of scientific articles and the high resolution digital elevation models[5]. It was based on two prerequisites:

- first, the segments should **gather the three constitutive phenomena** of continental break-up (faulting/magmatism/uplift);
- second, these phenomena should be **clearly displayed in the landscape** through distinctive features.

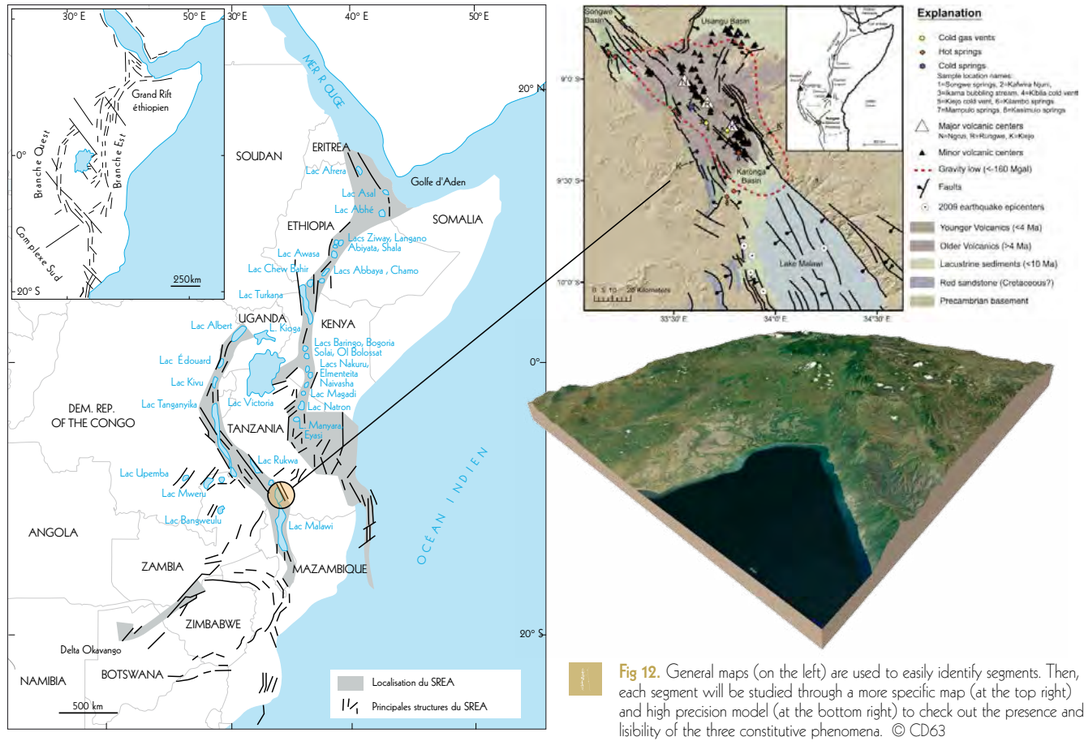


Fig 12. General maps (on the left) are used to easily identify segments. Then, each segment will be studied through a more specific map (at the top right) and high precision model (at the bottom right) to check out the presence and lisibility of the three constitutive phenomena. © CD63

5 - Shuttle Radar Topography Mission from http://www.opentopography.org/

In depth analysis of the pre-selected segments.

Once identified, the relevant segments have been **analyzed in depth** through both a **qualitative description** (Cf. full comparative analysis in annexes) and the semi-quantitative approach defined after Brilha[6] (2016, Geoheritage 8(2):119-134).

To avoid bias in favor of the nominated property, this semi-quantitative approach was founded on **rift-based indicators**, objectively referring to the expression of faulting and subsidence; magmatism; uplift; connectivity and science. Major indicators were scored from 0 to 5, additional once from 0 to 2 to balance their importance.

Last, all those descriptions and scorings were sent for verification and confirmation to at least two widely recognized specialists of each of the thirteen examined sites, so that the results of the comparative analysis are certified by objective external scientists. The credentials of each expert can be found in the annexes, along with the detailed analysis.

The pre-selected sites

Thirteen sites had been chosen for their completeness, relative compactness and clarity of expression. They belong to:

The Rio Grande rift: 1. Sandia Peaks and the Petroglyph national monument (USA)
The Basin and Range province: 2. Steens Mountain Rift and Diamond Craters (USA)
The Central American rift: 3. Mateare fault and Chiltepe Volcano (Nicaragua)
The Dead Sea rift: 4. Hula valley and Golan Heights (Israel, Lebanon, Syria)
The Baikal rift: 5. Northern Tunka (Russia)
The Western European rift: 6. Freibourg – Kaiserstuhl (Germany)
7. Krušné Hory fault (Czech Republic)
8. Limagne fault and Chaîne des Puys volcanoes (France)
The East African rift: 9. Lake Malawi fault (Tanzania, Malawi)
10. Muhindu Escarpment and the Virunga Volcanoes (DR of Congo, Rwanda)
11. Kenya Lakes (Kenya)
12. Adama rift – Boset volcanic centre (Ethiopia)
13. Alid volcano (Eritrea)

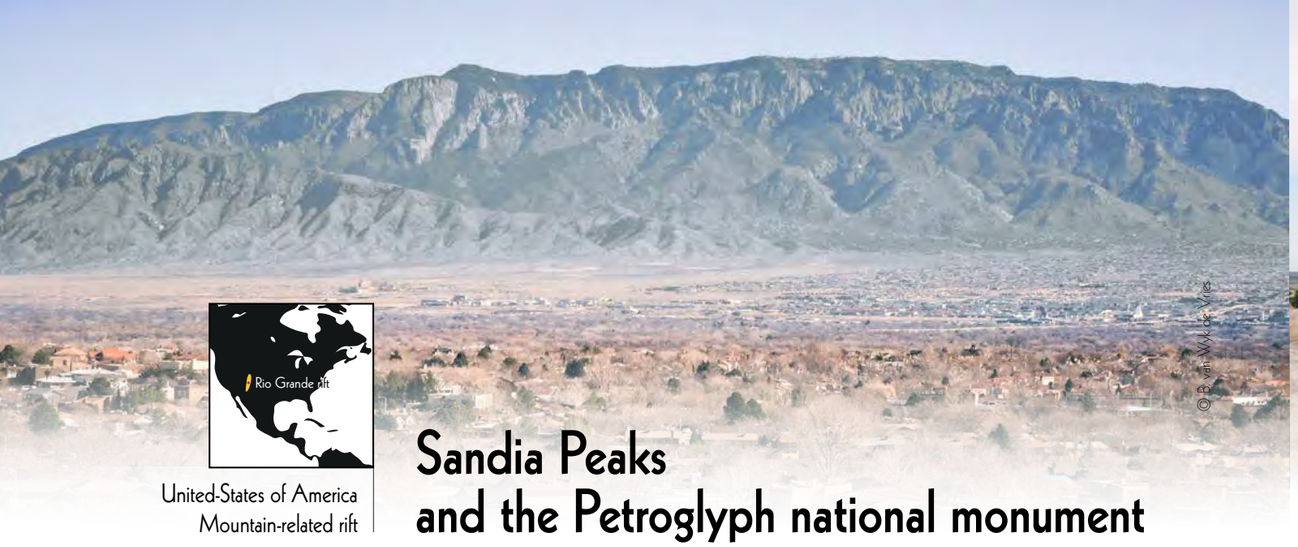
Among the major rift systems, the only one that is not represented here is the West-Antarctic one because all features are covered with ice.

Ice crevasses near the coast of West Antarctica from a window of a NASA Operation IceBridge airplane, Oct. 28, 2016.
© M. Tama/Getty Images.

6 - Brilha J., 2016. Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage 8(2): 119–134.

INDICATORS		SITE NAME
A. Faulting and subsidence: *A primary process of continental break-up is faulting and crustal thinning, causing the surface subsidence and a basin. Sediments eroded from escarpment are transported and fill the basin. Clarity, distinctiveness and freshness of tectonic features will take an important part in their scoring as well as the evidence of break-up and subsidence.*		
Main indicator: net faulting	One or several linear escarpment(s)/ fault plane / clear subsided area (graben) **(scoring from 0 to 5)**	
Additional indicator: pronounced surface processes, minor scale outcrops of faults and fractures	Erosional or sedimentation features, on-going transport seen in the landscape and fault outcrop. **(scoring from 0 to 2)**	
	Sub-total:	
B. Magmatism: *Magmatism is a primary continental break-up process, characterized by alkaline composition and by diverse compositions due to substantial modification of mantle and crust. Visible and significant magmatic features are scored such as, volcanoes, lava flows, flood basalts, intrusions. To be in accord with heritage values, fresh and active volcanoes will be the most valuable assets because they are the best known and recognizable magmatic expression.*		
Main indicator: remarkable rifting magmatic features in landscape	Alkaline volcanism, number, surface area, size, visible diversity of magmas, freshness **(scoring from 0 to 5)**	
Additional indicator: activity	Persistent activity, active, dormant or extinct. **(scoring from 0 to 2)**	
	Sub-total:	
C. Uplift: *Uplift is an essential element to perceive the rifting process in full and the link to the deep Earth. It can be caused either by a mantle plume or by the thinning of the crust due to its stretching, and so starting or ending the continental break-up. For the heritage perspective, we will not distinguish its different origins and will only consider its topographic expression.* *This process is the most difficult to perceive for non-specialists. Raised ancient surfaces (peneplaine), plateaux, concordant summits elevations, inverted reliefs are the most visible signatures. Their landscape impact and distinctiveness will take an important part in the scoring.*		
Main indicator: raised surfaces	Old surfaces raised up **(scoring from 0 to 5)**	
Additional indicator: uplifted sediments, plateau dipping away from rift	Sediments deposited low down now found high up, evidence of the uplift dome. **(scoring from 0 to 2)**	
	Sub-total:	
D. Connectivity: *Faulting/subsidence, magmatism and uplift features need to be connected. In a heritage perspective, we are looking for sites that allow continental break-up to be understood as one single and integrated process. All features should be seen together and there must be visible causal links between them. Scoring concerns features close enough to be seen at the same time in the landscape; that their layout shows their structural linkage; and that their proportions are balanced such that one mechanism does not overwhelm others.*		
Main indicator: intrinsic links between all elements of a site	Proximity of the different features allowing them to be seen simultaneously (whole process can be observed in its entirety), layout of features (are the elements arranged in as to convey a clear sense of connection), proportionality of features. **(scoring from 0 to 5)**	
Additional indicator: chronology	Can the elements of the site convey the sequence of events in the landscape so the geological history of the site can be seen (stratigraphic indicators / layering of rocks; paleo-surfaces meaningfully show the succession of processes, including on-going processes). **(scoring from 0 to 2)**	
	Sub-total:	
E. Science: *The scientific standing of the site can be judged in relation to the history of Science, the importance of the discovery of a site and its impact into developing scientific theories of the time. Scientific quality can also be judged by the modern scientific activity, chosen here as dating from the discovery of plate tectonics about 50 years ago.*		
Main indicator: modern Science	Standing in the time after the plate tectonic revolution (50 years). **(scoring from 0 to 5)**	
Additional indicator: history of Science	Standing in the beginnings of scientific understanding (beginning depends on geographical location and culture). **(scoring from 0 to 2)**	
	Sub-total:	
	FULL TOTAL:	

