Chaîne des Puys and Limagne fault tectonic arena, FRANCE
Chaîne des Puys and Limagne Fault tectonic arena, France

Additional information for the nomination to the World Heritage List

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Signature
on behalf of the State Party

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Permanent Delegate of the French Republic to UNESCO
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Foreword

A consistent argument but a confusing wording

The Chaîne des Puys - Limagne fault tectonic arena is nominated for inscription under criterion (viii). This emblematic segment of the West European rift is an exceptionally complete, diverse and eloquent expression of the continental break-up process.

This additional package is the result of a fruitful and iterative work with the IUCN under the auspices of the World Heritage Center. In that regard, we would like to pay respects to the professionalism and thoroughness of Mrs Metchild Rossler, Mr Tim Badman and their respective teams, who have accepted to take part to an in-depth discussion during the last two years. The technical exchange allowed the French State and the local stakeholders to understand the former misreading and attain a better definition of the potential outstanding universal value, as acknowledged by the World Heritage Committee in its decision 40 COM 8B.13.

A clarified and reformatted justification, along with the withdrawal of criterion (vii), supports this additional information package. The aim was:

- To comply with the nomination format regarding the justification for inscription;
- To articulate a clear heritage narrative maintaining a robust scientific content;
- To ensure the independence and objectivity of the comparative analysis through an international expert elicitation;
- To provide additional information on management issues as required by the World Heritage Committee in its last decision.

Thanks to the constructive IUCN feedback, the French State and the local stakeholders have been able to identify the enduring problems with this application, despite favorable reports from the international scientific community and the Independent Technical Mission mandated in 2015. Indeed, the previous propositions were too dense and complex. The OUV statement was based on too many foundations, focusing on each of the geomorphological features of the rifting instead of the whole process itself. It sounded like a collection of geological features and gave the assessors a confused impression.

To amend this, some necessary adjustments have been made to the terminology employed and the way of presenting the main rationale. The wording has been simplified to better express our consistent argument: the Chaîne des Puys - Limagne fault tectonic arena presents a complete sequence of the processes that give rise to continental break-up.

The contribution of international scientists has been essential in that context. This additional synthesis has once again required a huge amount of scientific materials, academic articles, as well as an intense expert elicitation so to be able to provide an updated and objective comparative analysis. More than twenty first-class rift specialists from different parts of the world have been solicited. It allows the present comparative analysis to deliver a global, rigorous and objective vision of the Earth’s continental rift systems and their specific segments.

Because plate tectonics are an essential paradigm for the history of the Earth, the French State defends the Chaîne des Puys - Limagne fault tectonic arena for nomination on the World Heritage List as an eminently representative site to illustrate continental break-up. It is unequaled globally in terms of its completeness, density and clarity of topographic expression, providing a unique evidence of the genetic and chronological links between the rifting features.
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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 km² (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 Pangaeic 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.

- 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.

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.
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.

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 makeup 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).

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).

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 Geologically 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.

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.](https://via.placeholder.com/150)
The Chaîne des Puys - Limagne fault tectonic arena: an exceptionally representative example of the process of continental break-up

Less than 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 kilometres 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.

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 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 exceptionally 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. 3.1b), as well as geological elements which testify to their fundamental interdependence. The perimeter thus contains:

- 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 Serré. 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 Serré. 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 Serré 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.  

These fundamental attributes, as well as their intrinsic relationships (volcanic alignment parallel to 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 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 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.

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 and the latest demographic figures indicate a slight reduction in population within the site and a low percentage of second homes (8.7%).

**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 Sere are concerned, they are relatively clear of woodland.
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 Sère 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. The 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, 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, 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.

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:

1. 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;
2. 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 pozzolane quarries, which will be incorporated into the revised plan which is currently being drawn up;
3. 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. 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:

1. 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 Sère) are speciﬁcally identiﬁed as natural zones to be preserved;
2. National and local measures provide speciﬁc protection for the exceptional ecological zones (Natura 2000, Sensitive Natural Areas);
3. Lastly, forestry regulations allow for the implementation of strategies to share land-use between forest and pasture.

1 - Classification of the puy de Dôme volcanoes in 1933 in the domain of landscape and sites.
2 - Sixth site to be listed in France.
3 - IUCN 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-requisite 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.
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.

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 million euros, of which 46.5 million euros 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 euros over five years towards the management of the nominated property.

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: 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 rift and its passive or active nature. So there is no single classical sequence with one feature appearing first, then is overlain, destroyed, or juxtaposed by another one. Also each of these phenomena is associated with characteristic morphologies. 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 rift process.

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.

The reasons 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).

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, just like the Dead Sea. But the rift zone includes a graben/basin, volcanoes, and uplift. If the graben/basin is the most visible feature, the volcanoes and uplift are often not perceived if they are not associated with the graben/basin. If the graben/basin is not visible due to superimposed sediments or water, the volcanoes and uplift are not visible either.

4 - Downthrow: faulting and graben / basin; volcanism; 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.

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.

Prerequisites – 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. 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.

SOMALIA
ETHIOPIA

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 prominence and liability of the three constitutive phenomena. © C63
The pre-selected sites

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

1. Sandia Peaks and the Petroglyph national monument (USA)
2. Steens Mountain Rift and Diamond Craters (USA)
3. Mateare fault and Chiltepe Volcano (Nicaragua)
4. Hula valley and Golan Heights (Israel, Lebanon, Syria)
5. Northern Tunka (Russia)
6. Freibourg – Kaisersuhl (Germany)
7. Krušné Hory fault (Czech Republic)
8. Limagne fault and Chaîne des Puys volcanoes (France)
9. Lake Malawi fault (Tanzania, Malawi)
10. Muhindo Escarpment and the Virunga Volcanoes (DR of Congo, Rwanda)
11. Kenya Lakes (Kenya)
12. Adama rift – Boset volcanic centre (Ethiopia)
13. Akid 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.

<table>
<thead>
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<th>INDICATORS</th>
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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. 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.

Steens Mountain Rift and Diamond Craters

Description: The Steens Mountain’s fault is 1800 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 (3518 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.
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 kilometers 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.

Hula valley and Golan Heights

Description: The Hula valley - Golan Heights is located at the very end of the Dead Sea rift. The site encompasses a small pull-apart basin (85 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 neat 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.
Northern Tunka

Description: The Tunka rift segment is 15 km away from the Lake Baikal. It is a deep structural depression, 45 km wide and 100 km long, flanked by steep alluvial fans and glacial moraines. The fault scarp to the North is sharp and demarcates the change from plain. The basin contains the small Chersky 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.
- 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.

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 fault 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 Kaiserstuhl 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.
**The Krušné Hory fault**

**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.

**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. The 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.

**Limagne fault and Chaîne des Puys volcanoes**

**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.
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 strato-volcanoes. 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 textbook style of hotspot rifting.

Weak points:
The volcanoes do not present very strong alignments along faults, their intra-rift situation gives 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.

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, 1,000 m high and 55 km long) and Lake Edward escarpment (1,100 m high, 80 km 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:
Migmatism 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 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 grabens 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 (criterion (vi), (ix), (x)).

Strong points:
This site provides two examples of the main types of graben (full and half). They clearly display the interlinked 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.

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 (350 m high), while the East side had only a 40 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.
**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**

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**SUMMARY**

| A. Faulting and subsidence     | Out of 7 | 5 | 7 | 5 | 5 | 7 | 5 | 4 | 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 | 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 | 2 | 4 | 5 | 5 | 6 | 5 | 7 | 6 | 4 | 2 |
| **FULL TOTAL**                 | Out of 35 | 15 | 32 | 36 | 55 | 22 | 20 | 22 | 21 | 27 | 30 | 36 | 29 | 35 |
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 feedback and supported by a broad range of researchers (e.g. a 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(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.

**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 Sire), 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.

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 textbook 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).

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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.

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
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 flatter 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 Sère, from an earlier phase of volcanism, straddles the basement and the sedimentary basin, which it overlies. This inverted topography is a characteristic indicator of the widespread 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.
Additional information on management

1. Active quarries: minor boundary modifications while awaiting definitive closure...
2. For a better understanding of regulations
3. Strengthening the implementation of regulations

In response to the questions posed by the World Heritage Committee in their document 40 COM 8B.13 about the management of the site, the following material provides complementary information concerning:

- Minor modifications to the boundary of the nominated property to temporarily exclude the two active pouzzolane quarries, up to their imminent definitive closure;
- Application and up-to-date knowledge of the different legislative measures applicable to the nominated property and its buffer zone;
- New commitments by the State party aimed at reinforcing joint management with the different stakeholders, particularly for private land.
1. Active quarries: minor boundary modifications while awaiting definitive closure

There were two active pozzolane quarries within the site’s perimeter. While they only cover 0.1% of the overall surface area, are undergoing landscape rehabilitation, and have a working lifetime limited to 1 and 13 years respectively, their presence is nevertheless incompatible with World Heritage Status.

France agrees with this, and has therefore undertaken official commitments concerning the termination of this activity in the Chaîne des Puys. This issue is fully dealt with in the management plan, which:

- Protects the site from any new quarrying activity, in accord with the Departmental Quarry Plan which stipulates that for pozzolane quarries “any request for a new operation within the classified and protected sites of the Chaîne des Puys will be rejected except if it involves the rehabilitation of a highly damaged site”. In addition, the Schéma de Cohérence Territoriale (territorial coherence plan) for Greater Clermont states that it is “forbidden to find or open new operational sites within the Greater Clermont perimeter that are located in the heart of protected natural environments with significant landscape features”. The Chaîne des Puys, the Limagne fault and the inhabited relief of the Montagne de la Serré, the three major geological components of the site, constitute part of this protected natural environment and significant landscape features. Local planning documents must abide strictly by this legislative document, and in consequence could not sanction the opening of any new quarry;

- Engages to follow through with exemplary rehabilitation of the active quarries in collaboration with the quarry operators and the Auvergne Volcanoes Natural Park;

- Together with the Ministry for Ecological Transition and its regional services, will monitor the closure of the two active pozzolane quarries.

This last point constitutes one of the management plan’s central issues, and is the object of binding commitments on behalf of the State to not renew the extraction permits of the two existing operators when they expire. This was made official in a letter from Ségolène Royal, then Minister for the Environment, Sustainable Development and Energy, dated 9 October 2015 (see below).

In the meantime, in accordance with the World Heritage Committee’s request, the State party has carried out minor alterations to the boundary of the nominated property, in order to temporarily exclude the two active pozzolane quarries. Once they are closed and have been definitively rehabilitated, they will be reintegrated into the site’s perimeter as they constitute an integral part of the Chaîne des Puys volcanic alignment.
Les deux carrières actives retirées du périmètre du bien avec pour objectif une réintégration future après fermeture et réaménagement.

**Puy de la Toupe Quarry**
- Planned closure in 2018
- Surface area: 0.10 km²
- Coverage:
  - 0.04 % of the central zone of the nominated property
  - 29.74 % of the edifice involved

**Tenusset Quarry**
- Planned closure in 2030
- Surface area: 0.16 km²
- Coverage:
  - 0.06 % of the central zone of the nominated property
  - 35.45 % of the edifice involved

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**La ministre**

Monsieur le Président,


Je vous confirme que la France soumettra à l’inscription sur la Liste du patrimoine mondial de l’UNESCO, la candidature de la Chaîne des Puys et la Faille de Limagne comme aire d’une beauté naturelle exceptionnelle et en tant que témoignage des grands stades de l’Histoire de la Terre.

Afin de répondre aux demandes du Comité du patrimoine mondial, nous avons accompli conjointement et avec l’ensemble des parties prenantes un important travail d’amélioration du dossier. Celui-ci a été présenté cette semaine aux experts scientifiques proposés par les grandes organisations géologiques internationales pour faciliter les échanges entre nous et l’Union internationale de conservation de la nature. Le dialogue fructueux qui s’est établi permettra encore d’enrichir le dossier qui devra être remis en janvier prochain.

La Chaîne des Puys et la Faille de Limagne doivent être préservées et je salue vos efforts pour mettre en place un plan de gestion effectif avec les acteurs locaux. Plus particulièrement, l’exploitation des ressources naturelles sur ce site a été soulevée dans le rapport de l’Union internationale de conservation de la nature en 2014 et nous devons y répondre.

Aujourd’hui la réglementation interdit déjà la création de toute nouvelle carrière dans la Chaîne des Puys et seules deux carrières de pouzzolane restent en activité. Ces autorisations portent sur des quantités et une durée de vie limitées et une remise en état paysagère est prévue.

Monsieur Jean-Yves GOUTTEBEL
Président du Conseil départemental du Puy-de-Dôme, Vice-Président de l’Assemblée des Départements de France – Hôtel du Département
24 rue Saint-Esprit
63003 CLERMONT-FERRAND CEDEX 1

Hôtel de Région – 261, boulevard Saint-Cernin – 75007 Paris – Tél : 33 (0)3 46 81 21 22
www.developpement-durable.gouv.fr
2. For a better understanding of regulations

Specific information tools have been developed by the project leaders, within the framework of the management plan and its implementation, to monitor the land use and regulations in place on the site and its buffer zone. They target four main groups of people:
- inhabitants and land owners;
- visitors (tourists, professional guides, school parties and their leaders, organisers of sports events);
- socio-economic actors (farmers, forestry workers, local entrepreneurs);
- elected representatives.

The aim of these tools is to define the specificities of the site, both its heritage value and its vulnerable aspects, and the scope of current regulations. They can be divided into three categories:

- A wider availability of information about regulations and their boundaries of their application. This information is disseminated via the website of the Ministry of Ecological Transition, notably through interactive maps and a geographic information system, to make it easier for people to locate the perimeters for the application of the various laws. There are also websites directly related to the property, notably the Departmental Council’s website.

- Other documents reinforce this online information and are specifically aimed at:
  - visitors: mainly comprising geotourist maps and information sheets on the vulnerabilities of the site (edited by the Departmental Council and made freely available in French and English at all the tourist centres and visitor sites in the Department).

