World Heritage Volcanoes

Classification, gap analysis, and recommendations for future listings

Thomas J. Casadevall, Daniel Tormey and Jessica Roberts

United Nations Educational, Scientific and Cultural Organization
World Heritage Convention
WORLD COMMISSION ON PROTECTED AREAS
문화재청
Cultural Heritage Administration

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Cover photo: Teide volcano, Teide National Park World Heritage site. The red bugloss (*Echium wildpretii*) is one of the National Park's most spectacular plants. (c) Thomas Casadevall

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Contents

Figures

Tables

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Executive summary

Volcanoes are a true wonder of the planet; they demonstrate geological processes fundamental to understanding how the dynamic Earth works, linking processes in the Earth's interior with those on its surface. Volcanoes are also central to formation, evolution, and sustaining of biological systems; they form some of our deepest and most significant cultural attachments to the land; and they attract large numbers of visitors for their aesthetic appeal. Volcanoes are among the most easily-recognisable natural areas included on the World Heritage Site list, notable for their combination of geological, biological, cultural, and aesthetic values to communities on every continent. The global recognition of many volcanic landscapes as World Heritage raises important questions for the appropriate guidance of their future representation on the List. As advisory body for natural sites, the International Union for the Conservation of Nature (IUCN) prepares thematic studies in response to such important and programmatic questions, including this *Volcano Thematic Study*. In particular, at the UNESCO World Heritage Committee meeting in 2013, the IUCN was requested:

"to revisit and update its thematic study on World Heritage Volcanoes to clearly articulate a short and appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List..."[1]

The context for this *Volcano Thematic Study* is that the World Heritage Convention seeks a representative, balanced and credible World Heritage List of sites (including volcanic sites) that demonstrate Outstanding Universal Value (OUV). The World Heritage List is not the appropriate international conservation instrument to collect many sites representing very specific values; rather, the List highlights those sites which are demonstrated as truly exceptional at a global scale.

Classification System for Volcanic Themed World Heritage Sites and Gap Analysis

The *Volcano Thematic Study* begins by developing a classification system for volcanic landscapes based on **plate tectonic setting** to provide a conceptual framework for developing a balanced and representative World Heritage List for volcanic sites. The classification system establishes a taxonomic basis for classifying different types of volcanic terrains and their heritage value. The classification system organises the data on volcanic sites and values represented on the List and forms the framework for conducting the gap analysis and articulating an appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List under criterion (viii)[2].

Classification of volcanic landscapes for world heritage must support dialogue among scientists, decision makers, local populations, and other stakeholders. The classification must address heritage values, educational values and understand regional diversity to identify the most globally exceptional volcanic sites. As noted above, classification must also recognize that the World Heritage List is not intended to ensure the protection of all properties of great interest, importance or value, but only for a select list of the most outstanding of these from an international viewpoint. The different elements of the classification do not all automatically require representation on the World Heritage List: sites must also meet the conditions of Outstanding Universal Value, including those for integrity, and for protection and management. Some components of the classification may be represented by very few sites, because even the best sites within a taxonomic component may not satisfy integrity, protection and management criteria.

Plate tectonic setting provides an organizing principle that is readily understood, easy to communicate on maps and graphics, and neither too broad nor too narrow. Plate tectonics is the result of a scientific revolution that completely transformed how geologists consider the dynamic earth, and volcanism is the visible evidence for many plate boundaries.

Within the context of only considering sites of Outstanding Universal Value, the regional representation of the most significant volcanic features and sites is an important factor in ensuring a representative, balanced, and credible World Heritage List. World volcanoes are most abundant in convergent margin settings on land or in submarine divergent margin settings. Therefore, in considering representation by plate tectonic setting, we would not expect to see comprehensive regional representation. The most direct way to consider regional representation is to logically consider the degree to which areas with the greatest number of active volcanoes are adequately represented on the World Heritage List. Per country, the greatest abundance of active volcanoes is found in Indonesia (75), USA (65), Japan (58), the Russian Federation (52) and Chile (42). Of these five countries, Indonesia, Japan and Chile do not have any volcanic sites on the List for criterion (viii). There are also relatively few listed sites in North America, which has many excellent, well-studied and accessible examples of volcanoes. Considered in this way, volcano-rich regions that are unrepresented or poorly represented include the Southwest and Western Pacific, South America and North America.