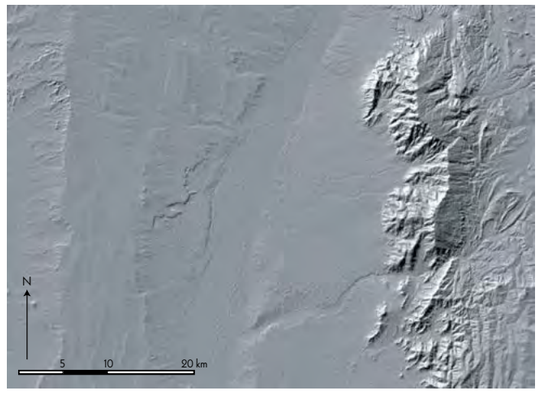
Table of continental break-up indicators for scoring sites
© CD63

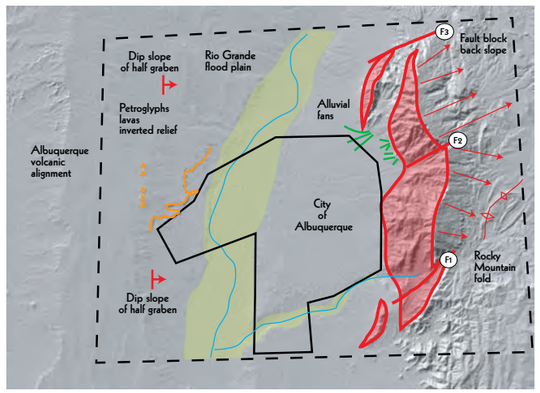


United-States of America
Mountain-related rift

Sandia Peaks and the Petroglyph national monument

Description: Sandia Peak escarpment is a 26 km long, irregular fault scarp, which rises to 900 m high at its maximum. The escarpment is deeply cut by numerous erosional valleys. The plain is occupied by the river, low brush savannah and the city of Albuquerque. Petroglyph volcanic field is a 6 km long eroded alignment made of five small scoria cones (~170,000 to 70,000 years). The site is famous for its indigenous archaeological and cultural assets.



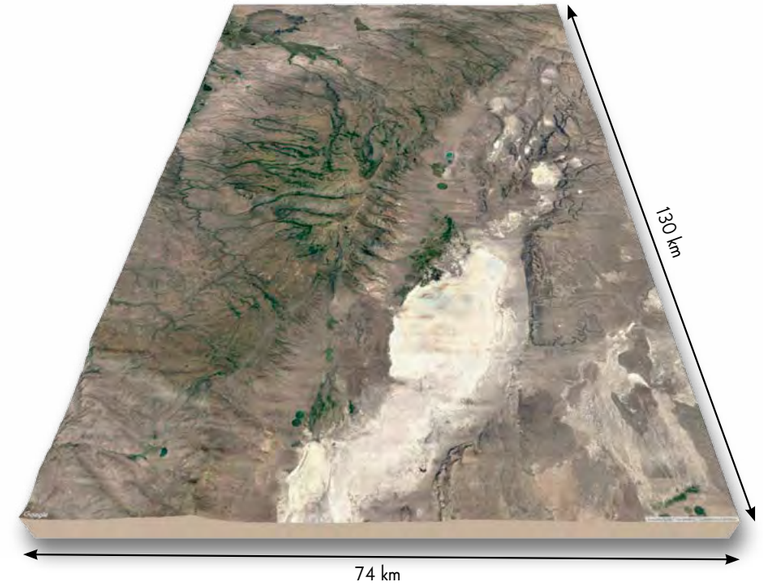


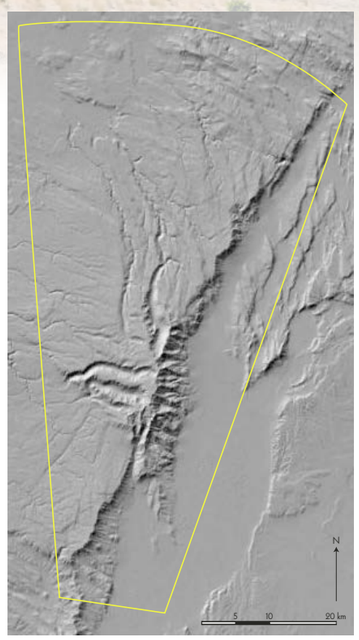
Strong points:
Impressive long single fault scarp and clear on-going basin filling in a desert environment.

Weak points:
Indistinct eroded alignment of five small basaltic scoria cones. They are 30 km away from the fault and visually separated by the city of Albuquerque. The distance and disequilibrium between volcanic and tectonic features blurs their intrinsic links. The site weakly conveys a sense of a whole continental break-up process.

United-States of America
Subduction related rift

Steens Mountain Rift and Diamond Craters

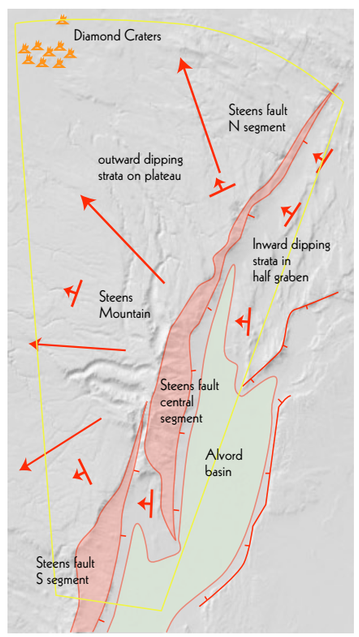




Description: The Steens Mountain's fault is 1 800 m high and 80 km long. It cuts a very large old stratovolcano (15 My) with glacial erosion which is tilted by uplift. The main associated volcanic field is the Diamond craters which is an atypical basaltic monogenetic eruption (~25,000 to 9,000 years). It stands at the foot slope of the uplift, 40 km away from the escarpment.

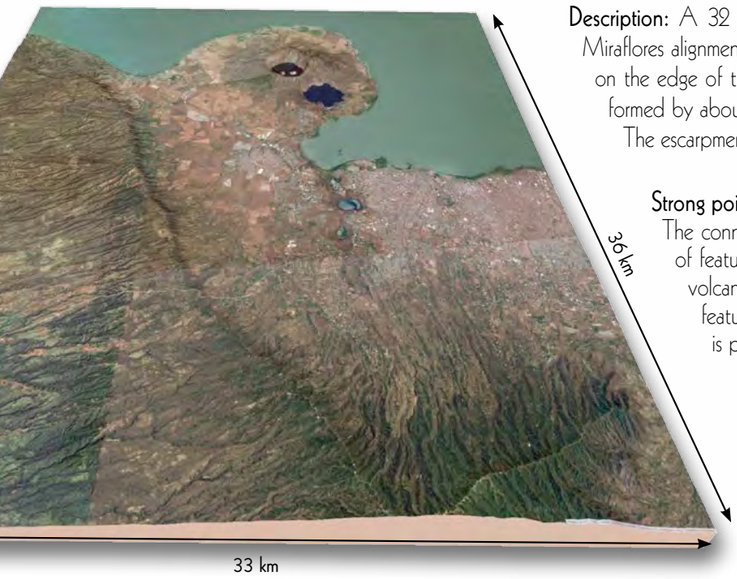
Strong points:
The fault escarpment is particularly high and long, and the processes of faulting and subsidence are strongly expressed in this spectacular landscape. Uplift features are also present, with raised lava beds, inclined plateau and concordant summit elevation.

Weak points:
The area is very large (3 518 km²) with the faulting and basin located on one area, while the volcanism is situated in an isolated part, so that the major features are not visually connected. In addition to that, the size of the Diamond craters field is 100 times smaller than the Steens Mountain.