1. Geographic information system to locate the regulation limits of application © DREAL
2. Information leaflets and geotourist maps for visitors (available in French and English) © CD63
people involved in tourism: comprising a Professional Guide to Tourism in the Chaîne des Puys - Limagne fault (given to all the Tourist Offices in the Department and those involved in local tourism), with an additional Teachers Guide for leaders of school parties;

forestry workers: comprising a Forestry Charter for the Classified Site – a guide for good management practice within the perimeter of the Chaîne des Puys - Limagne fault (produced by the regional State services who oversee forestry practice within the nominated property);

sports clubs: by means of an events timetable and information page to prevent over-use in certain areas at peak times of the year, as well as to remind users of the rules applicable to the site.

Regular discussion meetings to allow direct exchanges and satellite meetings to reach a broader audience:

- During Local Commission meetings (local governance body which includes representatives of all the site’s stakeholders) and in regular scheduled meetings held in communes throughout the site between elected representatives and inhabitants;
- Through information bulletins (the newsletter dedicated to the application has more than 55,000 followers) and media releases (a series of themed programmes dealing with the geology of the site, its vulnerabilities and the management issues).

In addition, there are specific signs up around the countryside about the regulations in place (visitor traffic, dogs to be kept on a lead to avoid problems with grazing animals, and unauthorised access), as well as physical barriers (fencing made of natural materials, low barriers marking authorised paths, and trellises) and information boards.

3. Strengthening the implementation of regulations

As described in section 3.1e (pages 24 to 26), the site is protected by a very strong regulatory network which applies equally to public and private land.

Local teams in charge of the site’s management have been using a range of means to ensure the proper implementation of these legislative protections. Since 2016 four guiding measures have made it possible to reinforce the application of legislation to private land:

- Specialised training for outdoor guides who bring people to private properties open to public, thus enabling them to improve the level of information and awareness among their groups. A diploma is issued to those who pass the training programme set up by the Auvergne Volcanoes Natural Park, as well as a request to respect quotas in terms of visitors per day at certain sensitive sites.

- Preventative actions and control measures in sensitive sectors of the site:
  - the presence of Park rangers from the Auvergne Volcanoes Natural Park, civic services, and rangers on horseback from the National Forestry Service in the most heavily-visited areas, carrying out the dual role of monitoring and harmonising land-use on the site;
  - the creation of an on-line reservation site by the Clermont-Ferrand Schools Academy in order to ensure a better distribution of school trips;
  - Coordinated control meetings between State groups and their institutional partners (Park rangers, municipal police, gendarmes, forest rangers, environmental inspectors and mediations). The aim of these day-long workshops is to inform the general public about the regulations applicable to the site and to carry out checks.

- Coordinated control meetings between State groups and their institutional partners to inform the general public about the regulations applicable to the site and to carry out checks.

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Help towards unifying the private land owners into associations in order to create a decision-making body which can act as the representative for local groups in terms of site management issues. This not only provides the land owners with the opportunity to choose what actions will be implemented on the site, but also allows the public bodies to deal with a single representative to set coordinated conservation measures in motion.

Experimental contractual projects which enable model means of management to be developed for private land. Such measures are in place on nine of the Chaîne des Puys edifices (with a total budget of 500,000€): Puy de Jumes, Puy de la Coquille, Puy de Chaumont, Puy de la Mey, Puy de la Vache, Puy de Charmont, Puy de Lassolas, Puy de Combegrasse and Puy de la Rodde (from north to south).

The philosophy behind these projects is to work closely with the owners or managers within the framework of multi-disciplinary agreements between the State, the Department, the Auvergne Volcanoes Natural Park and the stakeholders. The aim is to define together medium and long term measures to improve the appearance of the geological forms within the context of new forestry practices linked to a return to pasturing. In particular forestry practices need to ensure the preservation of the fragile volcanic soils, the biodiversity of the sites (notably ‘nesting’ and older trees), and to encourage the development of greater diversity in terms of age and species.
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Annex
Expert elicitation of the detailed comparative analysis

World Heritage List

Within the framework of the referral of the nomination to the World Heritage List

Chaîne des Puys and Limagne Fault Tectonic Arena, France

November 2017
Chaîne des Puys and Limagne fault tectonic arena, FRANCE

Annex
Expert elicitation of the detailed comparative analysis

November 2017
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Expert elicitation:
list of the consulted international rift specialists

Between August and November 2017, about 30 rift experts have been solicited to build up the site descriptions and analyse their features. Each scoring table has been submitted to, corrected and approved by the following scientists, allowing an objective and robust comparative analysis.

A. Rift System: The Rio Grande rift
   1. Segment: Albuquerque segment – Site: Sandia Peaks / Petroglyph national monument
      - Mike Petronis - New Mexico Highlands University, USA
      - William I. Rose - Michigan Tech, USA
      - Fraser E. Goff - The University of New Mexico, USA

B. Rift System: The Basin and Range province
   2. Segment: Basin and Range North – Site: Steens Mountain Riff / Diamond Craters
      - Anita Grunder - Oregon State University, USA
      - Mike Petronis - New Mexico Highlands University, USA

C. Rift System: The Central American rift
   3. Segment: Nicaraguan Depression – Site: Mateare fault / Chiltepe Volcano
      - Peter LaFemina - Penn State, USA
      - Hugo Delgado - Instituto de Geofisica, Mexico

D. Rift System: The Dead Sea rift
      - Amotz Agnon - Hebrew University of Jerusalem, Israel
      - Eoghan Holohan - Helmholtz Centre Potsdam, Germany

E. Rift System: The Balkal rift
   5. Segment: Tanka Rift – Site: Northern Tanka
      - Hans Thybo - University of Oslo, Norway
      - Irina Artemieva - University of Copenhagen, Denmark
      - Alexander Shchetnikov - Institute of the Earth’s Crust, Irak, Russia

F. Rift System: The Western European rift
      - Peter Bitschene - Geopark Volcanéif, Germany
      - Steffi Burchardt - Uppsala University, Sweden

   7. Segment: Eger Rift – Site: the Krušné Hory fault
      - Vladislav Rappach - Czech Geological Survey, Czech Republic
      - Karel Martinek - Charles University, Czech Republic

   8. Segment: Limagne Rift – Site: the Krušné Hory fault - Chaîne des Puys
      - Alvaro Marquez - King Juan Carlos University, Spain
      - Alessandro Tibaldi - University of Milan, Italy
      - Derek Rust - University of Portsmouth, UK

G. Rift System: The East African rift
      - Karen Fontijn - University of Oxford, UK
      - Cindy Ebinger - Tulane University, USA

   10. Segment: Western branch of the East African Rift – Site: Malindi Escarpment / Young Volcanoes
       - Nicolas d’Oreye - European Center for Geodynamics and Seismology, Luxembourg
       - Benoît Delcamp - Vrije Universiteit Brussel, Belgium

       - Karen Fontijn - University of Oxford, UK

   12. Segment: Central Ethiopian Rift – Site: Adama rift /Bolet volcanic centre
       - Giacomo Corti - University of Florence, Italy
       - Derek Keir - University of Southampton, UK
       - Melanie Sieberg - University of Southampton, UK
       - Ian Bartow - Imperial College, UK
       - Miruts Hagos - University of Mekelle, Ethiopia

   13. Segment: Afar Riff – Site: Alid volcano
       - Steve Drury - Open University, UK
       - Joel Rush - King Abdullah University for Science and Technology, Saudi Arabia
       - Miruts Hagos - Mekelle University, Ethiopia

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*Limagne fault and graben seen from the South*
Indicators for the scoring of a continental break-up site for UNESCO World Heritage and the assessment of the value of the Chaîne des Puys - Limagne fault tectonic arena

In the context of the Chaîne des Puys - Limagne fault World heritage candidacy, the IUCN has invited the French State to simplify and make more comprehensive and objective the case of its application. To do so, the views of international scientists are required to review and revise the mandatory comparative analysis.

To be nominated on the World Heritage List, a site has to provide a simplified, popularly understandable statement to demonstrate that it is of outstanding universal value. This statement has to be challenged by comparing its features and merits with equivalent sites to determine if it is the most representative site of its category. To avoid bias, the French State committed to submit its own comparative analysis to experts of each of the thirteen compared sites.

The Chaîne des Puys - Limagne fault is applying to World Heritage as a continental break-up representative that is an exceptionally complete, diverse and eloquent expression of this process. Its strength is to be clearly visible, proportionate and exemplary arranged. 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 rifting process in itself. In each case, the rift is but a backdrop (Virunga, Kenya Lakes, Ngorongoro, lake Malawi, Lake Turkana, Kondoa Rock-Art Sites), the properties were nominated either for their aesthetic values, the biodiversity or their cultural assets. The reason of this absence can be related to:

- the size of the continental break-up process;
- its time scale;
- its lack of accessibility for non-specialists.

So in many cases, the features are scattered over large areas without visual connection, so that it is difficult to 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 and displayed all together in a clear and coherent landscape.

The aim of this comparative analysis is to determine which site encapsulates the most elements of continental break-up and express their intrinsic connection. And doing so, which site 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 will stand along with tectonic structures as inherent parts of the continental break-up process and 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 the major stages of the drift of continents, characterized by divergence and convergence phases. Some World Heritage properties already illustrate plate tectonic movement as theorised in the Wilson cycle. There are several examples of continental collision for instance, but oceanization, oceanic ridge and continental break-up are not yet represented per se on the List and various sites could be eligible in the future to cover the full spectrum of plate tectonics as a whole.

**Scoring**

This is a heritage recognition exercise that has to be supported by sound science and also needs to be accessible to non-specialists. So it must be general and based on noticeable aspects. In that regard, geomorphological and topographical indicators will be favored to evaluate each feature.

The scoring method is defined after Biha (2016, Czechheritage 8(2):119-134); major indicators will be scored from 0 to 5, additional once from 0 to 2 to balance their importance. Each reviewer will have to go through the site description and the scoring table.

**A. Faulting and subsidence**

The primary process of continental break up comes through faulting and thinning of the crust, which causes the surface to subside making a basin. Sediments eroded from the fault 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.

- **Net faulting:** one or several linear escarpment(s)/ fault plane / clear subsided area (grabens) (scoring from 0 to 5)

**Additional indicators (scoring from 0 to 2):**
- Pronounced surface processes and minor scale outcrops of faults and fractures: erosional or sedimentation features, on-going transport seen in the landscape
B. Magmatism
The rifting process brings the mantle up, causing it to melt, and from that point, magmatism takes an active role in continental break-up. The rifting magmatism is first characterized by alkaline major composition (difference from hotspot and subduction zones) and second, by the diversity of chemical range due to the substantial modification of both mantle and crust. That instigates diverse magmas and the formation of chambers at different levels. Visible and significant magmatic features will be scored: volcanoes, lava flows, flood basalt, intrusions... To be in accord with heritage values, fresh volcanoes will be the most valuable assets in comparison with other magmatic features because they are the best known and recognizable magmatic expressions.

- Remarkable rifting magmatic features in the landscape (alkaline volcanism, number, surface area, size, visible diversity of magmas, freshness (scoring from 0 to 5)

Additional indicators (scoring from 0 to 2):
- Activity: persistent activity, active, dormant or extinct

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.

- Raised surfaces — old surfaces raised high (scoring from 0 to 5)

Additional indicators (scoring from 0 to 2):
- Uplifted sediments / plateau dipping away from rift: sediments deposited low down now found high up / evidence of the uplift dome

D. Connectivity
It is challenging for a large audience to see a rift as a full system, including not only faulting/subsidence but also magmatism and uplift. In a heritage perspective, we are looking for sites that allow the continental break up to be understood as one single and integrated process. That means that all features are seen together and that there are visible causal links between them. What will be scored here is the fact that all the features are 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 the others.

- 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), geometry, proportionality of features (scoring from 0 to 5)

Additional indicators (scoring from 0 to 2):
- 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)

E. Scientific standing of the site

- Standing in the time after the plate tectonic revolution (50 years) (scoring from 0 to 5)

Additional indicators (scoring from 0 to 2):
- Standing in the beginnings of scientific understanding (beginning depends on geographical location and culture)
Sandia Peaks escarpment rises to 900 m high at its maximum, it is a 26 km long, irregular fault scarp which rises from the plane in the North and descends to a low eroded ridge at the Southern end. The escarpment is deeply cut but numerous erosional valleys indicating the age and long exposure of the fault (~30 My). Large buttresses stand out from the upper peaks giving the escarpment a stepped look. The back side is much smoother dip-slope conveying the uplift of the outer slope. The basin is low and flat with alluvial fans descending to the Rio Grande river plain. This plain is occupied by the river, ‘bosque’ (low brush savannah), and the city of Albuquerque. Down-cutting by the river in response to uplift has produced limited inverted relief in the rift-axis lavas of the Petroglyph volcanic field. This field is a 6 km long eroded alignment made of five small scoria cones and associated lavas (~170,000 to 70,000 years). The site is famous for its indigenous archaeological and cultural assets.

Why choose this site?

The Rio Grande rift (~1000 km long, 35–29 My) is a major rift system associated with extension west of the Rocky Mountains front. It runs from central Wyoming (USA) to Chihuahua (Mexico). Within this rift system, the Albuquerque segment is a half graben infilled with 4,407 to 6,592 metres (14,459 to 21,627 ft) of sediments associated with the Rio Grande river and associated slope alluvial fan and eolian deposits.

The most relevant site for continental break-up within this segment is the ensemble Sandia Peaks / Petroglyph national monument because it has the largest fault scarp of the Rio Grande rift with an aligned volcanic field below it. In addition, the Petroglyph lavas show inverted relief. Last, the site was quoted for comparison in the first IUCN evaluation report.

The Petroglyph field is located along a system of intra-rift ~N-S trending structures. These intra-rift faults served as conduits for magmas south of Albuquerque near Belen to the Embudo structure north of Espanola.