The relative youth and dramatic aspect of active volcanic sites compared to other geological themes lends cultural, biological, and aesthetic importance to volcanic sites. The relatively rapid growth of new terrain, standing above surrounding areas, leads

1. IUCN Decision 37 COM 8B.15 adopted at its 37th session in Phnom Penh, 2013

2. Criterion (viii) for inclusion on the World Heritage Site list encompasses geologic sites, including volcanic sites: "to be outstanding examples representing major stages of Earth's history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features."

to an unusually high degree of micro habitats that lead to high levels of biodiversity and endemism. The growth rate of volcanic terrain often takes place on similar timescales within human memory, and this immediacy often leads to an active involvement with cultures and human history. In addition to the primary elements of representation of volcanic sites by plate tectonic setting and regional representation, the classification system therefore includes secondary consideration of specific heritage values, including cultural and spiritual value (including whether the volcano is considered iconic), biological and ecosystem value, aesthetic value, and educational and communication value.

The study then conducts a gap analysis of whether volcanic sites currently on the World Heritage List are representative of the world's volcanic estate, organized according to the classification system. The analysis first considers volcanic sites listed under criterion (viii), and the degree to which the current List adequately represents the world's volcanic estate. The List currently has 80 sites with some volcanic features, but only 23 are listed under criterion (viii) (geological values). The others are listed for cultural (78), biological (67), and aesthetic values (36). Frequently individual sites are frequently listed for multiple criteria.

The study notes that many World Heritage sites are listed in volcanic terrain, but for reasons that are not covered by criterion (viii). In regard to the management of all volcanic World Heritage properties, even if a volcanic property is not listed for criterion (viii), there is the potential that the risk of hazardous conditions (eruptions, gas emissions, hydrothermal activity, landslides, and other volcanic hazards) may not be adequately addressed in the site's management plan. The World Heritage List includes some notably dangerous volcanoes, and the monitoring of volcanic activity and risk contingency planning should be essential parts of the management process in all potentially active volcanic World Heritage properties. In addition, the site's key volcanic features may not receive adequate emphasis or protection by the managing authority.

There are significant gaps in representation of volcanic sites listed for criterion (viii). The southwestern Pacific island arc settings, with several volcanoes with potential Outstanding Universal Value, are unrepresented on the List. The Andes of western South America is the most prominent example of continental arc volcanism, and yet is poorly represented. For divergent margin sites, the mid-Atlantic Ridge (including iconic volcanoes of Iceland), the Great Rift Valley of Africa, the Red Sea Rift, are poorly or not represented. Submarine volcanic systems are dominantly rift systems and are not represented. Volcanism in back arc basins is unrepresented, although there are outstanding examples in Argentina and the southwest Pacific. Collision zones are not represented. Ancient volcanic terrains on the World Heritage List contain no continental flood basalts, ring-dike complexes, or komatiites, despite the importance of these terrains in remaking continental surfaces, and as components of most mass extinctions on the planet.

Sites with Strong Potential for Inscription on the World Heritage List

An important part of the process used in preparing this Study was to engage the global community of volcano scientists in a series of 'expert consultations' to ensure that the study rigorously covered the key volcanoes, volcanic features and volcanic landscapes of the various regions of the globe. This engagement had the added benefit of bringing the concepts of geoconservation of volcanic landscapes to a broad global audience not accustomed to thinking about the protection of volcanic landscapes. The authors carried out expert consultations through a combination of site visits to existing protected volcanic areas (National Parks, World Heritage sites, UNESCO Global Geoparks and Biosphere Reserves), correspondence with regional experts, participation in several regional meetings focused on protected volcanic landscapes, particularly in Asia and Europe, and through proactive solicitation of opinions and perspectives.