Nicaragua
Subduction related rift

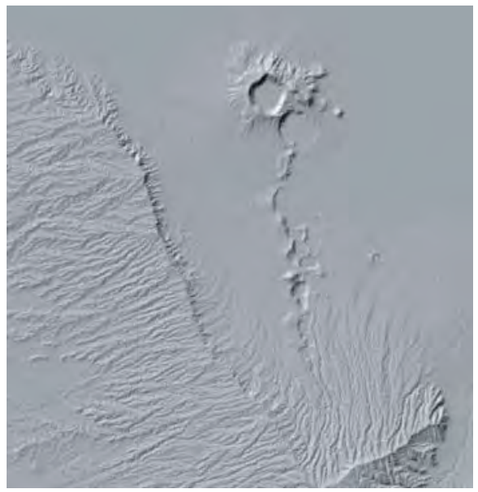
Mateare fault and Chiltepe Volcano

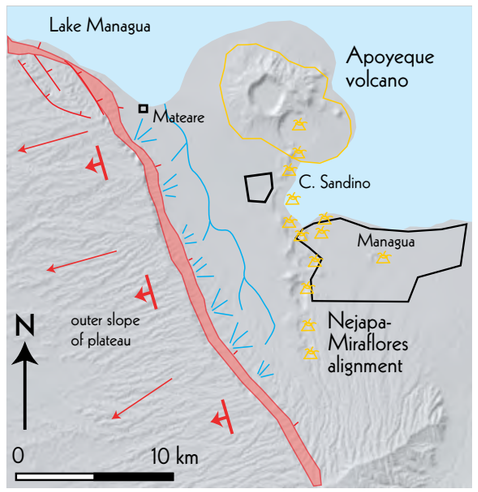


Description: A 32 km main escarpment almost parallel to the Nejapa-Miraflores alignment of the Chiltepe volcano (1 million to 10,000 years) on the edge of the capital city of Managua. The volcanic alignment is formed by about 20 dormant maars and cones (~25 -10,000 years). The escarpment culminates at 300 m high.

Strong points:
The connectivity of the site is well expressed by the closeness of features with less than a few kilometres between fault and volcanoes. The disposition is interesting with easily visible features, seen simultaneously in views and with a size that is proportional.

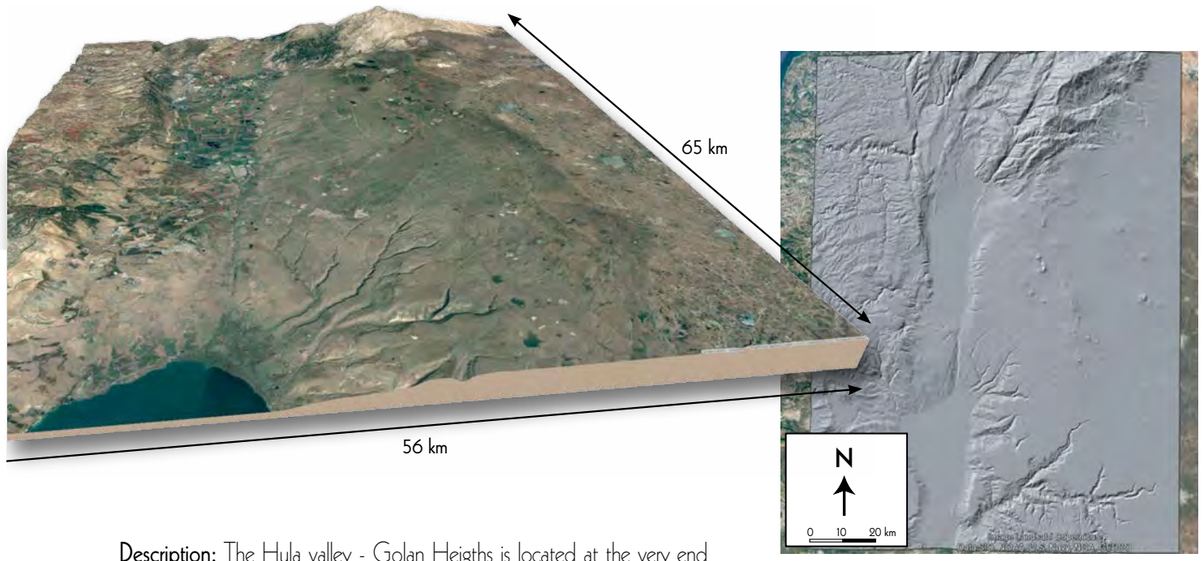
Weak points:
Although net, the linear escarpment is not very high compared to other downthrow features. Regarding volcanism, being in a subduction zone, the magma composition is not directly related to the rifting process, so not the typical alkaline type.





Israel, Lebanon, Syria
Transform rift

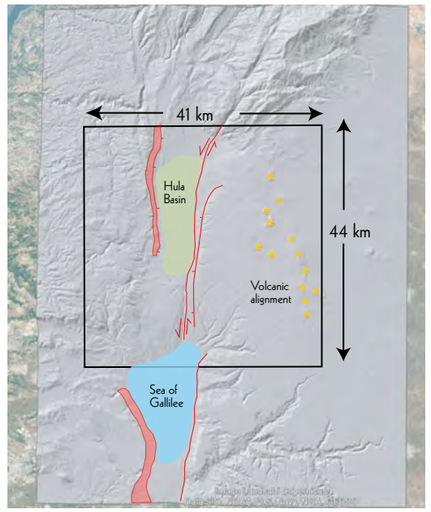
Hula valley and Golan Heights



Description: The Hula valley - Golan Heigths is located at the very end of the Dead Sea rift. The site encompasses a small pull-apart basin (8,5 km wide, 25 km long) with gentle shoulders (500 m) and a broad plateau with a low double chain of 25 volcanoes on it (29 km, 120-95,000 years).

Strong points:
The most remarkable aspect of this segment is the small and deep pull-apart graben with both side faults, very angular and delineated. The base of the scarp is sharply defined, making an abrupt and net limit with the sedimentary basin.

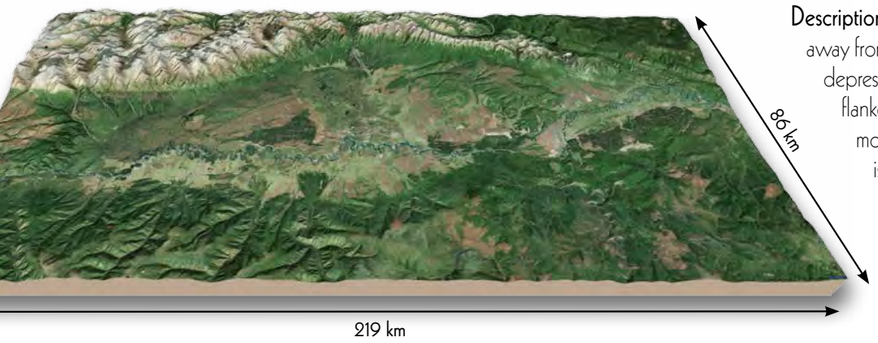
Weak points:
The magmatism is seen through small edifices. The disposition of the extinct chain gives a modest sense of alignment, roughly parallel to, and 13 km away from the escarpment. There is no significant uplift of the rift shoulders nor uplifted sediments or outward dipping plateau. The site does not give a full picture of continental break-up except seen from a digital elevation model.

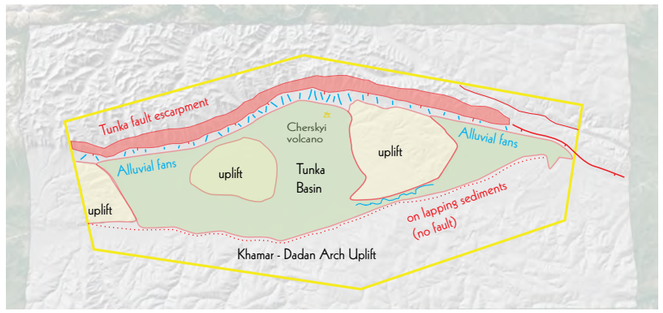


© P. Boivin

Russia
Subduction/mountain-related rift

Northern Tunka





Description: The Tunka rift segment is 15 km away from the Lake Baikal. It is a deep rhombic depression, 45 km wide and 100 km long, flanked by steeper alluvial fans and glacial moraines. The fault scarp to the North is sharp and demarcates the change from plain. The basin contains the small Cherskiy volcano (age probably Pleistocene), which is the most obvious of some small scoria cones, partly buried by the on-going sedimentation in the basin. A small raised area of hills to the West of the volcano has some low inverted relief of unknown origin.

Strong points:

The escarpment of the Tunka segment provides an excellent example of mountain-related rift cut by glacial erosion. The height and the length of the escarpment are particularly well-balanced, creating a very spectacular and distinctive landscape. The surface processes are abundant and noticeable. Last, the fault line is exposed at outcrop all along the escarpment. This is probably one of the finest expressions of a fault line.

Weak points:

Only a few very small monogenetic cones of less than 50 m high and 600 m diameter, are disseminated on the plain. Their age is unknown, no specific articles are available because the volcanic field in itself is not substantial. The site diverges from an archetypal continental break-up because of the interplay of convergence and rifting.