Other sites are less representative for comparison for the following reasons: the Sangre del Cristo fault with the Great Sand Dunes forms a remarkable half graben in the Northern Rio Grande rift, but has no magmatism. The Taos area has an irregular fault scarp and an old eroded volcanic plateau. The Santa Fe Valles caldera is extensive flat topography with no distinct fault scarp. The southern part of the Rio Grande rift becomes broad and dispersed from Socorro to the south. Fresh exposed faults are found just north of Taos Embudo, west of Las Alamos, Pajarito; just south of Santa Fe La Bajada-San Francisco, and very clearly at the Rincon Faults near Albuquerque.

It is noted that the two major volcanic fields of Mount Taylor (stratovolcano) and Zuni Bandera (dispersed monogenetic volcanoes) are not applicable as they are ~130 km from the fault and not located in the rift.

Continental break-up features analysis

Faulting and subsidence: There is an impressive long single fault scarp (23 km), rising from the basin at each extremity to a high central ridge (900 m). The escarpment is slightly eroded and the fault plane is exposed locally but is often covered by alluvium. The sedimentary deposits show on-going and clear basin filling in a desert continental rift environment.
with a clear progression from course fault scarps to a major river system. There are many more exposed fault scarps such as the Rio Grande rift system on the north end of the Sandia escarpment.

**Magmatism:** At the magmatic level, the Petroglyph volcanoes lineament is an existing eroded alignment of five small basaltic cones coeval with the fault. The alkaline basalt is rift-related but have very low diversity. An interesting note: At 110 Kya a sequence of lava flows erupted from Vulcan, the largest of the volcanoes, captured a transitional geomorphic field. This failed geodynamic polarity reversal is recognized globally as the Albuquerque excursion. This field is extinct.

**Uplift:** Regarding uplift, slight inverted relief of the Petroglyph lavas illustrates uplift of the basin but it is a subtle feature. The back slope of the escarpment clearly shows the rise of the fault block (evidence of uplift dome) but there are no uplifted sediments.

**Connectivity:** For concentration, the Sandia faulting and the uplift are juxtaposed so that their connection is clearly seen on the Sandia Peaks. However, the magmatic link is less clear as the few volcanoes are 30 km away from the fault, visually separated by the city of Albuquerque which covers most of the basin except from a North and South stripe. As stated above, the concentration of volcanoes is small, as there are only five, minor, quite separated cones. For disposition, the distance between volcanic and tectonic features blurs their intrinsic links. Also, the distance between the fault and volcanoes is small as they are only five, minor, quite separated cones.

**Science:** The Sandia Peaks segment has been part of the general research on the Rio Grande rift while not being outstanding in either pre or post tectonic research.
Description:
The Steens Mountain rift forms the North Westerly edge of the Basin and Range. The main fault is 1800m high and 80km long. It cuts a very large old stratovolcano (15 My) with glacial erosion which is tilted by uplift. The long segmented fault escarpment is formed of three successive sections with their own characteristics. The first one, is 20 km long next to lake Alvord, is strongly modified by landslides and eroded plateau lavas. The second one, is 30 km long and forms the highest part of the escarpment. It is steep and continuous although it is incised by deep quebradas and landslides. The northern segment changes direction and is 40 km long. It is the lowest and the straightest with a noticeable rotated fault blocks. The half-graben is filled with sediments in the South and narrows strongly in the North to expose the downthrown strata. Apart from the ancient Steens Mountain volcano, the main associated volcanic field is the Diamond craters which is an atypical basaltic monogenetic eruption made of uplift, lava flows and maars fed from underground sills (~25,000 to 9000 yrs). It stands at the foot slope of the uplift, 40 km away from the escarpment.

Why chose this site?
The Basin and Range is a 700 km wide succession of at least thirty tilted blocks of crust which form mountains ranges alternating with sedimentary basins. It is the largest and extended subduction related continental rift. The interior ranges tend to form a very symmetric and homogenous ensemble which is hard to differentiate from one another. Steens Mountain stands out in both scale (twice as long as the average Basin and Range structure), position (at the very edge of the Northern limit) and clarity of feature (freshness of the fault scarp) while still maintaining the typical geometry of Basin and Range. The Diamond Craters is at the base of Steens Mountain and is a superb basaltic monogenetic field, with spectacular uplifts, maars, collapse craters and lava flows concentrated in a small area.

The Salt Lake City segment forms the opposite side of the province and while high and long, it is a much more complicated fault system, not associated with magmatism.

The Death Valley marks the Southern boundary of the Basin and Range. It has evolved from an extremely stretched basin and range rift with a metamorphic core complex, to a pull-apart related to the San Andreas fault system, and therefore a complex type of continental rift. This complexity is translated into the landscape.

Continental break-up features analysis
Faulting and subsidence: the fault escarpment is particularly high and long but can be seen in its entirety from the basin, forming a striking et of ramparts rising up to a continual skyline ridge. Individual fault blocks can clearly be distinguished in the landscape giving the impression of downthrow into the basin. The half-graben is very net in the Northern section where it is at the same time tilted and clean from sediments. The processes of faulting and subsidence are strongly expressed in this spectacular landscape. 25 km to the North-West, on Diamond craters, outcrops of faults and fractures are a small scale replica of the main escarpment. Concerning surface processes, the deep valleys, ephemeral rivers, depositional fans and salt lakes provide a full sequence of rift sedimentation. At a small scale, the Steens Mountains faults are exposed in seasonal valleys.
There are two main volcanic features, The Steens Mountain itself and the Diamond craters. The first one is a broad shield and ancient shield-like volcano related to the Columbia river type flood basalts (60 km, 20 to 17 million years ago). The nearly 1,000 m thick Steens mountain lavas were erupted before the rifting and the province now extinct. Two large ignimbrites (Devine Canyon and Rattlesnake Ash-Flow tuffs) are also found in the area. They date from 9 and 7 M yrs respectively, and erupted just after rifting started. The ignimbrites form plateau that are not in inferred relief, especially near Diamond Craters volcano. The Steens volcano is cut by the fault and different from a classical volcanic edifice in being very flat. Seen from the basin it also has an irregular shape and long semided skyline that does not bring to mind a typical volcano to the lay person. Diamond craters are visually a long-way behind the fault scarp, at the foot of the uplift slope. This atypical extinct volcanic field is made of a complex mixture of uplift, explosion craters and lavas. It is more striking for its uplift and faulting than for its subtle and unusual volcanic assembly. A lay person would not immediately see Diamond craters as a volcanic field as there are no clear edifices.

 uplift: The process of uplift is well expressed in Steens Mountain with the raised lava beds, the inclined plateau and the concordant summit elevation. Inferred relief is clear but discrete in the landscape, the ridges being low and merging into the plateau.

connectivity: The area is large with the faulting and basin located on one area, while the volcanism is situated in a visually isolated part. So there are two highly concentrated areas, a large gap between them. For the disposition, there are the two groups of features that are visible separately, around Diamond fault and around Steens fault. Some small tectonic faults can be seen at Diamond (cutting the ignimbrite), and the older volcanics are exposed in the Steens area. They date from 9 and 7 M yrs respectively, and erupted just after rifting started. Two large ignimbrites (Devine Canyon and Rattlesnake Ash-Flow tuffs) are also found in the area. They date from 9 M yrs and 7 M yrs respectively, and erupted just after rifting started. The integrated interaction of uplift, explosion craters and lavas make the area the best known and recognizable magmatic expression.

magmatism: Alkaline volcanism, number, surface area, size, visible diversity of magmas, freshness (scoring from 0 to 5)

uplift: One or several linear escarpment(s)/ fault plane / clear subsided area (graben) (scoring from 0 to 5)

protection: Magmatism is a primary continental breakup process, characterized by rather complex and by slower compositions due to substantial mobilization of mantle and crust. Volcanic and ignimbrite magmatic tuffs are scored such as, volcanics, fault, fault planes, fault, faults, fissures, faults. To be accorded with heritage value, fault and active volcanism will be the most valuable assets because they are the best known and recognizable magmatic expression.

science: At a scientific level, the Basin and Range has high importance for global tectonics. At a scientific level, the Basin and Range has high importance for global tectonics. For the heritage perspective, we will not distinguish its different origins and will only consider its topographic expression.

Full total: 22
A 32km 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 years old). The fault escarpment is part of the still active Quaternary Central American Rift. The rift first opened as pure extension (in the early Quaternary) but has recently moved into mainly a strike-slip regime, so it is not opening any more but pulling apart along north-south oriented fractures.

The fault escarpment central part culminates at 300m high, tapering down to the North to lake Managua and to the South, merging with the high topography of Las Sierras caldera. The fault line is quite continual, trending North—North West, with small successive quebradas giving the escarpment a crenulated aspect.

The volcanic alignment is located inside the half-graben, at 20° offset from parallel with the fault. The 20 km long alignment is 6 km from the escarpment in the South; 8 km at Motatepe volcano in the center; and 12 km from the Chiltepe caldera in the North.

The basin below the fault is enclosed by the volcanic lineament, forcing drainage northward into lake Managua. The sediments consist of course alluvial fans interspersed with volcanic ash from the nearby eruptions. Most of the basin is occupied by farmland and Ciudad Sandino, the satellite city of Managua which stands on the other side of the volcanic alignment.

Why chose this site?

The Central American rift runs 650 km from Nicaragua to El Salvador, containing the eponymous volcanic arc. In southern Nicaragua, the rift boundary is low and unclear along the Rivas fault and the related volcanoes, although huge, stand faraway 40 km from the escarpment in lake Nicaragua. The segment from Grenada to Managua is a complex mix of calderas and faults that mask the continental break-up features. In North-West Nicaragua, the rift is completely buried by the volcanoes into the gulf of Fonseca. Finally, in El Salvador, the tectonic features are a complex and irregular chain of horst and graben interspersed with large volcanic cones and calderas that do not constitute an obvious rifting landscape.

Mateare fault and Chiltepe Volcano is the best site along the Central American rift because it gathers and displays the different features of continental break-up in a visually connected area, with each element clearly separated from the others.

Continental break-up features analysis

Faulting and subsidence: There is one net and linear escarpment, standing clear in the landscape although it is not very high compared to other downthrow features. It is relatively fresh with erosional valleys (quebradas) that are regularly spaced. This crenulation gives a sense of distance and linearity to views along the fault escarpment. The enclosed basin, although covered by farmland and urbanisation, is positioned to provide a sense of stretching and subsidence.

Erosion transport and deposition are evident from fault scarp through to the lake basin within the vegetated landscape. The fault plane is covered by sediments and outcrops or fractures are only seen further North, out of the main escarpment where fault breaks into many branches.
**Magmatism:** In terms of magmatism, the alignment is dominated by two prominent calderas on the active Chiltepe stratovolcano (fumaroles), while the other 20 smaller maars and cones are dormant. Being in a subduction zone, the magma composition is not directly related to the tilting process, so not the typical alkali type. On the other hand, there is a large diversity of magma compositions, showing a progression from primitive basalt in the South to evolve dacite on Chiltepe. This is seen through a change from scoria cones to domes to large calderas, giving a picture of the evolution of magmas through the crust as influenced by the faulting. The volcanic forms are relatively fresh though damaged by quarrying and partially surrounded by urbanisation.

**Uplift:** There is no inverted relief but a well-defined tilting behind the fault scarp, which descends down in a gentle slope to the Pacific coast. Lake sediments are seen high on the fault scarp, demonstrating the uplift over the Quaternary.

**Connectivity:** 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 as influenced by the faulting. The volcanic forms are relatively fresh though damaged by quarrying and partially surrounded by urbanisation.

**Science:** At a scientific level, the area has been important for the connection between tectonics and magmatism, especially due to the Managua earthquake of 1972. It was mentioned in the colonial archives and the first scientists arriving at the end of the 19th century, but it was not immediately identified as a significant geological site.

### TABLE: MATEARE - CHILTEPE SUBDUCTION

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<tbody>
<tr>
<td><strong>A. Faulting and subsidence:</strong> A primary process of continental break-up is tectonic and crustal subsidence, causing the surface subsidence and a basin. Sediments eroded from mountains are transported and fill this basin. Gully, alluvial fans, and outcrops of lavas and intrusions will take an important part in their scoring as well as the evidence of uplift and subsidence.</td>
</tr>
<tr>
<td>Main indicator: net building</td>
</tr>
<tr>
<td>Additional indicator: pronounced surface processes, minor scale outcrops of faults and features</td>
</tr>
<tr>
<td><strong>B. Magmatism:</strong> Magmatism is a primary continental break-up process, characterized by alkali composition and by diverse compositions due to substantial modifications of mantle and crust. Fluid and volatile magnetic features are scored such as, volcanoes, lava flows, fluidity, brecciation. 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 expressions.</td>
</tr>
<tr>
<td>Main indicator: remarkable tilting magma features in landscape</td>
</tr>
<tr>
<td>Additional indicator: activity</td>
</tr>
<tr>
<td><strong>C. Uplift:</strong> Uplift is an essential element to perceive the rifting process in full and the tectonic displacement. 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.</td>
</tr>
<tr>
<td>Main indicator: raised surfaces</td>
</tr>
<tr>
<td>Additional indicator: uplifted sediments, plateau dipping away from rift</td>
</tr>
<tr>
<td><strong>D. Connectivity:</strong> In order for a site to be perceived as a heritage site, its landscape formation should be seen as a whole. 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 as influenced by the faulting. The volcanic forms are relatively fresh though damaged by quarrying and partially surrounded by urbanisation.</td>
</tr>
<tr>
<td>Main indicator: intrinsic links between all elements of a site</td>
</tr>
<tr>
<td>Additional indicator: chronology</td>
</tr>
<tr>
<td><strong>E. Science:</strong> 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, shown here as dating from the discovery of plate tectonics about 50 years ago.</td>
</tr>
<tr>
<td>Main indicator: modern Science</td>
</tr>
<tr>
<td>Additional indicator: history of Science</td>
</tr>
</tbody>
</table>

**FULL TOTAL:** 24
Description:
The Dead Sea rift extends from the Red Sea in the South to the Golan Heights in the North. The southern boundary joins an opening ocean basin while the North joins a collision zone, so the Dead Sea rift in its entirety (630 km long) links the two end stages of the Wilson Cycle. It is the transform rift, meaning that most of the movements are along the axes of the rift making a line of very deep small basins (pull-apart basins). The Hula valley – Golan Heights is located at the very end of the Dead Sea rift, at the junction with the Mount Hermon collision zone, where the fault takes another direction. The site encompasses a small pull-apart basin (8.5 km wide, 25 km long) with gentle shoulders (500 m); a broad plateau with a low double chain of 20 volcanoes on it (900 m). The main escarpment finishes in a pronounced ravine illustrating the strike-slip movement. The area is vegetated with farmlands and wetland, while the plateau is dry with mostly grasslands.