Based on the above analysis, and following extensive study, review of the scientific literature and extensive outreach to professional societies and other experts in volcanology and geoheritage, the study identifies a limited list of several volcanic sites with strong potential for inscription on the World Heritage List, presented by region in two categories:

i) iconic sites with clear high potential to meet criterion (viii), and
ii) additional sites that may be further considered for the potential to meet criterion (viii), but where justification of the criteria would require further study.

The presentation of sites with a focus on criterion (viii), is not exhaustive and has not attempted to analyse whether these suggested locations meet the necessary conditions of integrity or their level of protection and management. Both considerations are elements of Outstanding Universal Value required for the possibility of nomination. Certainly for the additional sites and possibly for the iconic list, State Parties may alternatively consider evaluating the options of nomination as Global Geoparks or Biosphere Reserves in the event they do not fully exhibit OUV, or if these other designations are better adapted to the goals of the State Party than is World Heritage. In all cases State Parties are recommended to seek advice from UNESCO and IUCN prior to beginning work on nominations for sites covered in the present study.

Advice to States Parties and Nomination Reviewers

The *Volcano Thematic Study* also provides advice to States Parties on the application of criterion (viii) to volcanic sites. The advice includes the use of the classification system and feature identification presented in this study to support the nomination of volcanic sites under criterion (viii), including a checklist that can also be used by the reviewers of the nomination. The advice also describes a method for developing a comprehensive global comparative analysis to support the nomination. The global comparative analysis is central to the application and review process in establishing the evidence-based justification for Outstanding Universal Value.

Other UNESCO Designations

The analysis in this *Volcano Thematic Study* also includes properties listed in the UNESCO Global Geoparks Programme and sites listed in the UNESCO Man and the Biosphere Programme (Biosphere Reserves). These programmes offer global recognition and may provide additional protection to natural properties. Expanding the analysis to include these two other related UNESCO programmes is of benefit because it further highlights the range and diversity of values exhibited by volcanic sites: UNESCO Global Geoparks are well suited for sites of scientific and cultural importance with sustainable development of the volcanic resource, while Biosphere Reserves emphasise that volcanic geodiversity can support globally-significant biodiversity alongside sustainable development. Together with World Heritage, these three UNESCO programmes offer a broader palette of recognition that States Parties may consider for volcanic properties.

Introduction

1

Lavas from Kilauea Volcano flowing into the Pacific Ocean, Hawai'i, USA © Thomas Casadevall

1. Introduction

A World Heritage site is a place (such as a building, monument, desert, forest, cave or volcano) that is inscribed on the World Heritage List (the List) by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as being of Outstanding Universal Value (OUV): significance so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. The List is administered by the UNESCO World Heritage Committee, composed of 21 UNESCO Member States that are elected by the General Assembly of States Parties to the World Heritage Convention. World Heritage was founded on 16 November 1972 through the agreement of the Convention Concerning the Protection of the World's Cultural and Natural Heritage (the World Heritage Convention, the Convention). Since then, 193 States Parties have ratified the Convention. The International Union for the Conservation of Nature (IUCN) has the statutory role of advisory body within the Convention regarding natural heritage, which includes evaluation of natural sites nominated to the List, and making recommendations on inscriptions to the World Heritage Committee. The International Council on Monuments and Sites (ICOMOS) is responsible for the evaluation of cultural sites nominated to the List. IUCN, ICOMOS and a third advisory body (the International Centre for the Study of the Preservation and Restoration of Cultural Property – ICCROM) perform a range of other roles within the Convention. The functioning of the different processes of the Convention, including the submission and evaluation of nominations, is governed by the Operational Guidelines for the Implementation of the World Heritage Convention (the Operational Guidelines).