© Backcastimages

Germany
Mountain-related Rift

Freibourg - Kaiserstuhl

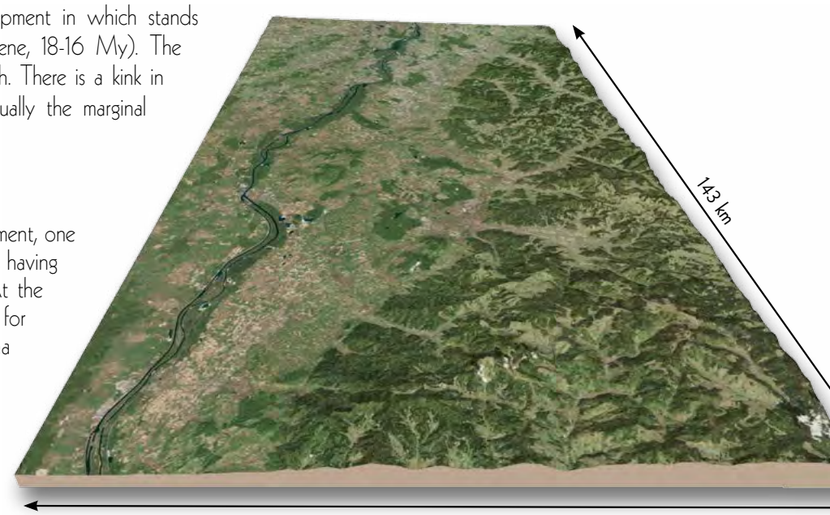
Description: The Freibourg - Kaiserstuhl site (length 50 km, Width 30 km) encompasses a rift margin escarpment in which stands the Kaiserstuhl volcanic area (age Miocene, 18-16 My). The site escarpment is 400 m to 700 m high. There is a kink in the Upper Rhine Rift that enhances visually the marginal escarpment by doubling it.

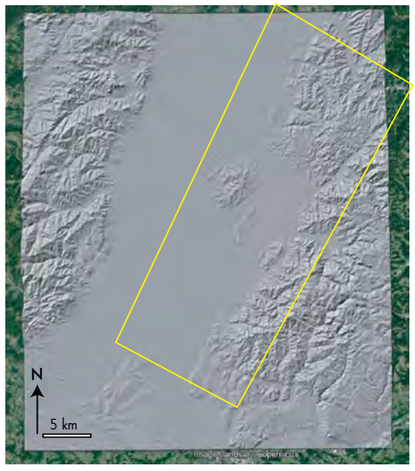
Strong points:

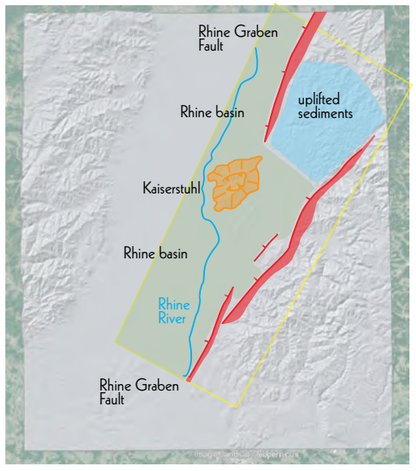
From the sharp, angular, distinctive escarpment, one can see the opposite side of the graben, having a full picture of the basin subsidence. At the volcanic level, the Kaisertuhl is notable for its highly potassic and carbonatic magma compositions, that show a particular and important type of rift-related magmatism. For scientific value, the Rhine Rift stands out as one of the sites where early theories were heatedly discussed and the rift is probably the first to be recognised as such. It was this region that consolidated this german term of graben in the geological terminology in the 19th century.

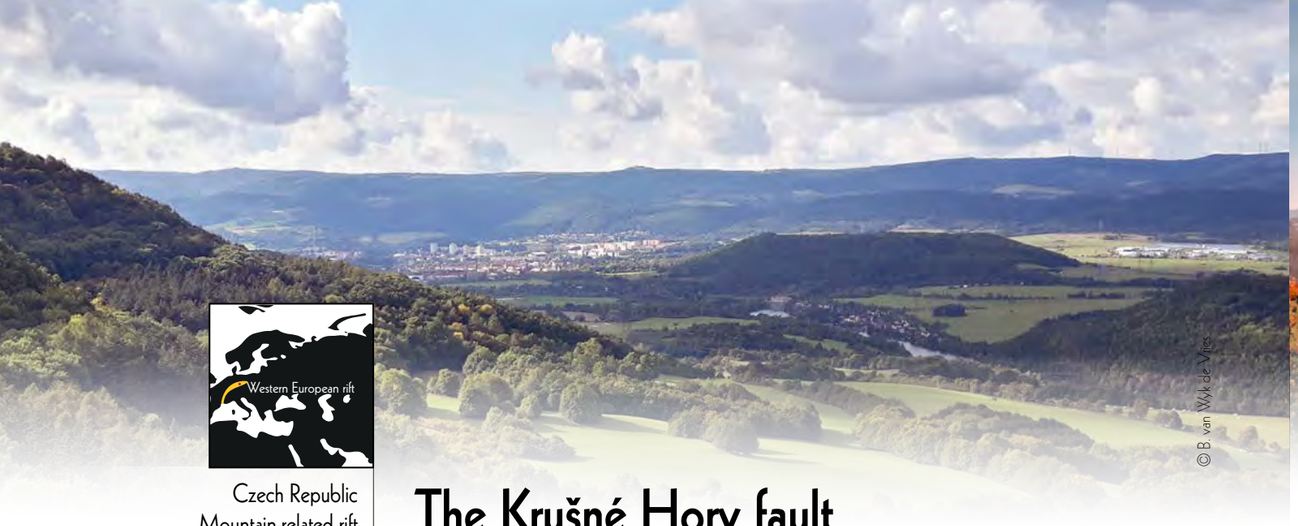
Weak points:

There are not a high number of structures and the tectono-volcanic features are eroded from several million years of exposure so that their geological significance is not immediately obvious to a general audience. Uplift features are a general part of the landscape without being highly distinctive.





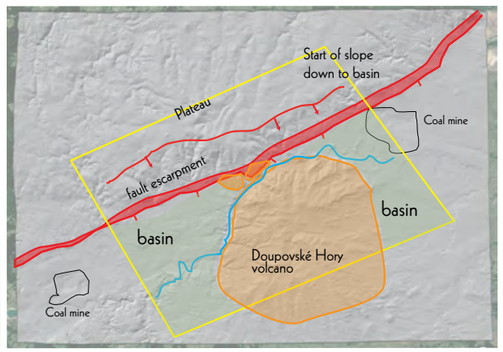




Czech Republic
Mountain-related rift

The Krušné Hory fault

Description: The Krušné Hory fault escarpment segment is a distinctive 30 km long and 500 m high landscape feature that separates the highland from the Eger rift plain. This fault is separated by the northern edge of the Doupovské Hory shield volcano. This Oligocene edifice forms a major volcanic site in the rift, while there are smaller monogenetic volcanoes dotted around the rest of the rift and its flanks. Erosion and consequent inverted relief testify to uplift and erosion after sedimentation.



Strong points:

Well-developed inverted relief ridges that form an important part of the landscape and give a strong indication of its progressive incision. This is reinforced by the on-going river system that cuts through the volcano.

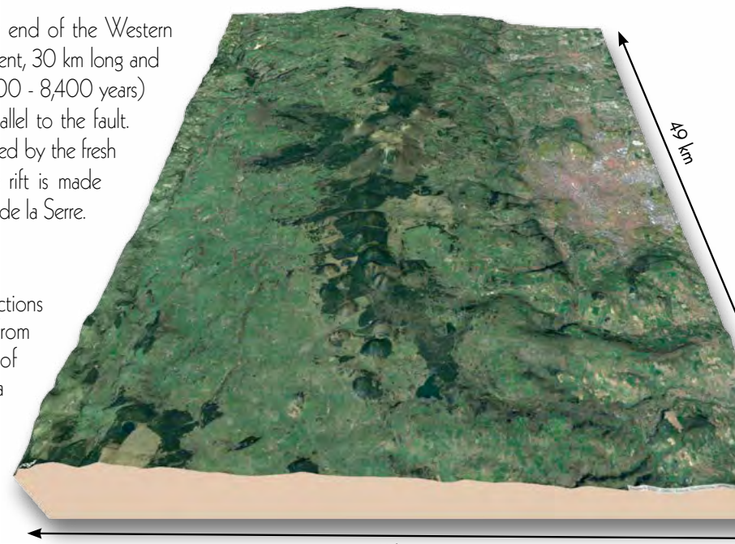
Weak points:

The volcano is ancient and its degree of erosion does not make it stand out in the landscape. It is a subtle feature, seen as an area of hills that fill the basin. There is no clear geometrical association between the volcano and the fault-basin alignment.

France
Mountain-related rift

Limagne fault and Chaîne des Puys volcanoes

Description: The Limagne forms the extreme southern end of the Western European Rift. The fault is a pronounced linear escarpment, 30 km long and up to 700 m high. The young Chaîne des Puys (95,000 - 8,400 years) has 80 volcanic edifices over 32 km length, strictly parallel to the fault. The rich magmatic compositions are spectacularly illustrated by the fresh and varied volcanic landforms. Uplift of the Limagne rift is made obvious by the inverted relief, especially the Montagne de la Serre.