Why chose this site?
The Hula valley – Golan Heights has a classic combination of continental break-up features, including a volcanic field, absent in the rest of the rift (Figure 1). It is the narrowest and best-defined segment of the Dead Sea rift which is dryer to the South but the tectonic aspect is lost amongst the other desert landforms. Plus, it broadens to the South and there is not such a clear magmatic association.

Continental break-up features analysis
Faulting and subsidence: The most remarkable aspect of this segment is the small and deep pull-apart graben with both side faults. This is due to the peculiar conditions of a strike-slip rift which produces rhomboid basins, very angular and delineated. The two inclined escarpments are cut by few gullies and both start at a low level at the South, rising to the North where they merge with the Mount Hermon range. The faults are straight but the crests of the escarpments are inclined, more typical of strike-slip faulting than pure continental rift faulting. The base of the scarp is sharply defined, making an abrupt and not limit with the sedimentary basin. The marked ravine to the South is exemplary as an illustration of a strike-slip fault seen in the landscape. Sedimentary features are mostly obscured by the intensive irrigation. One notable quality of the site is the associated influence of fault movement on archaeological sites, showing earthquake effects. However, the area is not known for outstanding outcrops.

Magmatism: The magmatism is seen through small monogenetic edifices (cones and maars, 120-95 Ka) with a restricted basaltic composition. The disposition of the extinct chain gives a modest sense of alignment, roughly parallel to, and 13 km away from the escarpment. The most distinctive bridged cones around Mount Golan are fresh but have residential buildings or fields within their crater.

Uplift: There is no significant uplift of the rift shoulders nor uplifted sediments or outward dipping plateau. The basin rises to the North in response to the Mount Hermon collision...
Connectivity: For convection, the small volcanic edifices have gaps of a few kilometres at most, but are distant from the fault (+10 km). For disposition, each feature is individually distinct so the pull-apart basin is the outstanding feature, conveying a strong vision of subsidence due to the two boundary escarpments. However, the volcanoes are over 13 km from the nearest escarpment and are too low to be noticeable from the basin, as well as the basin is not distinctly seen from the volcanoes, so simultaneity is not a strong feature. The subsidence overwhelms all other features, as the pull apart dwarfs the much smaller volcanoes. In terms of geometry, there is parallelism between faulting and edifices. For chronology, the separation of features does not lead to a sense of sequence of events; however, the combination of erosion, sedimentation and faulting is strongly expressed as an on-going process. There is no particular continental break-up chronodactical story that can be read from the landscape. Thus, the main conclusion is that there is not a full picture of continental break-up except seen from a digital elevation model. The particular strike-slip setting puts this site apart, as a distinct rifting environment from the others considered here.

Science: Regarding the scientific importance, the Dead Sea rift in its entirety is first-class example of a transform margin and the literature is abundant. Specifically for this site, the most interesting aspects are the junction to the mountain range and the tectonic to archaeological example of a transform margin and the literature is abundant. Specifically for this site, the most

### Table: HULA-GOLAN TRANSFORM

<table>
<thead>
<tr>
<th>INDICATORS</th>
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<tbody>
<tr>
<td>A. Faulting and subsidence:</td>
<td>4</td>
</tr>
<tr>
<td>Main indicator: net faulting</td>
<td>(one or several linear escarpment(s)/ fault plane / clear subsided area (graben)) (scoring from 0 to 5)</td>
</tr>
<tr>
<td>Additional indicator: pronounced surface processes, minor scale outcrops of faults and features</td>
<td>Erosional or sedimentation features, on-going transport seen in the landscape and fault outcrops. (scoring from 0 to 2)</td>
</tr>
<tr>
<td>Sub-total</td>
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</tr>
<tr>
<td>B. Magmatism:</td>
<td>2</td>
</tr>
<tr>
<td>Main indicator: remarkable rifting magmatic features in landscape</td>
<td>Alkaline volcanism, number, surface area, size, visible diversity of magma, freshness (scoring from 0 to 5)</td>
</tr>
<tr>
<td>Additional indicator: activity</td>
<td>Persistent activity, active, dormant or extinct. (scoring from 0 to 2)</td>
</tr>
<tr>
<td>Sub-total</td>
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</tr>
<tr>
<td>C. Uplift:</td>
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</tr>
<tr>
<td>Main indicator: raised surfaces</td>
<td>Old surfaces raised up (scoring from 0 to 5)</td>
</tr>
<tr>
<td>Additional indicator: uplifted sediments, plateau slipping away from rift</td>
<td>Sediments deposited low down now found high up, evidence of the uplift dome (scoring from 0 to 2)</td>
</tr>
<tr>
<td>Sub-total</td>
<td>3</td>
</tr>
<tr>
<td>D. Connectivity: Faulting/subsidence, magmatism and uplift features need to be connected to heritage perspectives we are looking for sites that allow continental break-up to be understood as one large and integrated event. All features should be seen together and there must be visible links between them. Scoring occurs between clear 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.</td>
<td></td>
</tr>
<tr>
<td>Main indicator: intrinsic links between all elements of a site</td>
<td>Proximity of the different features allowing them to be seen simultaneously (whole picture can be observed in its entirety), layout of features (are the elements arranged in a way to convey a clear sense of connection), proportionality of features. (scoring from 0 to 5)</td>
</tr>
<tr>
<td>Additional indicator: chronology</td>
<td>Can the elements of the site convey the sequence of events in the landscape so the chronological historic of the site can be seen (chronostratigraphic indicators / layering of rocks, baked surfaces meaningfully show the succession of processes, including on-going processes). (scoring from 0 to 2)</td>
</tr>
<tr>
<td>Sub-total</td>
<td>2</td>
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<tr>
<td>E. Interest: 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 subject for the modern scientific antique, chosen here as dating from the discovery of older techniques about 50 years ago.</td>
<td></td>
</tr>
<tr>
<td>Main indicator: modern Science</td>
<td>Standing in the time after the plate tectonic revolution (SO years). (scoring from 0 to 5)</td>
</tr>
<tr>
<td>Additional indicator: history of Science</td>
<td>Standing in the beginning of scientific understanding (beginning depends on geographical location and culture). (scoring from 0 to 2)</td>
</tr>
<tr>
<td>Sub-total</td>
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<tr>
<td>FULL TOTAL</td>
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The Lake Baikal rift stretches some 1500 km from the Tunka rift segment in the South-West, near the Mongolia-Russia border to a series of pull-apart graben to the North-East at the town of Chara. On either side, the rift transfers into strike-slip faults that join to the East the sea of Okhotsk, and to the West the Altai mountains. The lake Baikal itself forms a main central rift segment drowned by the waters of the lake.

The Tunka rift segment is separated from the Lake Baikal by a 15 km stretch of low mountains and joined to the South part of the Baikal by the Ikurt river strike slip fault. Tunka is a deep rhombic depression (45 km wide and 100 km long) floored by a marshy alluvial plain, flanked by steeper alluvial fans and glacial moraines. The fault scarp to the North is sharp and demarcates the change from plain. The scarp itself has notable lower triangular facets separated by deep glacial valleys. The higher ground is a range of serrated glaciated peaks, with concordant summit heights. The southern side of the basin is less steep, forming a half-graben structure, and here the mountains rise slowly from the plain with some deeply incised meandering river valleys that testify to the slow uplift of this arched-area.

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.

Why chose this site?
The Tunka site is the most obvious in the Baikal Rift system, to see together the main processes of rifting (faulting, subsidence, sedimentation, volcanism, and uplift). The site is better for this than other Baikal rift sites in that it is not drowned by water that hides features, and has the best developed magmatism of the whole rift system, close to the main fault. Other sites, such as the separate graben to the North-East of Lake Baikal, have well-developed faults and subsidence but the magmatic aspect of rifting is not seen at any place (the volcanism in the region is far off the rift axis). Lake Baikal itself is a major site, inscribed on the World heritage List for its fresh water system (criterias (vi), (vii), (x), (xii)), however there is no volcanism clearly associated with this impressive feature and the drowning of the basin means that the inner part of the graben is under water.

Continental break-up features analysis
Faulting and subsidence: The escarpment of the Tunka segment is long, sinuous, serrated by erosion, giving a typical faceted profile. This contrast with many other rift faults that are more linear and continuous and it provides an excellent example of mountain-related rift cut by glacial erosion. In contrast with the Rhine graben for instance, the height and the length of the escarpment are particularly well-balanced, creating a very spectacular and distinctive landscape. The curve of the fault reinforces the perspective like in a natural amphitheatre. There is a very clear subsided basin, mostly filled with sediments, that also encompasses unusual areas of uplift. This is the effect of the Himalaya mountain collision that complexes the basin without disturbing the overview of the segment.
In addition, the surface processes are abundant and noticeable through the deep erosion on the scarp, passing to the alluvial fans and rivers that merge into the marshes of the plain. Last, the fault line is exposed at outcrop all along the escarpment. This is probably one of the finest expression of a fault line.

**Magmatism:** In terms of magmatism, only a few very small monogenetic cones of less than 50m high and 600 m diameter, are disseminated on the plain. Their age is unknown and there is no known eruption. No specific articles are available because the volcanic field in itself is not substantial, although this is the only volcanism in the Baikal rift.

**Uplift:** The North of the segment displays a continual line of concordant summits, indicating the general uplift of the ancient pre-rift plain. There is inverted relief inside the basin, however this is related to compression from the Himalayas not to the rifting process. The same with uplifted sediments, that are related to the mountain compression.

**Connectivity:** For concentration, the fault escarpment and its erosional and sedimentary features are large but closely knit features, that are continual across the landscape. The volcanoes, in contrast, are too small and separate to have any significant concentration. The disposition of features is strong for the visualisation of the fault escarpment and its features, while the magmatic features are not highly visible. The magmatic features are entirely dwarfed by the huge fault escarpment. The geometrical arrangement of fault and basin is clear, while the intra-basin uplifts are more or less orthogonal to the main fault. The presence of collosional structures inside the basin adds complexity to the interpretation of the landscape. For chronology, the main fault escarpment does not show a clear stratigraphic record, although the concordant summits indicate an ancient escarpment uplifted. On-going processes show the change from glacial to fluvial erosion on the escarpment, and the intra-basin uplifts are more or less orthogonal to the main fault. The presence of collosional structures inside the basin adds complexity to the interpretation of the landscape. For chronology, the main fault escarpment does not show a clear stratigraphic record, although the concordant summits indicate an ancient escarpment uplifted.

**Science:** The Baikal is a classic rift site, identified early on by Russian scientists and since then intensively studied, especially on the main lake segment. More recently the Tunka area has been considered for its geomorphological and tectonic linkages.

### Science

Standing in the time after the plate tectonics revolution (50 years).

- **Main indicator:** Standing in the time after the plate tectonic revolution (50 years).
- **Additional indicator:** Modern Science
  - Standing in the time after the plate tectonic revolution (50 years).

### Faulting and subsidence

A primary process of continental break-up is faulting and crustal thinning, causing the surface subsidence and a basin. Sediments outside the escarpment are transported and fill the basin. Glacial, fluvial, and sedimentary features of terraces, lakes, and rivers will take an important part in their scoring as well as the evidence of break-up and subsidence.

- **Main indicator:** net building
  - One or several linear escarpments(of?) / fault plane / clear subsided area (gaping) (scoring from 0 to 5)
- **Additional indicator:** pronounced surface processes, minor scale outcrops of faults and features
  - Erosional or sedimentation features, on-going transport seen in the landscape and fault escarpment. (scoring from 0 to 2)

### Uplift

- **Main indicator:** remarkable rifting
  - Alkaline volcanism, number, surface area, size, visibility of magma, freshness (scoring from 0 to 5)
- **Additional indicator:** activity
  - Persistent activity, active, dormant or extinct. (scoring from 0 to 2)

### Magmatism

- **Main indicator:** remarkable rifting
  - Alkaline volcanism, number, surface area, size, visibility of magma, freshness (scoring from 0 to 5)
- **Additional indicator:** activity
  - Persistent activity, active, dormant or extinct. (scoring from 0 to 2)

### Faulting and subsidence

- **Main indicator:** net building
  - One or several linear escarpments(of?) / fault plane / clear subsided area (gaping) (scoring from 0 to 5)
- **Additional indicator:** pronounced surface processes, minor scale outcrops of faults and features
  - Erosional or sedimentation features, on-going transport seen in the landscape and fault escarpment. (scoring from 0 to 2)

<table>
<thead>
<tr>
<th>INDICATORS</th>
<th>TUNKA MOUNTAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Faulting and subsidence:</td>
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<tr>
<td>Main indicator: net building</td>
<td>5</td>
</tr>
<tr>
<td>Additional indicator: pronounced surface processes, minor scale outcrops of faults and features</td>
<td>2</td>
</tr>
<tr>
<td>Sub-total:</td>
<td>7</td>
</tr>
<tr>
<td>B. Uplift:</td>
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</tr>
<tr>
<td>Main indicator: raised surfaces</td>
<td>4</td>
</tr>
<tr>
<td>Additional indicator: uplifted sediments, plateau dropping away from escarpment</td>
<td>1</td>
</tr>
<tr>
<td>Sub-total:</td>
<td>5</td>
</tr>
<tr>
<td>C. Magmatism:</td>
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</tr>
<tr>
<td>Main indicator: remarkable rifting</td>
<td>1</td>
</tr>
<tr>
<td>Additional indicator: activity</td>
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</tr>
<tr>
<td>Sub-total:</td>
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<tr>
<td>D. Connectivity:</td>
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<tr>
<td>Main indicator: intrinsic links between all elements of a site</td>
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<td>Additional indicator: chronology</td>
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<td>Additional indicator: history of Science</td>
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<tr>
<td>Sub-total:</td>
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<tr>
<td>FULL TOTAL:</td>
<td>22</td>
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The Rhine Rift is made of two segments: the northern, Lower Rhine Rift and the Southern, Upper Rhine Rift. They are separated by an upland region, which coincides with a major geological boundary, the Ardennes – Rhennish shield, a major Hercynian structural region. In this boundary zone between the two segments is contained much of the Rhine rift-related volcanism.