For a property to be inscribed on the World Heritage List, the World Heritage Committee must find that it displays OUV in relation to one or more of the following ten selection criteria, and meets the related conditions of integrity, authenticity (for cultural sites), and conditions of protection and management. The criteria are typically referred to by roman numerals, such as criterion (viii) (in bold text below), which allows for inscription of geological heritage, including volcanic landscapes, on the World Heritage List:

i) to represent a masterpiece of human creative genius;

ii) to exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;

iii) to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared;

iv) to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;

v) to be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;

vi) to be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance;

vii) to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;

viii) to be outstanding examples representing major stages of Earth's history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features;

ix) to be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, freshwater, coastal and marine ecosystems and communities of plants and animals; and to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of OUV from the point of view of science or conservation.

Mt. Fuji reflected in Lake Misaka, Hokusai woodblock print, Japan
© Hokusai woodblock print collection, Metropolitan Museum of Art, USA

Box 1.

Iconic is defined in this study as 'so famous as to be an integral part of a broad culture'. An iconic volcano is one that is easily and widely recognised in the scientific and popular culture. It may be famous not only for its distinctive form, but also its spectacular eruptions, the role it may play in cultural, historical and social contexts, and its importance in the science of geology and volcanology. Examples of iconic volcanoes include Mount Fuji, Mount Etna, Kilauea Volcano, Krakatau, Mount Kilimanjaro, Volcan Cotopaxi, Yellowstone Caldera, or Volcan Popocatepetal. These iconic volcanoes adorn postage stamps, coins, currency, literature, cinema, and other representations of what a culture considers to be iconic.

Iconic is distinct from UNESCO's Outstanding Universal Value, which means cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. However, consideration of iconic volcanoes is helpful in identifying whether they demonstrate OUV.

In current World Heritage Listings of iconic volcanoes, approximately half are included for their OUV under criterion (viii), while half are not listed for their volcanic values [not listed for criterion (viii)].

(x) to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Fernandina, Galapagos Islands, marine iguana in foreground, Ecuador © Richard Reynolds

Volcanic landscapes demonstrating OUV for their geological attributes can potentially be listed under criterion (viii). Volcanic landscapes are among the most easily-recognisable and frequently-nominated natural areas of the World Heritage Convention. Volcanoes demonstrate geological and geomorphological processes fundamental to understanding how the dynamic Earth works, from the global to the local scale and linking processes in the Earth's interior with those on its surface. In addition to their core geoscience values, volcanoes provide one of Nature's most dynamic stages, which has expressions in the great biodiversity found in many volcanic landscapes, the cultural connections between people and their environment, and as a record of human developments on every continent. As such, volcanic landscapes have frequently been nominated, and inscribed, under many criteria other than (viii). The global recognition of many volcanic landscapes as World Heritage raises important questions for the appropriate guidance of their future representation on the List.

As advisory body for natural heritage, IUCN prepares thematic studies in response to important and programmatic questions. The UNESCO World Heritage Committee requested IUCN *"to revisit and update its thematic study on 'World Heritage Volcanoes' … to clearly articulate a short and appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List."*[3]

Some tools for volcanology, Central Andes, Chile/Argentina © Dan Tormey

IUCN is publishing the present report, *World Heritage Volcanoes: Classification, gap analyses, and recommendations for future listings.* (*Volcano Thematic Study,* or Study), in response to this request. Although this *Volcano Thematic Study* builds on and replaces the work of the earlier 2009 *World Heritage Volcanoes study* (Wood, 2009), its objectives are distinct and its methods differ.