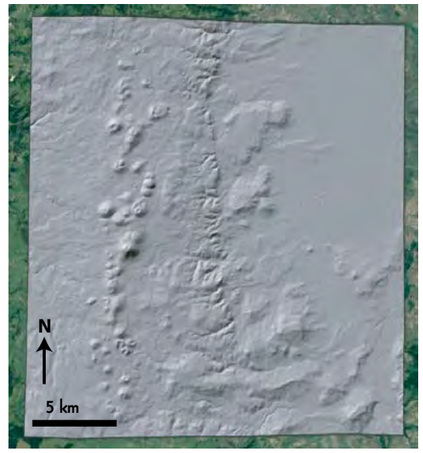


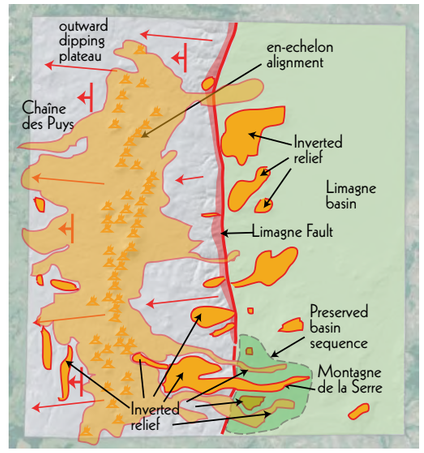
Strong points:

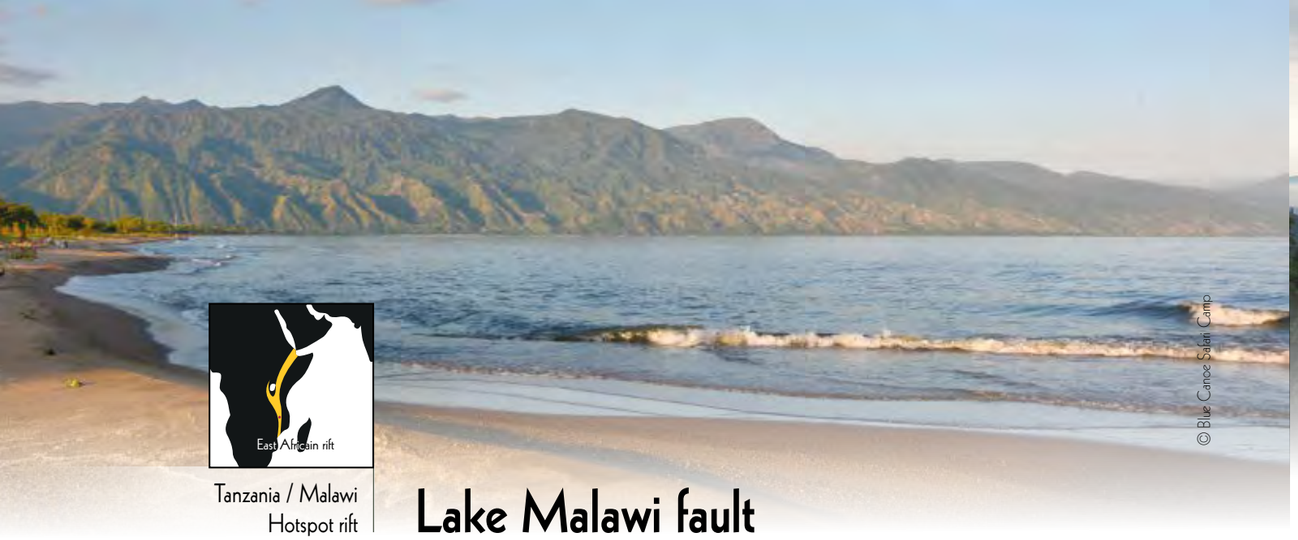
The site is exceptional in the number and clarity of connections that demonstrate the different components of rifting: from faulting to magmatism (double alignment and full range of alkaline lava series); magmatism to uplift (inverted lava flows) and uplift back to faulting (uplifted sediments and tilted plateau). The closeness, proportionality and geometry of all the features enhance this remarkable sense of connectivity. In terms of magmatism, it is particularly notable that this series is continuous, while in many other areas there is a gap (Daly gap). Ever since modern science began in the 18th century, the Chaîne des Puys - Limagne fault has been a mecca for geologists. It was the cradle of major controversies that lead to the definition of the main geological theories.

Weak points:

The site is of smaller dimensions and the volcanism, although well-expressed, is dormant.



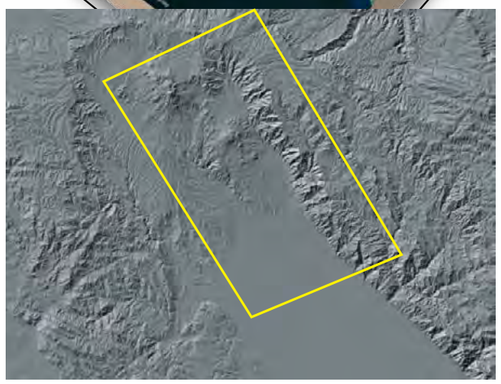


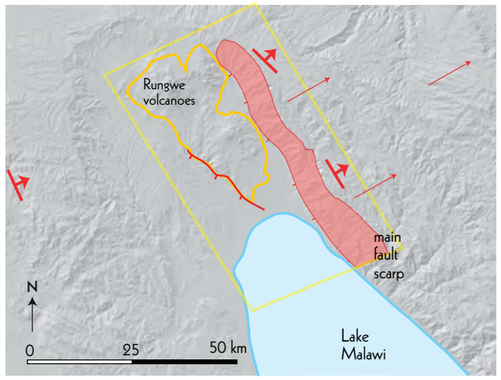


Tanzania / Malawi
Hotspot rift

Lake Malawi fault

Description: Lake Malawi is a triple junction of the different branches of the East African rift system. At the North end of the lake, the fault escarpment rises just over 1 000 m to meet the Rungwe volcanic province, a group of large stratovolcanoes. The whole area has been uplifted prior and during rifting.



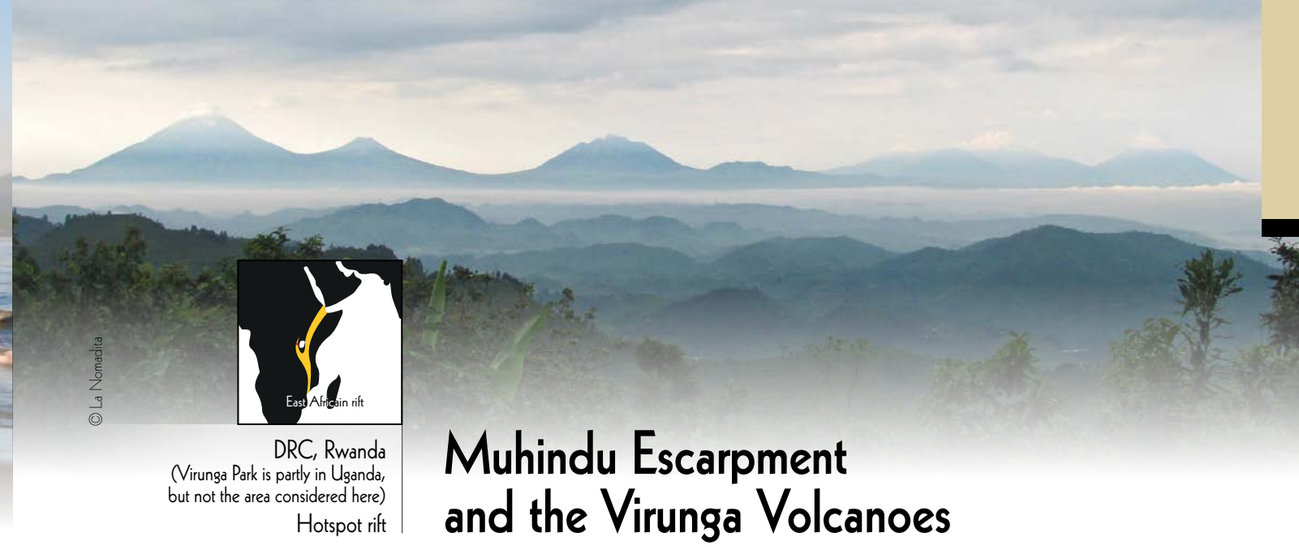


Strong points:

The features form a coherent unit of rift margin, rift basin and intra-rift volcanics which have comparable sizes. The topographic dome related to the mantle plume influence and the triple junction rift configuration is very well-displayed. It is a classic text-book style of hotspot rifting.

Weak points:

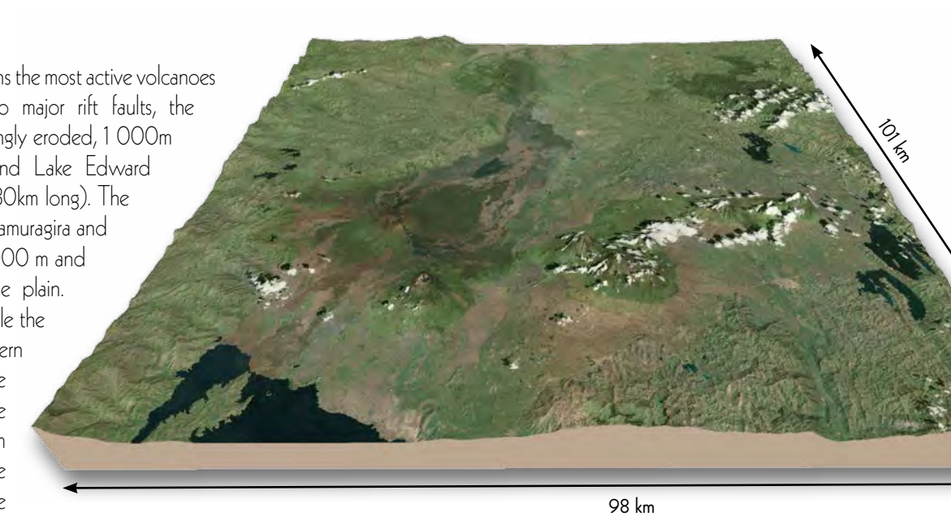
The volcanoes do not present very strong alignments along faults, their intra-rift situation give them a weak parallelism. The plateau uplift is separated on the outside of the rift and is only glanced at as a rising fault skyline, there is no inverted relief present.