The Lower Rhine Rift continues from Germany into the Netherlands, where its structures are buried under sediments from the Rhine and other rivers. The Rhine rift finally joins the North Sea Rift, which is entirely hidden under the sea. The southern, Upper Rhine Rift segment has long, straight boundaries that separate the plateaux of the Vosges in France and the Swartwald in Germany. The segment terminates, not far from the city of Basel, at the Alpine collision front. This area suffered a catastrophic rift-related earthquake in 1356.

The Freibourg – Kaiserstuhl site encompasses a rift margin escarpment, which has a sharp right angle bend, in which stands the Kaiserstuhl volcanic area. The site escarpment is 200 to 400 m high.

The basin is a patchwork of arable fields, while the slopes of the volcanic massif are terraced for wine. The rift flanks along most of the Upper Rhine Rift, including the site, are deeply forested making a strong contrast with the plain. Views from one margin to the other give a clear image of a classic ‘graben’.

Why chose this site?

The area of Freibourg has been chosen as the most representative because of the presence of a rift related magmatic massif (Kaiserstuhl), and because there is a kink in the rift that enhances visually the marginal escarpment by doubling it. The escarpment and the Kaiserstuhl stand out from the basin, both representing rifting processes. Other areas of the Rhine Rift do not juxtapose these features so clearly. For example, where the Upper Rhine Rift continues North from Freibourg there is a straight, continual escarpment with a text book example of graben, but this shows no volcanism. The rift is evident in the landscape, but while faulting and subsidence are obvious, uplift and volcanism are less obvious, or absent. Northwards, the Eiffel volcanic region is not on the rift but on the Ardennes-Rhennish massif, and while volcanic features, such as the Laacher See are significant features, the connection to rifting processes can not be made in the landscape.

Continental break-up features analysis

Faulting and subsidence: The Freibourg – Kaiserstuhl site has an obvious fault escarpment (700m at the highest in the South) with a sharp, angular, distinctive change from escarpment to basin. This is highlighted by the vegetation difference from wooded scarp to cultivated basin. From the escarpment, one can see the opposite side of the graben, having a full picture of the basin subsidence. The Freibourg escarpment is deeply incised due to 30My of exposure. For the fault, this translates in a more gentle slope and numerous side valleys that break slightly the continuity of the escarpment. The basin is a site of intense agriculture and the transition from erosion on the scarp to alluvial plain sediments and Rhine flood plain.
are essentially seen in the land use changes. No reference could be found about outcrops of the fault along the escarpment.

**Magmatism:** The Kaiserstuhl stratovolcano (15 My) is the only volcanic edifice in this area, the other magmatic features being minor outcrops. It stands out from the plain and is notable for its terraced slopes with vineyards. The original form is not distinctly seen in the land use changes. No reference could be found about outcrops of faults and fractures.

**Uplift:** Uplift features are a general part of the landscape without being highly distinctive, like for instance the raised shoulder of the Swartfjeldt that illustrates the elevation occurred around the Rhine Rift (22 My) and that is still slightly rising. The plateau is deeply incised by meandering river valleys that display the change transition from flat plain to upland plateau. No uplifted raised sediments are known and inverted relief is not a feature of this area.

**Connectivity:** For concentration, the volcano is one single large feature and the fault another, so this characteristic does not really apply. However for disposition, the site’s escarpment can be clearly seen from the volcano and vice versa, and the uplifted margins of both sides of the rift are evident in the wider landscape, so visibility and simultaneity are fulfilled. The volcano and fault have similar proportions. On the other hand, the features are eroded from more than 200 million years of exposure and their geological significance is not immediately obvious to a general audience. For geometry, the link in the fault provides an en-echelon type of arrangement which enhances visibility. For chronology, the single volcano cannot be immediately connected to the rifting process except its position inside the graben (it happened after the graben formed). The only other element that indicates a chronological sequence of events, is the presence of uplifted sediments on the North fault shoulder.

**Science:** For scientific value, the Rhine Rift stands out as one of the sites where early theories, such as neptunism and plutoism were heatedly discussed, and the rift is probably the first rift to be recognised as such. It was this region that consolidated this german term of graben in the geological terminology in the 19th century. The Kaiserstuhl is also a classic area for the discovery and description of the potassic and carbonatitic magmatic series. More recently, research on the Rhine Rift has contributed strongly to the knowledge of rifting, especially through modern geophysical studies.

**INDICATORS**

**FREIBOURG KAISERSTÜHL MOUNTAIN**

- **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. (scoring from 0 to 5)
- **B. Magmatism:** Magmatism is a primary continental break-up process, characterized by alkaline, carbonatic and boehmite compositions due to substantial mobilisation of mantle and crust. Visible and significant magmatic features are scored such as, volcanoes, lava flows, flood basalts, linear features. (scoring from 0 to 5)
- **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 extension and thinning or ending the continental break-up. (scoring from 0 to 5)
- **D. Connectivity:** Faulting subsidence, magmatic and uplift features need to be connected to a heritage perspective, we are looking for sites that allow continental break-up to be understood as one single interrelated process. All features should be seen together and not for their isolated link between them. (scoring from 0 to 5)
- **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 for the modern scientific activity, chosen here as dating from the discovery of plate tectonics about 50 years ago.

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<th>INDICATORS</th>
<th>FREIBOURG KAISERSTÜHL MOUNTAIN</th>
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<tr>
<td>B. Magmatism:</td>
<td>1</td>
</tr>
<tr>
<td>C. Uplift:</td>
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<td>D. Connectivity:</td>
<td>3</td>
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<td>E. Science:</td>
<td>2</td>
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**Sub-total:** 11

**Sub-total:** 5

**Sub-total:** 2

**Sub-total:** 3

**Sub-total:** 1

**Sub-total:** 5

**FREIBOURG KAISERSTÜHL MOUNTAIN**

**FULL TOTAL:** 20
Description:
The Eger rift forms the extreme eastern end of the Western European Rift, and the system terminates against the Lužice (Lausitz, or Lusatian) reverse fault on the East. To the west, the rift is cut by the Mariánské Lázně strike-slip fault and the Cheb basin.

The Krušné Hory fault segment chosen is a 60 km long (the fault itself is 160 km), South-facing escarpment that forms the North side of the Eger Rift just North of Karlovy Vary (Carlsbad), Kadaň, Chomutov and Teplice. The South side of the rift has much lower topography, so the rift has a rough half graben aspect, despite geologically significant vertical offset is documented in Cretaceous sediments in which the southern rift margin is developed.

The Krušné Hory fault can be divided into two parts, separated by the northern edge of the Doupovské Hory shield volcano. This Oligocene to Lower Miocene volcano forms a major volcanic site in the rift, while there are smaller volcanic fields and monogenetic volcanoes dotted around the rest of the rift and its flanks. The fault section described here is the central part that overhangs the city of Kadaň, and can be viewed especially well from the Úhošť hill, an isolated inverted relief remnant of the Doupovské Hory shield. The fault escarpment matches straight with 500-550 m height over a distance of at least 30 km.

It has a steep lower part, followed by a more gently sloping upper part that merges into the plateau behind. Deep valleys cut the fault line in places, but do not affect the sense of continuity of the escarpment. The basin is a major coal mining area, and hosts several large power stations, that dominate the lower landscape.

The erosion and consequent inverted relief testify to uplift and erosion in the rift, after sedimentation. The volcanism began before rifting and rafts of volcanic material can be seen tilted and hanging on the fault escarpment.

The volcano has a broad suite of alkaline rocks from foidites and ankaramites to phonolites, which are seen in piles of lavas exposed in inverted relief. Many breccia layers indicate lahars and debris avalanches from the volcano.

Why chose this site?
This site is the clearest representation of the Eger rift, and allows with the Rhine graben site at Freiburg to compare and contrast directly with the nominated property in the same rift system. The Krušné Hory fault escarpment is the longest and highest fault segment in the Eger Rift and has both sediments and erosional features, in addition to inverted relief showing uplift and consequent erosion. The Doupovské Hory Volcano is the equivalent of the Kasierstuhl volcano for the Freiburg site. It is the major volcanic centre in the Eger Rift, and has a high diversity of volcanic structures. The interplay between the volcano, the basin and the fault are of interest and can be seen in the landscape.

Continental break-up features analysis
Faulting and subsidence: The chosen Krušné Hory fault escarpment segment is a distinctive 30km long and 500m high landscape feature that markedly separates the Krušné Hory highland from the Eger rift plain. The subsided basin is clearly seen, especially exposed in the several large coal mines that dot the basin landscape. The coal mines and their...
power stations create a spectacular mix of anthropogenic and natural features in a stunning landscape. This is a clearly a mixed heritage site rather than purely natural, although the surface of the mountains of the upland and the volcano lack the anthropogenic impact and are more natural, so human activity and natural landscape are partly parcelled.

**Magmatism:** The volcano is an ancient shield with no Quaternary activity, and is best seen in the well-developed inverted relief ridges, that form an important part of its landscape. The magmatic series exposed in the lavas is complex and encompasses a wide range of compositions, reflecting the rift setting and sliding of the volcano on rift sediments.

**Uplift:** Uplift is seen as a whole in the Krusne Hory upland plateau, but it is best understood through inverted relief that shows deep valleys uplifted to ridges on the volcano, near the fault line. The on-going erosion is also seen in the exposure of plutonic rocks deep in the volcanic centre.

**Connectivity:** For concentration, the fault, basin and volcanics can be seen close together, as the extent of the landscape is not large and they are single large features. The fault and basin make a very visible feature; however, 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. The features can be seen all at the same time and are of similar proportions. There is no clear geometrical association between the volcano (a single mass) and the fault-basin alignment. For chronology, there are parts of the volcano plastered onto the fault and tilted by it, and inverted relief gives a strong indication of the progressive incision of the landscape. This is reinforced by the on-going river system that cuts through the volcano.

**Science:** This area played an important role in history of earth sciences. The rodent fossil found around 1690 in Early Oligocene pyroclastic deposits of the Doupeauve Hory Volcano was the first fossil of terrestrial animal ever found and it was for a long believed to represent witness of the Biblical flood, mentioned by great scientists of 18th Century (Carl Linne, Georges Cuvier, Alexander von Humboldt, Johann Wolfgang von Goethe). The first plant fossil ever was also described from this area (in Joachimsthal) – from a phreatomagmatic breccia in a vent of eroded volcano in the uplifted Krusne hory uplands.

**INTEGRATORS**

**A. Faulting and subsidence:** A primary control of continental break-up is faulting and crustal motion, causing the surface subsidence and a basin. Sediments eroded from mountain are transported and fill the basin. GK: distance and level of basins, features will take an important part in their scoring as well as the evidence of faulted sub and uplift.

<table>
<thead>
<tr>
<th>Main indicator: net building</th>
<th>One or several linear encampments(1)/ fault plane / deep subsided area (2)</th>
<th>(scoring from 0 to 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional indicator: prominent surface processes, minor scale outcrops of faults and features</td>
<td>Erosional or sedimentary features, on-going transport seen in the landscape and fault outcrops. (scoring from 0 to 2)</td>
<td>1</td>
</tr>
<tr>
<td><strong>Sub-total:</strong></td>
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<td>4</td>
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</tbody>
</table>

**B. Magmatism:** Magmatism is a primary continental break-up process, characterized by alkaline composition and by diverse compositions due to subduction evolution of mantle and crust. Visible and identifiable magmatic features are scoria such as, volcanoes, lava flows, fissures, dykes, and tectonic features. To be in second with heritage values, fault and active volcanism will be the most valuble assets because they are the best known and recognizable magnetic expression.

| Main indicator: remarkable rifting magmatic features in landscape | Alkaline volcanoes, mountain, surface area, size, visible diversity of magma, freshness (scoring from 0 to 5) | 3 |
| Additional indicator: activity | Persistent activity, active, dormant or extinct. (scoring from 0 to 1) | 0 |
| **Sub-total:** | | 3 |

**C. Uplift:** Uplift is an essential element to perceive the rifting process in full and the lift in the deep Earth. It can be caused either by a mantle plume or by the thinning of the crust due to its stretching, and in seismic or due to the continental break-up. For the heritage perspective, we will not distinguish it from different origins and only consider its topographic expression. The process is the most difficult to perceive for correspondences. Visible ancient outcrops (paleogeology) plateaus, concordant surface features, uplifted ridges are the most visible evidences. 

| Main indicator: raised surfaces | Old surfaces raised up (scoring from 0 to 1) | 3 |
| Additional indicator: uplifted sediments, plateau slumping away from rift | Sediments deposited low down now found high up, evidence of the uplift dome (scoring from 0 to 2) | 2 |
| **Sub-total:** | | 5 |

**D. Connectivity:** Faulting/subsidence, migration and uplift feature 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 their scale for visible scale links between them. Scoring system 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 then to be seen simulteneously (vehicle or on foot); specific as it has been observed in its entirety; layout of features (see the elements arranged in a way to convey a clear sense of connection), proportionality of features. (scoring from 0 to 5) | 4 |
| Additional indicator: chronology | Can the elements of the site convey the sequence of events in the landscape so the paleogeological history of the site can see be seen (isotopic evidence of relationships). (scoring from 0 to 5) | 1 |
| **Sub-total:** | | 5 |

**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, shown 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) | 4 |
| Additional indicator: history of Science | Standing in the beginnings of scientific understanding (beginning in dependence of geographical location and culture). (scoring from 0 to 1) | 1 |
| **Sub-total:** | | 5 |

**FULL TOTAL:** 22
**Description:**

The Limagne rift forms the extreme southern end of the Western European rift system. The fault is a distinct and linear escarpment, 30 km long and up to 700 m high. It has small changes in height that testify to different structures inherited from the ancient Hercynian mountain range. The very southern end is buttressed by inverted relief and the fault escarpment disappears under the Montagne de la Serre plateau (ancient lava flow). Northwards, the escarpment becomes rapidly higher with triangular facets of fault plane. A deep structurally controlled valley partially filled by lavas, cuts the fault in its centre. From there, the fault straightens and then links North-North East to a continual straight segment to the valley of Volvic, which is also drowned by lava flows. North of Volvic, the fault line heads straight to the fault-guided Emul gorge, then diminishes and a splay heads of to the North-East, towards the distant Rhine Rift segment.