The context for this *Volcano Thematic Study* is that the World Heritage Convention seeks a representative, balanced and credible World Heritage List of sites (including volcanic sites) that demonstrate OUV. The World Heritage List is not the appropriate international conservation instrument to collect many sites representing very specific values; rather, the List highlights those sites which are demonstrated as truly exceptional at a global scale. This context leads to several important questions that must be addressed by this study in responding to the World Heritage Committee's request; some examples include:

How broad or narrow should be the values of the nominated volcanic property? Heritage value includes considerations of the geological, biological, cultural, aesthetic and educational values that have emerged in specific locations over time because of interrelations between volcanoes and the socioecological environments that they create. The classification system presented in this Study addresses the need to clearly articulate the breadth (neither too broad nor too narrow) of volcanic-related values that must be represented by nominations to the World Heritage List.

What makes a volcanic terrain 'the best of the best', truly iconic and worthy of inscription on the World Heritage List? UNESCO requires sites to have OUV to be considered for inscription on the World Heritage List under at least one criterion (see box 1). Iconic is not necessarily the same as OUV, but it is a useful and simpler concept in helping judge whether volcanic sites might demonstrate OUV. Iconic is defined in this study to mean: so famous as to be an integral part of a broad culture. For example, there are many scientifically-important and aesthetically-pleasing oceanic islands, but the Galápagos Islands are an iconic volcanic terrain because they also host one of the world's most outstanding illustrations of how volcanic geodiversity supports unique biodiversity; Darwin's development of the theory of evolution by natural selection was also in part inspired there. Similarly, volcanic chains along the 'ring of fire' surrounding the Pacific Ocean contain several exceptionally beautiful, spiritually uplifting, snow-clad cone volcanoes, but

3. IUCN Decision 37 COM 8B.15 adopted at its 37th session in Phnom Penh, 2013

Mount Fuji is an iconic volcanic terrain because it has been represented in art and spiritual practice for millennia and is known globally as a site that represents the classic form of a volcano. Volcanic terrain frequently produces outstanding associated biological, cultural and spiritual values. As such, many iconic volcanic sites on the World Heritage List are *not* included for their OUV with respect to their geological attributes (such as Mount Fuji), whereas others such as the Galápagos are. The classification system presented in this Study therefore identifies specific secondary factors to weigh in assessing the potential of a scientifically-important volcanic terrain in an underrepresented category to demonstrate OUV. This Study also provides guidance on assessing both representativeness and OUV for volcanic properties and specifies how to conduct a Global Comparative Analysis to quantitatively evaluate the assessments.

Mt. Herðubreið, Iceland's "national mountain", perfect example of a subglacial volcanic structure (known as a tuya) © Dan Tormey

Are the geological values of iconic volcanic terrains appropriately identified in sites already included on the World Heritage List? The Galápagos Islands were listed for geological, ecological and aesthetic criteria. Therefore, the volcanic features were appropriately identified and recognised in the listing under criterion (viii). Mount Fuji, in contrast, was listed for a unique cultural tradition and tangible association with traditions and artistic works of outstanding universal significance. Mount Fuji was neither nominated for, nor listed for, its volcanic features under criterion (viii) despite being one of the first 'iconic volcanoes' many people, including most volcanologists, would name. If the volcanic features of a property warrant listing for criterion (viii) but they are not so identified, then there is no assurance that the geological attributes will be adequately represented or protected. There is also no assurance that the host of volcanic risks that may occur in drawing visitors to these active areas will be addressed in the management plan.

This *Volcano Thematic Study* does not revisit the criteria for which existing World Heritage sites were listed in the past; these represent the current listing status. In considering whether volcanic landscapes are relatively well represented on the List and to support guidance to States Parties for future listings, however, the question of importance of listing under criterion (viii) becomes primary. In determining whether the World Heritage list contains a representative collection of volcanic properties, we first consider volcanic landscapes that are listed for the OUV of their geological features (criterion (viii)), and then consider other volcanic sites on the List that do not include criterion (viii).