DRC, Rwanda
(Virunga Park is partly in Uganda, but not the area considered here)
Hotspot rift

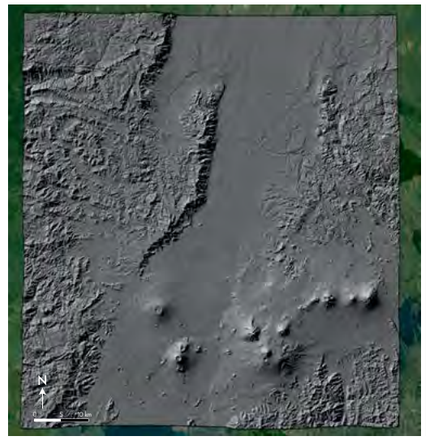
Muhindu Escarpment and the Virunga Volcanoes

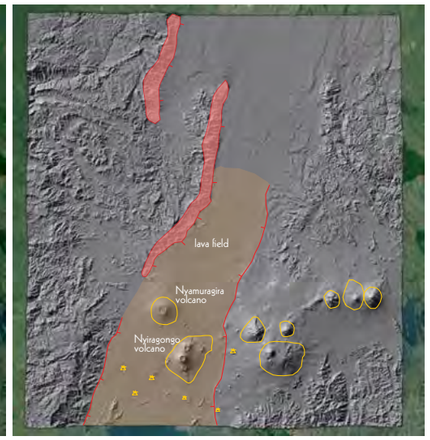
Description: The site contains the most active volcanoes in Africa, as well as two major rift faults, the Muhindu escarpment (strongly eroded, 1 000m high and 55 km long) and Lake Edward escarpment (1 100m high, 80km long). The two huge volcanoes of Nyamuragira and Nyiragongo reach over 4 000 m and arch 2 000 m above the plain. They are in the graben, while the others stretch onto the eastern shoulder. The basin can be clearly separated from the escarpments but lavas from the basin spill out over the rift margin, reducing the impact of the subsidence in the landscape.



Strong points:

Magmatism is superabundant and impressive. Each volcano is a magnificent geological landscape, full of diversity. The magmas typify one extreme of rift alkaline magmas. From a scientific perspective, the Virunga have been intensively studied from an early date and much research is on-going.



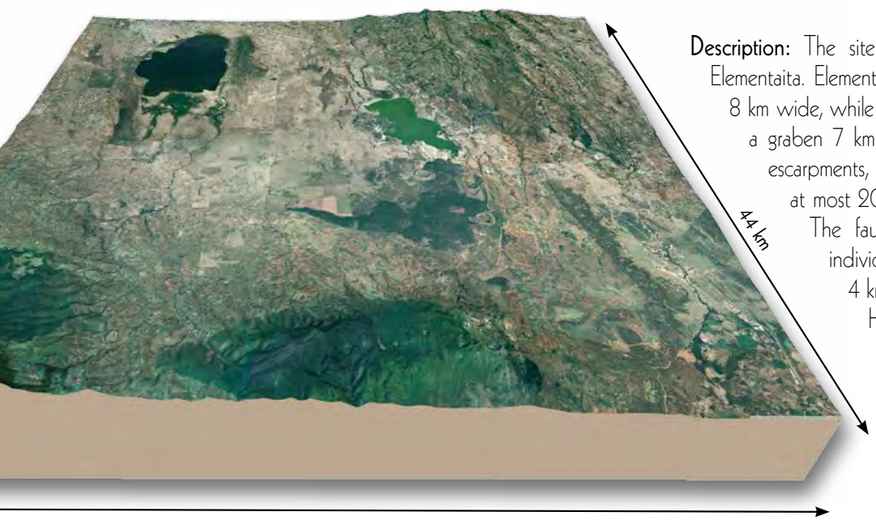


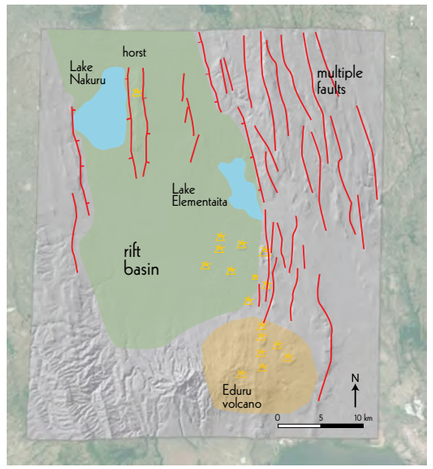
Weak points:

There is a low concentration of features. By their size, the volcanic systems dominate the present day rift conditions. Each volcano is too large and set too far apart to make a major connection. Uplift is not clearly shown.

Kenya
Hotspot rift

Kenya Lakes (Elementaita, Nakuru)

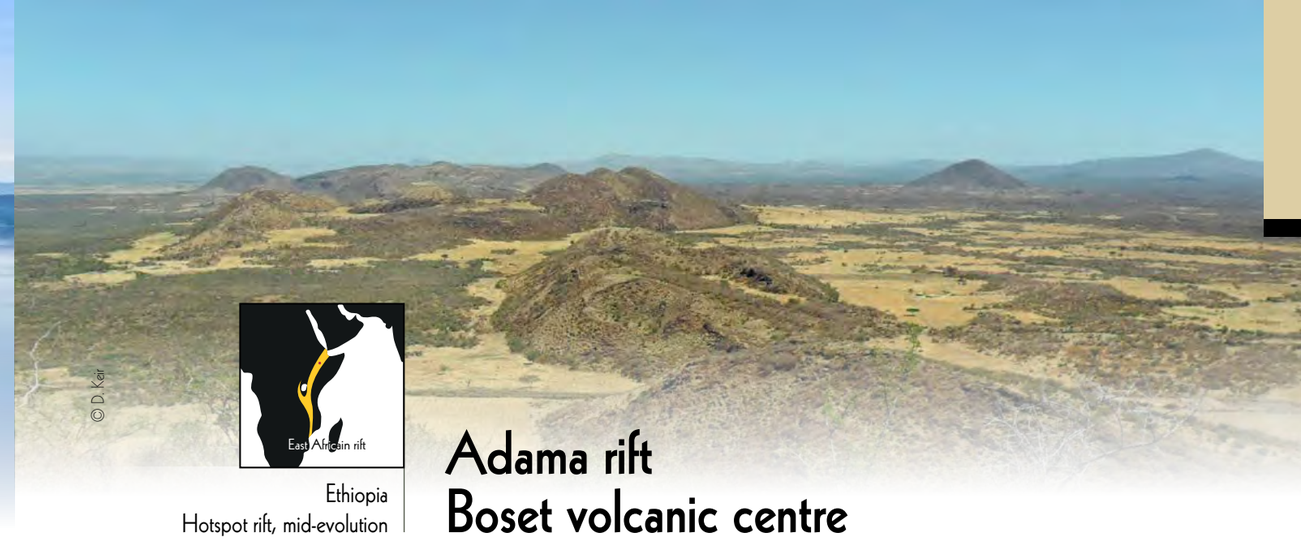




Description: The site is around the lakes Nakuru and Elementaita. Elementaita sits in a clear half graben about 8 km wide, while Nakuru has faults on both sides and a graben 7 km wide. Both graben have low fault escarpments, generally less than 100 m high and at most 200 m at the SE side of lake Nakuru. The fault escarpments are segmented into individual escarpments between 1 and 4 km long. This is also part of the World Heritage site (criteria (vii), (ix), (x)).

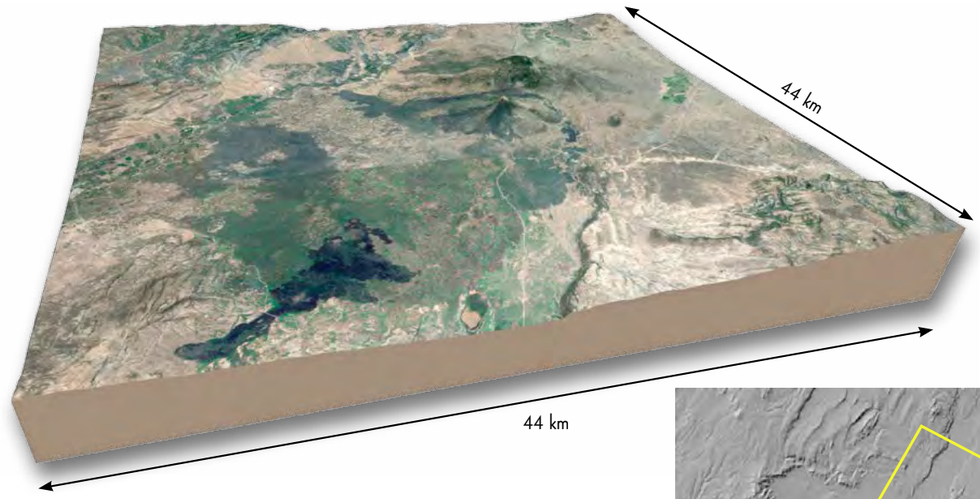
Strong points:
This site provides two examples of the main types of graben (full and half). They clearly display the inter-linked nature of the faulting and the subsidence with the development of isolated basins that fill with sediments and hold lakes.

Weak points:
All tectonic features are present at a small scale due to their position at the centre of the East African Rift that makes them a less dramatic landscape. Uplift is not a major part of the landscape of this area, as it is dominated by the subsidence of the rift.



Ethiopia
Hotspot rift, mid-evolution

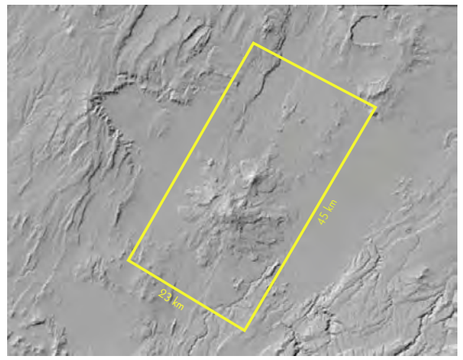
Adama rift
Boset volcanic centre

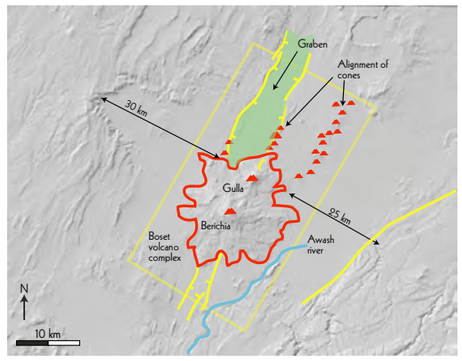


Description: The site is located in the North-East zone of Adama, where the Boset volcanic complex rises 1 000 m from the basin floor. Boset is cut by rift faulting that evolves as a half-graben (4 km wide). The West rim of the graben is steep (150 m high), while the East side had only a 50 m fault step. As the graben approaches the volcano, the margins are dotted with ten small aligned cones merging into the main stratovolcanoes. There is a second rough alignment of about 30 small cones, 8 km from the East rim.