The fault line remains visible as one escarpment along its length, but is also crowned by a series of inverted relief lavas. In the site chosen for this World Heritage nomination, the most famous is the Montagne de la Serre, followed by the ridge leading to Cézembre. Five more inverted relief features punctuate the escarpment, including the Montagne Trouée from which there is an impressive view over the rift and the plateau. The subsided basin of the Limagne is seen in views over the fault escarpment, but is importantly preserved under the Montagne de la Serre lava ridge with a complete succession of the basin infill. Rivers descending the fault escarpment, issued from springs under the volcanic lava flows of the Chaîne des Puys, show on-going erosion and transport of sediment to the rift basin.

The young Chaîne des Puys (95 000 – 8 400 years) has 80 distinctive volcanic edifices over 32 km length. The landforms are fresh and varied, including domes, cones, tuff rings, maars, lava flows and pyroclastic flows. A notable series of magmatic uplifts are present, such as the Petit Puy de Dome which is highly prominent in the serrated skyline formed by the chain. The last eruptions were in the Holocene and the alignment is considered active, with known magma bodies at depth and raised seismicity.

Uplift of the Limagne rift and the whole Massif Central is made obvious by the inverted relief, especially the Montagne de la Serre which runs out of the plateau without being cut by the fault and progressively remains above the level of the Limagne plain. In addition, some valleys are drowned by lava and stream flow below ground. In these areas, on-going inversion of relief is elevating lavas above their river base, which indicates a strong and continued uplift.

Why chose this site?

The Limagne fault is the most prominent feature in the Western European rift and the only site in this rift segment where volcanism and inverted relief are closely combined. The inverted relief is the result of several million years of magmatism, uplift and erosion, not found so well-expressed elsewhere in this important part of the Western European rift.

**Continental break-up features analysis**

Faulting and subsidence:

The Limagne fault makes a clearly defined long escarpment that displays both the simplicity of a faulted rift margin and the complexity brought by the long interaction between tectonic faulting, subsidence, magmatism, and uplift. The subsided area is seen both in the landscape, but also in the preserved rift basin under the inverted relief of the Montagne de la Serre. Here a unique complete succession of the basin infill, from granitic basement, through detrital fans to intra-basin limestone and marls, is seen with an associated fossil assemblage. This protected sequence is rare in rift environments where usually only the present surface manifestation can be seen, as burial is continual. This preservation allows the
surface processes of erosion, river transport and deposition in the basin to be appreciated through a geological time frame. On-going erosion is evident in present-day relief inversion and fault scarps erosion. The Limagne fault zone can be seen at outcrop in several places, such as in the Creux de l'Enfer where the fault slides on an ancient Hercynian dyke, or at the Envall geology where the fault plane is formed of many tilted features.

**Magmatism:** Magmatically, the area has a full range of the alkaline series from primitive basalts, through trachybasals, trachy-andesites to trachytes and rhyolites. It is particularly notable that this series is continuous, while in many other areas there is a gap (Daly gap). The magmatic compositions are spectacularly illustrated by a full range of volcanic landforms that stand out in the landscape.

The chain is dominant, but is known to have active magmas at depth.

**Uplift:** Uplift is seen by the pronounced inverted relief, that raises lavas that were at the base of valleys to high ridges. Nowadays the dominion of the lavas eroded from the sediments that were formerly laid down in the depths of the basin. From the volcanic chain, the shallow but constant slope of the plateau away from the Limagne fault, shows how uplift tilts the surface up.

**Connectivity:** For concentration, this site is notable for the crowding in of fault, volcanoes and uplift: chronological features. The fault is just a few kilometres from the line of closely packed volcanoes, and the inverted relief dips in between each feature. The site is exceptional in the number and clarity of connections that demonstrate the different components of: from faulting to magmatism (double alignment and complexity of fault controlled magmatism); magmatism to uplift (inverted lava flows) and uplift back to faulting (uplifted sediments and tilted plateaux). For deposition, at visual level, all the features are markedly visible landforms and can be seen simultaneously from many viewpoints. For example, from the Puy de Dome summit, the fault line, the basin subsidence, the uplifted inverted relief, the magmatism can all be seen in one glance. This is a rare combination in a rift setting and enhanced by their proportionality, each feature being in a compatible size range. For geometry, the parallelism of faulting and magmatism is obvious and enhanced by a well-developed secondary en echelon layout. The inverted relief is orthogonal, crossing at right angles from the volcanoes to the basin, adding to the geometrical connectivity. No other site has such a profound integration of geometrical features, which merits the highest scoring.

For chronology, the exceptional inverted relief lends itself to an especially well-illustrated historical narrative. The fault, which clearly separates the uplifted granitic basement paleo-surfaces from the uplifted basin sediments, is obviously covered by the Montagne de la Sere lava. This lava itself shows a long history of basin infill, magmatism, then uplift and erosion. On-going relief inversion is a striking aspect of many new valleys, which have been recently drowned by lavas.

**Science:** Ever since modern science began in the 18th century, the Limagne has been a mecca for natural scientists within to understand continental break-up and the underlying fundamental processes that of tectonics. It was the cradle of major controversies that lead to the definition of the main geological theories (uniformitarianism versus catastrophism; neptunism versus platonism; craters of elevation versus craters of emption). This continues to this day with important scientific works appearing every year on rift-related processes.
Lake Malawi forms the southward continuation of the western branch of the East African rift system. To the North, it is separated from the Lake Rukwa by the Rungwe volcanoes. The site is a triple junction with the Usangu basin forming a North-easterly branch that connects to the eastern rift. The land surface around this junction rises to nearly 3 000m in a topographic dome about 500 km across, in which the rift sits.

At the North end of Lake Malawi, the fault escarpment rises to meet the Rungwe volcanic province and makes an impressive rift margin on the East side while being less distinct on the West, due to the half graben symmetry. The Eastern escarpment is partly submerged by Lake Malawi, but the base appears out of the water as the Rungwe is approached, and rises up to a river valley cut between the volcanoes towards the North-West. The escarpment rises just over 1 000 m from the lake, and the scarp edge rises North westwards to maintain its height up to watershed between the two lakes, where it abruptly merges into the volcanic range. From Lake Malawi, the escarpment rises in a series of triangular facets cut by deep gorges, and continues with a steep lower portion into the Rungwe. Here, the river gorge at the base of the fault cuts deep into the escarpment base, and the gorges become more continuous, slightly crenulating the escarpment before it merges into the volcanics. The basin is an obvious feature and the progressing from lake to delta and to fluvial basin infill, is evident as well as the input of basin-filling volcanics from the Rungwe.

The Rungwe volcanics are a group of large stratovolcanoes (Ngozi, Rungwe and Keyjo volcanoes), with calderas and multiple flank vents. The magma compositions range from trachyte to basalt, and the eruption styles from caldera-forming pumice eruptions to fluid basaltic lava flows. At an early stage, in the Miocene, volcanoes erupted above the rift margin but these are now denuded and are not clearly expressed in the topography.

The whole area has been uplifted prior and during rifting, which is principally seen by the gradual rise of the fault escarpment crest and the plateau behind, towards the volcanic province.

Why chose this site?

For the southern margin of the East African rift, the lake Malawi and Rungwe site stands out as presenting the highest and most striking fault escarpment, while also having strong magmatic features. The transition from lake to basin filling sedimentary system follows the rise of the fault escarpment and provides a progression in geological surface environments that is particularly well exposed, especially in the context of the volcanic range, the erosion of which provides much of the sediment to the area. The general side of the land surface inside and outside the basin gives an impression of rising up and therefore displays well the topographic dome related to the mantle plume influence and the triple junction rift configuration, that is the classic text-book style of hot-spot rifting.

Continental break-up features analysis

Faulting and subsidence: The eastern side of the Malawi graben makes a clear and neat feature distinctive for its fresh topography with notable triangular facets that rise from the lake between deep gorges. The emerged escarpment to the North of the lake continues the structural distinctiveness with a sharply-defined lower fault scarp and a renewed upper scarp that keeps its height until merging with the Rungwe volcanic massif. The basin with the
lakes, the delta and river system extending from the volcanics, marks the subsided area with an abundance of evidence of ongoing surface processes. The faulting is not seen as clearly at outcrop, but there are two important intra-graben escarpments, the Malawi fault and the Mbaka fault, that indicate on-going deformation in the basin.

**Magmatism:** Magmatism is well displayed by the alkali series of the Rungwe province, which is composed of several major volcanoes with many minor vents. The magmatic compositions go from basalt to trachyte and phonolite. The volcanism has been very active in the Cretaceous and major eruptions have occurred from Rungwe in the last 2,000 years. Some fresh lava flows with scant vegetation also indicate recent activity, although there are no historical reports.

**Uplift:** Uplift of the Mbeya triple junction is seen in the continual rise of the sides of the rift from south towards the apex of the Rungwe volcanoes. From the escarpment shoulder, the gently sloping surface of the uplifted former plain is a clear feature in distant views, but there is no inverted relief present.

**Connectivity:** For concentration, there is a continual faulted escarpment that is close to the volcanoes inside the basin (4 to 10 km away). The volcanoes are massive stratovolcanoes that overlap each other. The size of the area (over 60 km) is vast for views, but the features are also large (fault escarpment 1,000 m, volcanoes 1,500 m), it compensates for the distance. The sedimentary basin features are close against the fault, as is the lake. The plateau, with outward dipping surfaces, is a much wider feature, which is not a concentrated element.

**Science:** From the scientific point of view, the Rungwe has not received much interest early in the history of science, due to its isolated and mountainous position and difficult terrain. However, more recently, the youthfulness of the volcanism and the strong seismic activity (Malawi Earthquake 1989) has led to a major increase in interest.

### Table: Lake Malawi Hopspot

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Lake Malawi Hopspot</th>
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<tbody>
<tr>
<td><strong>Main indicator:</strong></td>
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<tr>
<td><strong>Main indicator:</strong></td>
<td><strong>Raised surfaces</strong></td>
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<td><strong>Main indicator:</strong></td>
<td><strong>Sunken surface</strong></td>
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<td><strong>Main indicator:</strong></td>
<td><strong>Magmatism</strong></td>
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<tr>
<td><strong>Main indicator:</strong></td>
<td><strong>Faulting and subsidence</strong></td>
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</table>

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<thead>
<tr>
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**Total:** 27

### E. Science

**Main indicator:** Modern Science

- Standing in the time after the plate tectonic evolution (50 years) (scoring from 0 to 5)

- Additional indicator: History of Science

- Standing in the beginning of scientific understanding (beginning depends on geographical location and culture) (scoring from 0 to 5)

**Sub-total:** 5
Description:
The western branch of the East African rift encompasses a large area from Uganda to Malawi, containing lakes such as Albert, Edward, Kivu and Malawi. The rift often has a marked single escarpment, and the surrounding areas are uplifted around the Kivu dome and at the north end of Lake Malawi. These two areas support the majority of the magmatic manifestations with the Virunga and Rungwe volcanic provinces, as well as the much older and extinct South Kivu volcanic province.

The site discussed here is the striking Virunga area, contained in the Virunga National Park, which stretches from Lake Kivu to Lake Edward. It contains the most active volcanoes in Africa, as well as two major rift faults, the Muhindu escarpment and Lake Edward escarpment. The Muhindu escarpment is about 1000m high and 55 km long, while the Lake Edward escarpment is slightly higher and about 80km long. The Muhindu escarpment rises almost directly North of Nyamuragira volcano, then it trends North-East from 25km, before heading North from another 30 km and diminishing to be lost in the plain. The fault lines are high, but the escarpments deeply eroded. Their surmounting plateaux are also strongly incised, due to the Miocene age of the rift escarpments and the heavy precipitation in the area that favours rapid denudation. Most of the area is in fact deeply forested and often covered in clouds with an opaque atmosphere. Many visiting scientists have noted the difficulty of seeing more than one feature at the same time due to these conditions.

The main structural features are Muhindu and Edward escarpments, while the basin is mostly filled with the voluminous lavas from the large volcanic centres. Magmatism is concentrated in the Virunga province which traverses the rift from South-West to North-East. The two huge volcanoes of Nyamuragira and Nyiragongo are in the graben, while the others stretch onto the eastern shoulder in a rough oblique line. Eruptive fissures from the volcanoes are evident in the basin. They are orientated in various directions relative to the stresses from the volcanoes rather than from rifting forces. By their size, the volcanic systems dominate the present day rift conditions.

Sedimentary rocks and surface processes are a minor part of this basin due to the dominance of lavas. River systems only become a feature 60km North of the Virunga, near the lake Edward shores where some small intra-graben faults also appear.