1.1 Role of thematic studies in developing a representative, balanced and credible World Heritage List

The questions posed for this *Volcano Thematic Study* are not new ones for world heritage. As of April 2018, the cut-off date for the analysis in the present study, the World Heritage List has 1,073 sites; most are cultural sites in more developed parts of the world. There are 832 cultural, 206 natural and 35 mixed properties in 165 countries. Italy contains the greatest number of World Heritage sites (53), followed by China (52), Spain (46), France (43), Germany (42), India (36) and Mexico (34). Recognising these imbalances, UNESCO initiated a strategy in 1994 to develop a more representative, balanced and credible World Heritage List. The goal of the strategy was to identify and fill major gaps in different key **themes** and to balance regional representation. Less- developed countries and underrepresented regions were encouraged to participate, whereas countries whose heritage was already well represented were encouraged to reduce their rate of nominations and to focus on underrepresented themes. (Gray, 2013).

Box 2.

World Heritage Volcanic Sites

- 80 WH sites feature active volcanoes or volcanic features (-7.4%)
- 53 sites inscribed for natural *criteria (vii - x)*
- 23 sites inscribed for *criterion viii*
- 3 sites inscribed for *criterion viii* alone - *Mt. Etna, Aeolian Islands, Hawai'i Volcanoes*
- 27 sites inscribed for *cultural criteria (i-vi)*

Box 3.

World Heritage Sites

- 1073 World Heritage sites
- 206 natural sites
- 823 cultural sites
- 35 mixed sites (both natural and cultural)
- 80 sites feature active volcanoes or volcanic features (-7.4%)

through March 2018

Mount Saint Helens Volcano and Johnston Ridge Observatory, USA © Thomas Casadevall

To support the UNESCO strategy for a more representative, balanced and credible World Heritage List as it applies to geological sites listed for criterion (viii), IUCN published *Geological World Heritage: A global framework: A contribution to the global theme study of World Heritage Natural Sites* (Dingwall et al., 2005). The *Geological World Heritage* study established 13 geological themes and identified potential gaps in representation on the List:

1. tectonic and structural features
2. volcanoes/volcanic features
3. mountain systems
4. stratigraphic sites
5. fossil sites
6. fluvial/lacustrine systems and landscapes
7. caves and karst
8. coastal development
9. reefs, atolls and oceanic islands
10. glaciers and ice caps
11. ice ages
12. arid and semi-arid landforms and landscapes
13. meteorite impact.

Four of the themes identified in the *Geological World Heritage* study have been the subject of more specific thematic studies focused on geoheritage values: fossil sites (Wells, 1996), desert landscapes (Goudie & Seely, 2011), caves and karst (Williams, 2008), and volcanoes (Wood, 2009). Wells (1996) concluded that the fossil sites then on the List were "not representative of the history of life on earth." He recommended choosing fossil sites that contain well-preserved fossil accumulations of high species diversity that best document the story of community and environmental change through time. The purpose of the deserts study was to advise on nonpolar deserts as potential World Heritage Sites of Outstanding Universal Value with a focus on geomorphological aspects and recommended specific desert landscapes for consideration.

During the 31st World Heritage Convention in Christchurch in 2007, the World Heritage Committee indicated that it considered that both volcanic sites and caves and karst sites were relatively well represented on the List and commissioned thematic studies on each. For caves and karst, IUCN stated that "in the interests of maintaining the credibility of the World Heritage List, IUCN considers that there is increasingly limited scope for recommending further karst nominations," and that these should only be put forth if:

"There is a very clear basis for identifying major and distinctive features of OUV that has been verified by a thorough global comparative analysis …The basis for claiming OUV is a significant and distinctive feature of demonstrable and widespread significance, and not one of many narrow and specialized features that are exhibited within karst terrains."

The *Thematic Report of World Heritage Cave and Karst* sites (Williams, 2008) evaluated this finding. Williams (2008) identified poor representation of caves and karst in South America, Africa, Australasia and the South Pacific, Asia, and the Middle East. Williams (2008) also identified arid, semi-arid, periglacial and evaporite karsts as underrepresented.