Strong points:
Even if they are not very high, the two curvilinear sides of the small graben mirror each other, giving a clear sense of extension and subsidence. There are distinct cracks and fissures at outcrops inside the basin that reinforce the perception of extension. The varied volcanism gives a complete picture of magmatism processes in a rifting context.

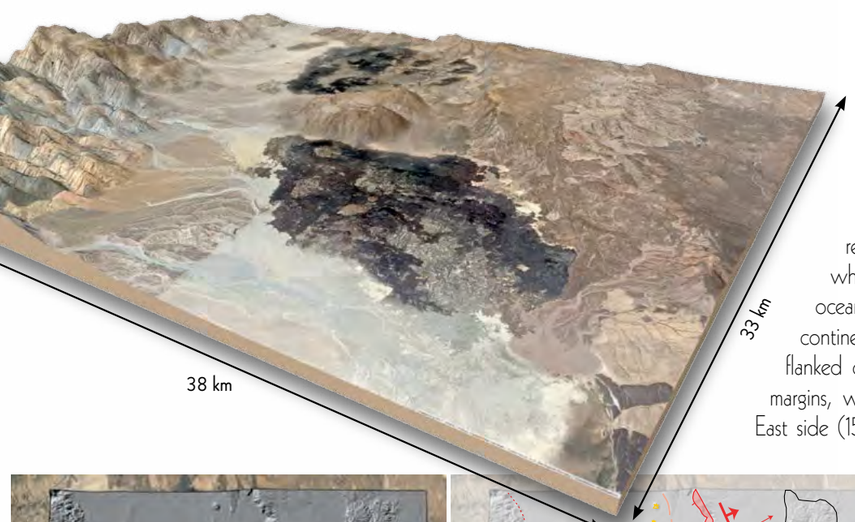
Weak points:
The evidence of uplift comes mainly from the elevation rather than from distinctive landscape features. The Central Ethiopian rift is more representative for dense inter-rift faulting than for the boundary escarpments that characterized the southern part of the East African rift.

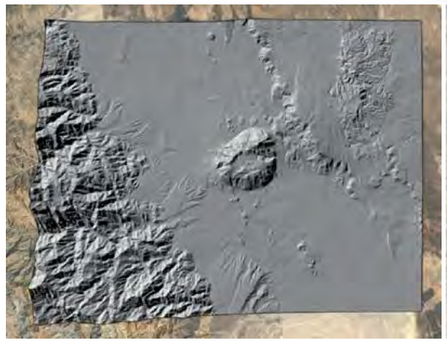


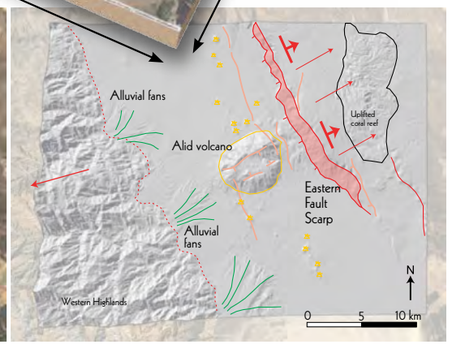


Eritrea
Hotspot rift

Alid volcano







Description: The Alid site is the most obvious continental remnant in the Afar region, where the rest of the rift is entering oceanization with the completion of continental break-up. The volcano is flanked on either side by the rift fault margins, which are steep sided on the East side (15 km, 300 m). On the West, in contrast, the rift margin is deeply eroded with profound valleys, looking more like a mountain range. Aligned with the fault direction, on either side of Alid, are chains of small cones and craters surrounded by large lavas. The basin is a half-graben (15 km wide).

Strong points:
The area is small for a continental rift, allowing the whole basin to be seen at one glance. Clear fault planes and fissures are noticed at many sites. Uplift is seen as a fresh feature with an easily-observed shallow dome rising to the fault line and external raised marine sediments.

Weak points:
The rift margin is not very high and long compared to others. Because of the disproportion between the major Alid volcano and the minor cones drawn in lavas, the volcanic alignment is blurred.

Scoring table and analysis

INDICATORS	SCORE RANGE	SITE AND SETTING 1 Sandia - Petroglyph *Mountain*	2 Steens - Diamond *Mountain*	3 Mateare - Chiltepe *Subduction*	4 Hula - Golan *Transform*	5 Tunka *Mountain*	6 Freibourg - Kaiserstuhl *Mountain*	7 Krusne Hory *Mountain*	8 Limagne - Chaîne des Puys *Mountain*	9 Lake Malawi *Hotspot*	10 Muhindu - Virunga *Hotspot*	11 Kenya lakes *Hotspot*	12 Adama - Boset *Hotspot*	13 Alid *Hotspot*
A. FAULTING AND SUBSIDENCE														
Net faulting	**0 - 5**	4	5	4	4	5	4	3	4	5	3	3	4	4
Pronounced surface processes, minor scale outcrops of faults and fractures	**0 - 2**	1	2	1	1	2	1	1	1	1	1	2	2	2
SUB-TOTAL:		**5**	**7**	**5**	**5**	**7**	**5**	**4**	**5**	**6**	**4**	**5**	**6**	**6**
B. MAGMATISM														
Remarkable rifting magmatic features in landscape	**0 - 5**	1	2	3	2	1	2	3	5	5	5	4	5	4
Activity	**0 - 2**	0	0	2	1	0	0	0	1	1	2	1	2	2
SUB-TOTAL:		**1**	**2**	**5**	**3**	**1**	**2**	**3**	**6**	**6**	**7**	**5**	**7**	**6**
C. UPLIFT														
Raised surfaces	**0 - 5**	2	3	3	2	4	3	3	5	3	1	3	4	4
Uplifted sediments, Plateau dipping away from rift	**0 - 2**	1	2	2	1	1	2	2	2	1	0	1	2	2
SUB-TOTAL:		**3**	**5**	**5**	**3**	**5**	**5**	**5**	**7**	**4**	**1**	**4**	**6**	**6**
D. CONNECTIVITY														
Intrinsic links between all elements of a site	**0 - 5**	2	3	4	2	3	3	4	5	5	1	4	5	4
Chronology	**0 - 2**	1	1	1	0	2	0	1	2	1	0	2	1	1
SUB-TOTAL:		**3**	**4**	**5**	**2**	**5**	**3**	**5**	**7**	**6**	**1**	**6**	**6**	**5**
E. SCIENCE														
Modern Science	**0 - 5**	3	3	3	2	3	3	4	4	4	5	4	4	2
History of Science	**0 - 2**	0	1	1	0	1	2	1	2	1	2	2	0	0
SUB-TOTAL:		**3**	**4**	**4**	**2**	**4**	**5**	**5**	**6**	**5**	**7**	**6**	**4**	**2**

SUMMARY														
A. Faulting and subsidence	**Out of 7**	**5**	**7**	**5**	**5**	**7**	**5**	**4**	**5**	**6**	**4**	**5**	**6**	**6**
B. Magmatism	**Out of 7**	**1**	**2**	**5**	**3**	**1**	**2**	**3**	**6**	**6**	**7**	**5**	**7**	**6**
C. Uplift	**Out of 7**	**3**	**5**	**5**	**3**	**5**	**5**	**5**	**7**	**4**	**1**	**4**	**6**	**6**
D. Connectivity	**Out of 7**	**3**	**4**	**5**	**2**	**5**	**3**	**5**	**7**	**6**	**1**	**6**	**6**	**5**
E. Science	**Out of 7**	**3**	**4**	**4**	**3**	**4**	**5**	**5**	**6**	**5**	**7**	**6**	**4**	**2**
FULL TOTAL	**Out of 35**	**15**	**22**	**24**	**15**	**22**	**20**	**22**	**31**	**27**	**20**	**26**	**29**	**25**

In continental break-up, the divergence is accomplished by a **trinity of essential processes**: subsidence, magmatism and uplift. Each may operate at a different time and in a different order depending on the plate tectonic context. This imprints a different record on the landscape. Because of this diversity, just like for collisional plate boundaries, a full representation of the various expressions of this major process would require other sites to be nominated on the World Heritage List, to cover a full range of break-up features and tectonics contexts.

This comparative analysis is synthesized (e.g. the full analysis and expert elicitation in annexes) to focus on the three important processes of continental rifting, as well as their connection and the site's scientific standing. The purpose is to find the most representative property for a clear illustration of the continental break-up process as a whole.

It is built on **sound scientific feed-back and supported by a broad range of researchers** (e.g. detailed list in annexes) who have worked on each site. They have assisted in the choice of sites, the review and validation of each site description and its scoring. The comparative analysis is thus as robust and objective as possible.

For each of the five categories of indicators defined in the scoring table page 33 (subsidence, magmatism, uplift, connectivity, science), one or more site top(s) the list:

- **Subsidence:** Steens mountain and Tunka are among the best examples of escarpments in the world, while the Limagne fault, although clearly marked, does not have the same height and length. But both Steens and Tunka do not cluster associated volcanic features and so, do not provide a full picture of the rifting process.