Why chose this site?
The Virunga area and the nearby Muhindu escarpment are retained for comparison as they are an iconic part of the Great Rift valley, where rift magmatism is super abundant. They are also a World Heritage site. Geologically speaking, the site is mainly incised for the remarkable volcanoes. Areas to the North and South have much less volcanism and diversity. For example, further North, the Rwenzori massif is an impressive horst, set within the rift, but has limited volcanism. To the South, there is no equivalent area until the Rungwe-Lake Malawi site, which is also compared here.

Continental break-up features analysis
Faulting and subsidence: The Muhindu fault escarpment is strongly eroded and forms individual fault crests with accompanying half grabens. The symmetry is very similar to the Sandia and the Steens mountain escarpments, though for this case the erosion is more pronounced.
and the plateau behind more incised. The basin can be clearly separated from the escarpments but lacks from the basin spill out over the rift margin, reducing the impact of the subsidence in the landscape. Volcanic related features are common in the basin, however true rift faulting and fracturing are not seen. In fact, the faults have been very hard to map in this area and there is still uncertainty about the structural geometry.

**Magnatism:** Magnatism is superabundant and impressive, with the two highly active massifs Nyiragongo and Nyirirogi producing frequent lava flows and semi-permanent lava lakes. The adjoining rift margin volcanoes reach over 4000 m and arch 2000 m above the plain. Over the whole province, the Virunga has a diverse set of lavas but they are also dominated by highly potassic magmas of foidite and nepheline to phonolite composition. The variation is related to very large volumes of very low degrees of melting (a big area melts a bit) and the complexity of the crust. The magmas typify one extreme of rift alkaline magmas.

**Upheaval:** For upheaval, the main escarpments do not show clearly the slope away from the rift, and the huge Kivu dome upper can not be appreciated from the ground, being nearly 500 km across. There is no inherent relief of uplifted sediments, or lavas.

**Connectivity:** In connectivity, the Virunga is vast and the individual volcanoes and structures are set very far apart. There is a low concentration of features. The problem arises that while each volcano is a magnificent geological landscape, full of diversity and surprise, each is too large and set too far apart to make a major connection. This is even more relevant for the volcanic–fault relationships, which are not easy to see, even to an expert eye. For disposion, visibility for each individual feature is moderate, as the size of each in an often turbid equatorial atmosphere does not lend to views. Close up, such features like the lava flows from the basin spill out over the rift margin, reducing the impact of the subsidence in the landscape. Volcanic related features are common in the basin, however true rift faulting and fracturing are not seen. In fact, the faults have been very hard to map in this area and there is still uncertainty about the structural geometry.

**Science:** From a scientific perspective the volcanoes of the Virunga have been intensively studied from an early date and much research is on-going. Recent tectonic work has focused on lake bathymetry and geophysics as well as remote sensing, while field work – the use of topography for science, has been a lesser aspect, not just due to the security issues but also for the difficulty of reading the landscape. Much field work is concentrated on the craters of the active volcanoes, such as Nyiragongo.

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**INDICATORS**

**A. Faulting and subsidence:** A primary process of continental break-up is faulting and crustal thinning, causing the surface subsidence and a basin. Sediments around these escarpments are not related to the rift for the basin. Usually, discontinuities and features of surface features will take an important part in their scoring as well as the evidence of basin and uplift.

<table>
<thead>
<tr>
<th>Main indicator: net faulting</th>
<th>One or several linear escarpment(s)/ fault plane / clear subsided area (grades)</th>
<th>(scoring from 0 to 5)</th>
<th>3</th>
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<tr>
<td>Additional indicator: pronounced surface processes, minor scale</td>
<td>outcrops of faults and features</td>
<td>(scoring from 0 to 2)</td>
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</tr>
<tr>
<td><strong>Sub-total:</strong></td>
<td></td>
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<td>4</td>
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**B. Magnatism:** Magnatism is a primary continental break-up process, characterized by alkaline composition and by diverse compositions due to substantial modifications of mantle and crust. Volatile and alkaline magmatic features are scored such as, volcanoes, lava flows, fissured lava streams. So to be accord with heritage value, fault and active volcanism will be the most valuable assets because they are the best known and recognisable magmatic expression.

| Main indicator: remarkable rifting | Alkaline volcanism, number, surface area, size, visible diversity of magmas, freshness | (scoring from 0 to 5) | 5 |
| Additional indicator: activity | Persistent activity, active, dormant or extinct. (scoring from 0 to 2) | 2 |
| **Sub-total:** | | | 7 |

**C. Uplift:** Uplift is an essential element to perceive the rifting process to unfold the rift, as 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 the different cases and will only consider the topographic expression. The process is the most difficult to perceive and so comparable. Raised ancient surfaces (peneplaine), plateaux, concordant summits, eroded plateaux, breached craters and depressions; natural and raised volcanic rim will be scored. Their landscape aspect and distribution will take an important part in the scoring.

| Main indicator: raised surfaces | Old surfaces raised up (scoring from 0 to 5) | 1 |
| Additional indicator: uplifted sediments, plateau sloping away from rift | Sediments deposited low down now found high up, evidence of the uplift dome (scoring from 0 to 2) | 0 |
| **Sub-total:** | | | 1 |

**D. Connectivity:** Faulting, subsidence, migration and uplift features need to be connected to a heritage perspective. We are looking for signs that allow continental break-up to be understood in one angle and integrated process. All features should be seen together and not for individual links between them. Scoring occurs highest if seen to be seen in situ in the landscape. This layout shows their structural linkage and that all the features are coordinated, not that mechanisms does not necessarily 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 (can see the elements arranged in as to convey a clear sense of connection), proportionality of features. (scoring from 0 to 5) | 1 |
| Additional indicator: chronology | Can the elements of the site convey the sequence of events in the landscape so the temporal history of the site can be seen (chronotopic indications / framing of rocks, marker surfaces meaningfully showing the succession of processes, including on-going processes). (scoring from 0 to 2) | 0 |
| **Sub-total:** | | | 1 |

**E. Interest:** The scientific standing of the site can be judged in relation to the history of Science, taking into account the discovery of a site and its impact into developing scientific theories. Recent tectonic work has focused on lake bathymetry and geophysics as well as remote sensing, while field work – the use of topography for science, has been a lesser aspect, not just due to the security issues but also for the difficulty of reading the landscape. Much field work is concentrated on the craters of the active volcanoes, such as Nyiragongo.

| Main indicator: modern Science | Standing in the time after the plate tectonic revolution (50 years). (scoring from 0 to 5) | 5 |
| Additional indicator: history of Science | Standing in the beginning of scientific understanding (beginning depends on geographic location and culture). (scoring from 0 to 2) | 2 |
| **Sub-total:** | | | 7 |

**FULL TOTAL:** 20
Description:
Three lakes in the interior of the Kenya Rift system form a serial World Heritage site called the ‘Kenya Lake system in the Great Rift Valley’. The World Heritage site description states that the area is ‘a natural property of outstanding beauty, comprising three inter-linked relatively shallow lakes (Lake Bogoria, Lake Nakuru and Lake Elementaita) in the Rift Valley Province of Kenya.’

And follows, ‘These lakes are on the floor of the Great Rift Valley where major tectonic and/or volcanic events have shaped a distinctive landscape. [...] Surrounded by hot springs, geysers and the steep escarpment of the Rift Valley with its volcanic outcrops, the natural setting of the lakes provides an exceptional experience of nature.’

The site retained for comparison is around the lakes Nakuru and Elementaita, where there is the most concentrated area of rifting structures. There, both the basin infill, the surface processes are seen in conjunction with volcanic and tectonic features. This is also part of the World Heritage site, listed for aesthetic and ecological values (criteria (vii), (ix), (x)) with mention to the background geological environment.

Why chose this site?
The rift is 60 km wide at in the Kenya segment. The main rift fault escarpment is to the East the Aberdare range (40 km from Lake Nakuru, and 60 from lake Elementaita), behind which stands Mount Kenya (100 km from Lake Elementaita). To the West, the main rift margin is 20 km away from Nakuru. The other lake, Bogoria, is separated by 60 km, and so is isolated as a landscape feature. The west side of the rift is broken into a series of smaller steps that make a gentler slope down into the basin. The Aberdare escarpment to the East is an impressive 80 km long - 1000 m high rift margin with one straight fault line that cuts some pre-rift volcanoes in half. It was not retained for comparison for not meeting the prerequisites since it is one single fault line without the other continental break-up features. It is a distant backdrop for the lakes area, but is too far away to be a contiguous part of a site.

The site retained has clear closely-spaced inter-rift faulting with small volcanic alignments as well as the lakes. So it is one of the best sites in the Kenya segment for seeing juxtaposed continental break-up processes in the landscape. Other areas further North are Lake Bogoria itself, which lies in an impressive half graben but which lacks the rift volcanism; Lake Baringo is a broader landscape where the faulting is less pronounced; Mount Silali is an impressive fault cut volcano in a broad shallow rift where rifting is less obvious.

Lake Turkana is also a World Heritage site and has a pronounced rift margin and minor volcanism within the lake. This area also has a large old eroded volcanic alignment, the Kulal massif, about 20 km from the rift margin. Although remarkable at a biodiversity level, this area does not have the density of geological features that the Kenya Lakes site does.

To the South, the Suswa and Longonot volcanoes dominate the graben, partly covering the tectonic structures. Finally, into Tanzania, Lake Natron area is more an extensive structural area, but has a lower density of structural and volcanic features spread over a very large area (70 km across the rift).

In conclusion, the compact Kenya Lakes region of Lake Nakuru and Lake Elementaita provides the best, most compact representation of continental break-up features in the Kenya Rift segment.

Continental break-up features analysis
Faulting and subsidence: The main tectonic feature of this area is the closely spaced step faulting that is seen especially well on the east side of Lake Elementaita, and to a lesser extent east of Lake Nakuru where there is a small horst. Elementaita sits in a clear half graben about 8 km wide, while Nakuru has faults on both sides and a 7 km-wide graben. This provides two examples of...
the main types of graben (full and half). 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. 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.

The subsidence of the area is essentially demonstrated by the small escarpments and the lakes with their accompanying river systems. These are the foundation of the ecological system for which the lakes are inscribed on the World Heritage list. As geological attributes, they clearly display the interlinked nature of the faulting and the subsidence with the development of isolated basins that fill with sediments and hold lakes.

**Uplift:** In terms of uplift, the south side of lake Elmenteita stands out as the most interesting area, where small scoria cones and maars have erupted along the numerous eastern border faults. While these do not form a single alignment, individual volcanoes show elongation along faults, and are cut by faults. At the Mount Elburu volcano is approached to the South of the site, the magma diversity changes from alkaline basalts to include more evolved types that form domes and thicker lava flows. One lava flow is fresh and indicates that the area is magmatically active. There are also geothermal manifestations in the area that show this.

**Magmatism:** In terms of magmatism, the south side of lake Elmenteita stands out as the most interesting area, where small scoria cones and maars have erupted along the numerous eastern border faults. While these do not form a single alignment, individual volcanoes show elongation along faults, and are cut by faults. At the Mount Elburu volcano is approached to the South of the site, the magma diversity changes from alkaline basalts to include more evolved types that form domes and thicker lava flows. One lava flow is fresh and indicates that the area is magmatically active. There are also geothermal manifestations in the area that show this.

**Connectivity:** For concentration, the features of faulting, subsidence and surface processes can be seen close together, none separated by more than a few kilometers. In terms of disposition, each element is distinct in the landscape. The volcanoes are small monogenetic features, except the larger southern massif, that stand out from the plain, so they have moderate visibility. For simultaneous, volcanism is mainly linked to the southern part of Elementaita, where the linkage with faulting is innate, but elsewhere the tectonic-magmatic link is not striking. The presence of maars is noticeable and conveys a sense of connexion to the large but distant rift margins, providing a moderate link to the broader picture of the continental break-up.

A certain chronology can be observed with the volcanoes’ positions on faults, indicating that they are later than the fault which eventually cuts them. Also, the basin escarpments are cut again by the faults, showing the on-going continental rifting. A chronological link with uplift is missing due to the very distant location of the feature, way out of the site’s boundaries, so a lineage is not 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.

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**Science:** The site is part of the intensely studied Kenya Rift, an area where the tectonic development was first combed by Gregory in 1892. While the rift has been the site of major geological investigations, the lake area here has been essentially an ecological research site, as the larger volcanoes and more recently active magmatically sites (like South Kenya/ Tanzania) have received more attention. The geology of the area is important as a foundation for the ecological system of the lakes.

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**A. Faulting and subsidence:** The process of continental break-up is a faulting and crust-thinning, causing the surface subsidence and a basin. Sediments inside this escarpment are transported and fill the basin. Crustal, dislocations and faulting 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 features**
- Erosional or sedimentation features, on-going transport seen in the landscape and fault outcrops (scoring from 0 to 2)

**Sub-total:** 3

**B. Magmatism:** Magmatism is a primary continental break-up process, characterized by subduction, compression and by dike intrusion due to sub-continental collision of crust and core. Volcanic and subvolcanic magmatic features are scored such as, eruptions, lava flows, fault fissures, lava streams. In order to succeed with heritage value, fault and active volcanism will be for the most valuable assets because they are the best known and recognisable magmatic expressions.

**Main indicator: remarkable rifing**
- Alkaline volcanoes, number, surface area, size, visible diversity of magma, freshness (scoring from 0 to 5)

**Additional indicator: activity**
- Persistent activity, active, dormant or extinct. (scoring from 0 to 2)

**Sub-total:** 4

**C. Uplift:** Uplift is an essential element to perceive the rift process in full and the link to the deep fault. It can be caused either by a mantle plume or by the thinning of the crust due to its stretching, and is scoring only when the continental break-up. For the heritage perspective, we will not distinguish its different origins and will only consider its tectonic expression. The process is the most difficult to perceive as it is associated with crustal extension which is sometimes accompanied by subsidence of the plate. Final ancient surfaces (peneplaine), concordance, subsidence, extension, which are the most visible indications.