Steens mountain is a vast site with a very well-expressed escarpement, but the associated volcanism is remote, 40 km away from the faulting. This does not allow a full picture of the whole rifting process
© M. Miller

- **Magmatism:** Virunga and Adama present undoubtedly the most impressive and active volcanoes, but those volcanic features largely overshadow the subsidence and uplift features. The Chaîne des Puys is a smaller dormant field, but it is exceptionally varied (all the varieties of alkaline magmas are present), parallel and proportionate to the Limagne fault, conveying a strong sense of connection between volcanic and tectonic features.

- **Uplift:** The nominated property excels in uplift expressions with a long inverted relief (The Montagne de la Serre), a tilted plateau and uplifted sediments. It acts like a geological clock which traces the chronology of the rifting process in the landscape.

- **Connectivity:** here again, The Chaîne des Puys - Limagne fault tectonic arena stands out in the number and clarity of connections that demonstrate the different rifting components. Concentration, layout and co-visibility of the property's features have no equivalent and create a very characteristic landscape, accessible even to non-specialists. For this it is a true continental break-up classic.

- **Science:** many of the compared sites, especially in the East African rift, are of great significance for both past and modern science, such as Virunga volcanoes which are a must for volcanologists. Ever since modern science began in the 18th century, the Chaîne des Puys - Limagne fault has been a mecca for geologists and continues to this day with important scientific works appearing every year on rift-related processes[1].

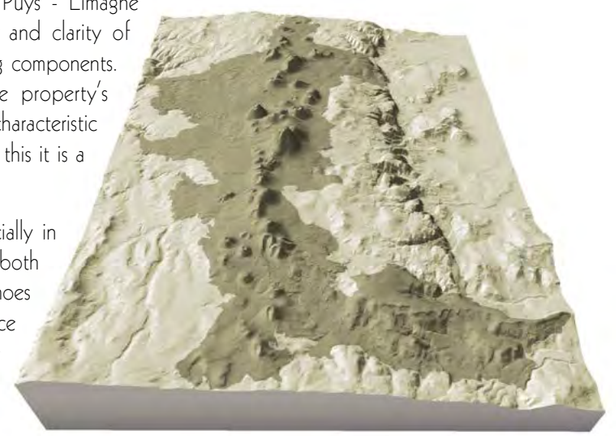


Fig 13. Proximity, proportionality and geometry of rifting features in the Chaîne des Puys - Limagne fault tectonic arena
© E. Langlois, CERAMAC

Along with the Chaîne des Puys - Limagne fault, two sites of the East African rift are very highly placed for all indicators:

- Malawi-Rungwe, which is a text-book example of hotspot rifting, although it does not display uplift as clearly;

- Adama-Boset very well expresses subsidence and magmatism in inter-rift faulting although it would need a much broader perimeter to display rift margins which are too far from the volcanoes. In doing so the site would lose in connectivity;

This comparison shows that the Chaîne des Puys - Limagne fault regroups excellent expressions of all the rifting features (subsidence and faulting, alkaline volcanism and uplift evidence) and **stands out in relation to their linkage**. Their genetic relationship is indeed obviously exhibited in the landscape because of their striking proximity, proportionality and geometry (Fig. 13).

1 - Martel, C., Champallier, R., Prouteau, G., Pichavant, M., Arbaret, L., 2013, *Trachyte phase relations and implication for magma storage conditions in the Chaîne des Puys (French Massif Central)*, Journal of Petrology, Oxford University Press (OUP), 2013, V. 54: 1071-1107.
Maccaferri, F., Rivalta, E., Keir, D., Acocella, V., 2014, *Off-rift volcanism in rift zones determined by crustal unloading*, Nature Geosciences, 7(4), 297–300.
Maccaferri, F., Acocella, V., Rivalta, E., 2015, *How the differential load induced by normal fault scarps controls the distribution of monogenic volcanism*, Geophysical Research Letters. V. 42: 7507–7512.
France L., Demarcon, M., Gurenco AA., Briot, D., 2016, *Oxygen isotopes reveal crustal contamination and a large, still partially molten magma chamber in Chaîne des Puys (French Massif Central)*, Lithos V. 260: 328-338.

While the nominated property **predominates in connectivity and for its on-going uplift processes** (especially inverted relief), it also **scores high in all other aspects**, which is not the case for the twelve compared sites, where **one or more elements are weaker or are disproportionate**. The proportionality for the nominated property is exactly related to it being an actively uplifting stage of a mountain related rift.

Conclusion

Continental break-up is an intricate part of the Wilson cycle in plate tectonics, the fundamental paradigm for how the solid Earth works. Break-up takes tens of millions of years to happen, starting as a continent begins stretching outwards. After this immensely long break-up stage, the continental fragments eventually separate to form ocean ridges after a transitional phase called 'oceanization'. This whole process of breaking continents is repeated continually over vast eons of time, and is a defining characteristic of the Earth compared with other planets.

The nominated property is a **highly representative of the trinity of rifting processes and a perfect archetype of a mountain related rift**, where the subsidence precedes magmatism and uplift comes later. This is remarkably seen on the Chaîne des Puys - Limagne fault landscape by **an explicit sequencing of distinctive geomorphological features and their intrinsic links**. An **exceptionally complete, diverse and eloquent expression of the continental break-up process** is seen in the Chaîne des Puys - Limagne fault tectonic arena. This is the underlying essence of its outstanding universal value.

The Chaîne des Puys - Limagne fault superbly displays the trinity of rifting features in its landscape
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3.3 Proposed Statement of Outstanding Universal Value

Brief synthesis

The Chaîne des Puys - Limagne fault tectonic arena, situated in the Auvergne-Rhône-Alpes Region in the centre of France, is an emblematic segment of the West European Rift, created in the aftermath of the Alps 35 million years ago.

In an aesthetical and theatrical landscape, the nominated property provides an **exceptional illustration of a spectacular and fundamental phenomenon in the Earth's history: the break-up of continents**. Imprinting the landscape, the long Limagne fault, the scenic alignment of the Chaîne des Puys volcanoes, and the inverted relief of the Montagne de la Serre, show how the continental crust cracks, then collapses, allowing deep magma to rise, causing widespread uplift at the surface.

Densely grouped and strikingly interconnected, these features provide direct access to this **major geological phenomenon**, of gigantic size and duration, and to its **overall understanding**.

Criterion (viii)

Continental drift is the main underpinning theory of Earth Sciences. It explains the current make-up of oceans and continents and their past and future movements. The nominated property is an exceptional illustration of the phenomenon of continental break-up, or rifting, which is one of the five major stages of plate tectonics.

The Chaîne des Puys - Limagne fault tectonic arena **presents a simultaneous view of all the archetypal processes of continental break-up and reveals their intrinsic links**. The geological formations of the nominated property, and their specific layout, illustrate with exceptional

An archetype of mountain-related rift
© J. Way

clarity, this colossal process and its effects on a large and small scale on the landscape. This concentration is **unparalleled in its completeness, density and eloquence**. This is one of the reasons why this site has been used as a scientific example since the 18th century for the study of classical geological processes.

Integrity

Due to its size, continental break-up creates rift systems several thousands of kilometers long. The site's perimeter encloses a surface area of 242 km² with no spatial discontinuity, comprising all the elements necessary for a full presentation of this process. **All the most impressive and best preserved examples are included.**

The site includes the most impressive section of the fault, which forms a marked border between the flattened continental basement and the wide adjoining graben. It also contains a young volcanic field, unaffected by erosion, exhibiting the complete spectrum of typical magmas in rift zones. Lastly, the long lava flow of the Montagne de la Serre, from an earlier phase of volcanism, straddles the basement and the sedimentary basin, which it overlooks. This inverted topography is a characteristic indicator of the wide-spread uplift which affects rift zones.

This natural site has a long history of conservation measures; it is sparsely inhabited (16 inhabitants/km²), with the main population being concentrated on the adjacent Limagne Plain. The geological features encompassed by the site's perimeter are **very largely intact**: they are preserved from urbanisation; the erosion is very superficial and has not altered the structures; and quarrying activity affects only a very minor part of the nominated property. Overall, human impact remains very limited and in no way compromises the geological value of the Chaîne des Puys - Limagne fault tectonic arena, **in accordance with paragraphs 90 and 93 of the Operational Guidelines concerning the integrity of the site in criterion (viii)**.

Protection and management requirements

The site has been the **object of management and preservation measures for nearly one hundred years**, under the impetus of local actors and supported by the State. Preservation of the outstanding universal value means preventing any degradation to the geological features and maintaining, even accentuating, their visibility in the landscape. The main potential threats that have been identified are thus the quarries, urbanisation, encroachment of forest covering the geological outlines, and erosion of soils linked to human action. **All of these threats are now managed** via a combination of regulatory measures, a proactive plan of action, and the availability of dedicated human and financial means.

The site is subject to **very strong national legislature** (classified site, the Montagne Law, the quarries plan) which **applies to both public and private land**. This prohibits in particular the opening of any new quarries, imposes that State authorisation be obtained for any changes to the site, and prohibits or strictly limits construction with a strong State regulatory control and monitoring on public and private land within the site. In addition there are local regulations which reinforce and add greater precision to these environmental, landscape and urban protection measures.

Proactive management measures are also applied to the site through a tailored management plan which is well-provided-for in terms of human and financial means. This operational plan of action is mainly directed towards the preservation of the geological features and their clarity of outline, management of visitor numbers, ensuring a place for traditional local activities, and informing the public of the outstanding universal value.

The clouds in the Limagne graben foreshadow the stage after continental rifting: the opening of an ocean. The effects of the rifting on Earth's surface and the landscape on a large scale.

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