**Main indicator: raised surfaces**
- Old surfaces raised up (scoring from 0 to 5)

**Additional indicator: uplifted sediments, plateaux dropping away from rift**
- Sediments deposited low down now found high up, evidence of the uplift dome (scoring from 0 to 2)

**Sub-total:** 1

**D. Connectivity:** Faulting, subsidence, magmatism and uplift feature need to be connected to be 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 their layout shows their structural linkage. For the heritage perspective, we will not distinguish its different origins and will only consider its visible expressions.

**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? The geological history of the site can be seen (chronostratigraphic features / layering of rocks, paleo-surfaces meaningfully show the succession of processes, including on-going processes) (scoring from 0 to 2)

**Sub-total:** 6

**E. Evidence:** 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 activities, shown here as 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 beginning of scientific understanding (beginning depends on geographical location and culture). (scoring from 0 to 2)

**Sub-total:** 2

**FULL TOTAL:** 26
Description:
The Central Ethiopian rift is a vast area, 90 km wide and 500 km long, with a dense and complex fault pattern. There is not one single major and linear escarpment, but an interweave of fault steps following several directions. The includes the eastern rift escarpment, which is distinctive along certain sectors, such as east of the Boset volcano. Some of the complexity is due to the inheritance of more ancient zones of weakness and partly to the long history of divergence compared with sites further south (e.g. Malawi). The area gathers about twenty major volcanic centers with large calderas and hundreds of smaller cones and craters. Within this area, to find a type example of continental break-up, we focus on the North-East zone of Adama (Oromia name, with Nazret being the national name), where the Boset volcanic complex made of the Bericha and Gudda cones, rises 1,000m from the basin floor. Boset is cut by rift faulting that evolves as a half graben (4 km wide). The traces of the graben shoulder and the West rim is very steep and 150m high, while the East side had only a 50m fault step. The east side is partly covered by lava, which may explain the lower fault height, that may also be due to a slight half graben asymmetry. As the graben approaches the volcano, the margins become sites of eruption, dotted with ten small aligned cones merging into the main stratovolcanoes. The faults reappear again to the South of Boset-Bericha volcano but without a clear graben, there are just single faults and fissures. There is a second rough alignment of about 30 small cones, 8 km from the East side of the graben. The basin is populated with small villages and town with scattered fields and wetlands that occur between the more barren lava flows. The East side is less populated than the West, being dominated by savannah and lava plains. The area is only 30 km from the city of Adama (Nazret), and the main train and main road connection to Djibouti runs through the graben. The volcano and faulting present a significant risk to the city, but also important landscape features seen from the city.

Why chose this site?
Within the complexity and the profusion of the Central Ethiopian zone, this site is chosen as the best one to meet the prerequisites of the present comparative analysis by having a simply defined conjunction of continental break-up features. Recent research has also focused on this area due to the clear conjunction of structural and magmatic features, as well the accessibility of the area. Inside the very broad area of the Central Ethiopian Rift, the site is concentrated enough for the features to be seen in the landscape and their layout reflects the interconnected processes. This is confirmed by a recent research study that also chose this area for a detailed LIDAR study. It has to be noted that 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.

Continental break-up features analysis
Faulting: The area sits within the rift, and the distant sides, with the main Ethiopian plateaux stand out as far-field features in the greater landscape (20 to 30 km either side of the site). The main tectonic feature of the Adama - Boset area is the small graben and the fault cutting the Boset-Bericha volcano. 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. The West side escarpment of the small graben is not eroded and very abrupt in the change from fault shoulder to basin. There are distinct cracks and fissures at outcrops inside the basin that reinforce the perception of extension. Erosion and sedimentation are displayed through small river systems and ravines that feed little lakes sit next to the East side of the graben.
Magmatism: There are three different volcanic assemblages in this site: the noteworthy Bericha and Gulba stratovolcanoes of the Boset complex and its huge and thick lava flows; the related small aligned extending to the North into the eastern part of the graben; and last, the independent basaltic field to the 8 km East of the graben. The twin-peaked stratovolcano complex of Boset illustrates the extreme evolution of magmas trapped in the complex faulted crust, while the alignments show the less evolved basic alkaline magma-type. The varied volcanism gives a complete picture of magmatism processes in a rift context. According to the freshness of the lavas, there has been recent volcanic activity on this site.

Uplift: Being in the center of the Central Ethiopian rift, the evidence of uplift comes mainly from the elevation (1200 m, 2000 m for the volcano), rather from distinctive landscape features. The distant views do show the uplifted rift sides and not far from the site the Awash and other rivers cut a deep gorge, showing ongoing erosion related to uplift.

Connectivity: In terms of connectivity, all the features are close enough to be observed at the same time. In the layout, the rift fault can be seen becoming magmatic and crossing the stratovolcanoes, clearly indicating their structural connection. Because of its modest size and its physical separation, the second alignment is harder to perceive together with the tectonic features. The disparity in heights between small graben (about 150 m) and volcanoes (up to 1000 m) does not compromise the balance in the appreciation of the tectonic and magmatic processes. In the larger landscape, Boset volcano is lower than the distant and elevated Ethiopian plateau shoulders. There the most distinctive landscape elements describing the landscape chronology are faults that cut lava flows, and the clear superposition of different lavas from the volcanoes.

Science: The Central Ethiopian rift in general is one of the major sites for on-going tectonic research. Other nearby sites have received more attention like the Fantale or the Abidjatta-Shalla areas. The Boset-Bericha is only just beginning to become a focus for study, often included in articles with bigger scope.
Description:
Alid volcano area is situated in the center of the northern part of the Afar rift in Eritrea, not far from the Red Sea. The volcano is flanked on either side by the rift fault margins, which are sharply defined and steep sided on the East side. There, the fault escarpment rises to over 300 m high, over just 1 km of horizontal distance. It runs straight over 15 km to just past the Alid edifice to the North. The eastern fault then separates into a series of fault splays, seen as discrete steps, and the escarpment dies out over 10 km into the Danakil plain.

On the West, in contrast, the rift margin is deeply eroded with profound valleys separated by rampart like ridges that rise toward the inner highlands. Here, the rugged landscape reaches almost 2000 m altitude, over 10 km. The western margin has indeed no clear fault scarps but rises progressively from the plain, looking more like a mountain range.

The present rift is thus a half-graben, although at the Ethiopian border to the South, faulting does show clear offsets indicating a switch of half-graben symmetry — a common feature in rifts. Inner rift features and faults can also be seen, and some cut through the Alid volcano. The basin is about 15 km wide, and filled with lavas, alluvial flood plain sediments, sand dunes and salt plays. The main influx of sediment comes from the deep western valleys. Towards Alid and the small cone alignments, the sediments are supplemented by lavas.

Alid volcano is an excellent example of a volcanic uplift, a type originally described as a center of elevation by Leopold von Buch in 1857. At Alid, magma has been trapped in the rift and has evolved under the center to finally balloon up, rising a dome (a forced fold) some 500 m above the surface of the basin. Strata of deep ancient basement rocks, as well as the rift deposits and volcanics, dip out from the centre of the dome. Aligned with the fault direction, on either side of the dome are chains of small cones and cuestas from which basaltic lavas have been erupted.

The outer flanks of the eastern escarpment dip away from the fault line, describing a shallowly sloped dome of uplift that merges, at its lowermost, into corals and limestones of the now vanished Danakil Sea. It is this area, and the Alid uplift, that cut off the Danakil depression, leading to its desiccation. More ancient uplift is seen from the long rise of rugged mountains on the West, formed by the original up-rise 20 My ago. This makes the backdrop of the area.

Why chose this site?
The Alid site is the most obviously continental remnant in the Afar region, where the rest of the rift is entering oceanization with the completion of continental break-up. The rest of the Afar should therefore be considered separately under ‘oceanization’. Ancient rock is exposed in the Alid dome, indicating that there is still significant continental crust in the rift center. The Afar rift is opening by a rotation of the Danakil block, and Alid is near the movement axis. For this reason, the amount of recent opening is less than in other Afar areas, leading to a relatively earlier stage of continental break-up. The site combines obvious faulting and subsidence with flank uplift and a diverse magnetism. Other sites in the Afar display important rift features, however as stated, these are closely related to the stage of oceanization than the stage of continental rifting. They undoubtedly form sites worth of World Heritage status for their advanced stage of ocean formation and could illustrate this next stage of the Wilson cycle.

Continental break-up features analysis
Faulting and subsidence: The tectonic landscape around Alid is wide and spectacular and eastern fault escarpment is an unequivocal example of a rift margin although not very high and...
long compared to others (300 m high, 15 km long). The fault and basin describe a half-graben, with a dominating side opposite the fault which rises to the inner highlands. This rise induces a slight question mark, as there two sides are so noticeably different. There is a clear fault plan and two sides are so noticeably different. The answer is that the basin and the Alid volcano.

### Uplift

Uplift is a fresh feature on the eastern outer slope of the escarpment, with an easily-overflowed shallow basin rising to the fault line. The external raised marine sediments also testify to uplift of the flank of the rift. The West side is part of the original Alid dome uplift, however SO My of erosion has made it less obvious. The Alid volcanic uplift should not be confused with broader tectonic uplift, but is a fine demonstration of the general consequence of raising rock at a small scale. There is no inverted relief.

### Magnatism

The Alid crater of elevation dwarfs all other magmatic features which are small cones drawn in lavas. The large lava flows are remarkable uplifting the lower part of the rift-flank. It demonstrates the complexity of the rifting crust that produces the range of rifting magma compositions. These are seen through the uplift, the explosive trachyte pumice and more primitive basaltic lavas. Because of the disproportion between the major crater and the minor cones, the volcanic alignment is blurred.

### Connectivity

For concentration, the single large volcanic uplift, Alid, has clusters of baby cones around its base. It is separated from the fault escarpment by a single saddle, so concentration is high. For disposition, each element is a distinct and separated landform. For visibility, the area is small for a continental rifting, allowing the whole basin to be seen at a glance. The East fault is only 5 km from the Alid summit, and the West side another 10 km away. For proportionality, the one odd feature is that the Alid volcano is higher than the East rift margin by 150 m, meaning that the summit sticks out from inside the rift. Rather than diverting the rift, however, this draws the view towards the spectacular volcanic up-doming.

### Science

Due to the extreme climate and difficult access, this site has been little studied, but has recently become a subject for scientific research. Studies on the geothermal potential and the volcanic-tectonics have been increasing. The main aspect of the research has been magmatic related, rather than rift-related.
## SITE AND SETTING

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<tr>
<td>11</td>
<td>Steens - Mount</td>
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<td>12</td>
<td>Mateare - Chiltepe</td>
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<td>13</td>
<td>Subduction - Kenyan</td>
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</table>

### Scoring table

#### INDICATORS

<table>
<thead>
<tr>
<th>INDICATOR</th>
<th>SCORE RANGE</th>
<th>A. FAULTING AND SUBSIDENCE</th>
<th>B. MAGMATISM</th>
<th>C. UPLIFT</th>
<th>D. CONNECTIVITY</th>
<th>E. SCIENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faulting</td>
<td>0 – 5</td>
<td>Net faulting: 1 2 1 1 2 1</td>
<td>1 2 3 2 1 2</td>
<td>1 2 2 1 2 1</td>
<td>1 1 1 0 2 1</td>
<td>0 1 1 0 1 1</td>
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<tr>
<td>Subsidence</td>
<td>0 – 2</td>
<td>Pronounced surface processes: 1 2 1 1 2 1</td>
<td>1 2 3 2 1 2</td>
<td>1 2 2 1 2 1</td>
<td>1 1 1 0 2 1</td>
<td>0 1 1 0 1 1</td>
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<tr>
<td>Magmatism</td>
<td>0 – 5</td>
<td>Remarkable rifting magmatic features: 1 2 3 2 1 2</td>
<td>1 2 3 2 1 2</td>
<td>1 2 2 1 2 1</td>
<td>1 1 1 0 2 1</td>
<td>0 1 1 0 1 1</td>
</tr>
<tr>
<td>Uplift</td>
<td>0 – 2</td>
<td>Raised surfaces: 1 2 3 2 1</td>
<td>1 2 3 2 1 2</td>
<td>1 2 2 1 2 1</td>
<td>1 1 1 0 2 1</td>
<td>0 1 1 0 1 1</td>
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<tr>
<td>Connectiv</td>
<td>0 – 5</td>
<td>Intrinsic links between all elements of a site: 1 2 3 2 1</td>
<td>1 2 3 2 1 2</td>
<td>1 2 2 1 2 1</td>
<td>1 1 1 0 2 1</td>
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<tr>
<td>Science</td>
<td>0 – 5</td>
<td>Modern Science: 1 2 3 2 1</td>
<td>1 2 3 2 1 2</td>
<td>1 2 2 1 2 1</td>
<td>1 1 1 0 2 1</td>
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#### CONCLUSIONS

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 different tectonic 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 break-up, as well as their connection and the site’s scientific standing. The purpose is to find the most representative site for a clear illustration of the continental break-up process as a whole.

It is built on sound scientific feedback 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 (subsidence, magmatism, uplift, connectivity, science), one or more site top(s) the list:

- **Faulting and 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.

- **Magmatism**: Virunga and Adama present undoubtedly the most impressive and active volcanoes, but those volcanic features largely overshadow the subsidence and uplift features.

- **Uplift**: The nominated property excels in uplift expressions with a long inverted relief (The Montagne de la Sere), 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 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
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. 

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

- Malawi-Rungwe, which is a textbook example of hotspot rifting, although it does not as clearly display uplift;
- Adama-Boset very well expresses subsidence and magmatism in inter-rift faulting although would need a much broader perimeter to display rift margins which are too far from the volcanoes. In doing so the site would lose 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. While the nominated property excels 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 other compared sites, where one or more elements are lacking, or are disproportionate. The proportionality for the nomination is exactly related to it being an actively uplifting stage of a mountain related rift.

Statement of outstanding universal value

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 time break-up stage, the continental fragments eventually separate to finally 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.
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