Box 4.
Protected Volcanic Landscapes - a global perspective

United Nations Educational, Scientific and Cultural Organization · World Heritage Convention

United Nations Educational, Scientific and Cultural Organization · UNESCO Global Geoparks

United Nations Educational, Scientific and Cultural Organization · Man and the Biosphere Programme

The concern that volcanic landscapes are already well represented on the World Heritage List led the 31st World Heritage Session in Christchurch to adopt similar specifications for the Volcano Thematic Study to those for Caves and Karst, suggesting that there is a decreasing potential for further nominations of volcanic properties:

"IUCN notes that volcanic systems are relatively well represented on the World Heritage List, including several properties whose inscription were justified based on arguments that are considered by a number of experts to be rather narrow. There are many volcanoes worldwide and at a detailed level every one of these can assert that it is in some way unique. In 1996 IUCN noted that the World Heritage Committee had already asked, 'How many volcanoes should there be on the World Heritage List?'

In the interests of maintaining the credibility of the World Heritage List, IUCN considers that there is increasingly limited scope to recommend further nominations for inclusion on the World Heritage List. In particular, IUCN recommends that the World Heritage Committee should consider indicating clearly to States Parties that further volcanic nominations should only be promoted where:

- There is a very clear basis for identifying major and distinctive features of Outstanding Universal Value that has been verified by a thorough global comparative analysis;
- The basis for claiming Outstanding Universal Value is a significant and distinctive feature of demonstrable and widespread significance, and not one of many narrow and specialized features that are exhibited within volcanic terrains.

IUCN recommends that States Parties considering volcanic nominations carry out an initial global comparative analysis prior to proceeding with the development of a full nomination, to minimize the possibilities of promoting a nomination that will not meet the requirements of the World Heritage Convention, including those concerning the conditions of integrity."

The first IUCN thematic *World Heritage Volcanoes* study (Wood, 2009) prepared in response to this request determined that volcanic landscapes were relatively well represented and that future nominations should be restricted to filling gaps in the present global coverage of volcanic sites where there is "a very clear basis for identifying major and distinctive features of Outstanding Universal Value that have been verified by a thorough global comparative analysis." Wood (2009) found that 57 properties on the List contain some volcanic geology, with less than half inscribed for criterion (viii). Wood (2009) concluded that although the World Heritage List appears to possess good overall representation of volcanic features, it also possesses "some gaps that might be filled by future nominations," as follows:

- Basaltic volcanism, such as fissure volcanoes, subglacial volcanic edifices and continental flood basalts;
- Silicic volcanism, including calderas and large ash or pumice flows (ignimbrites); and
- Some of the world's most iconic volcanoes. Wood (2009) particularly noted the absence of Mount Etna, Thera (Santorini), Mount Fuji, Paricutin, Mount Mayon, Mount St. Helens, Crater Lake, Laki, Mount Pelee and Tambora.

1.2 Objectives and scope of the second *Volcano Thematic Study*

The World Heritage Committee has requested IUCN to revisit and update the 2009 thematic study on *World Heritage Volcanoes* (Wood, 2009) to clearly articulate a short and appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List.

In response, this *Volcano Thematic Study* defines an approach to classifying volcanic landscapes for use in developing a balanced and representative World Heritage List for volcanic sites. The Study then provides an analysis of existing listed sites using the classification system as an organising principle and identifies gaps in representation on the World Heritage List. The analysis first considers volcanic sites listed under criterion (viii) and the degree to which the current List adequately represents the world's volcanic estate. Next, the analysis considers those sites on the List that have volcanic features but that are not listed for criterion (viii). Many of these sites do not display OUV for their volcanic features, but several of them certainly do. We consider how representative the current List would be with the addition of the sites not currently listed under criterion (viii) but with a likelihood of qualifying. We then consider sites on States Parties' Tentative Lists and consider the representativeness of the List with the potential inclusion of these sites in the future. Finally, through our own expertise and outreach to other experts in volcanology and geoheritage, we specify

Tenerife Island and Teide Volcano, Spain © NASA

additional sites identified during the preparation of this *Volcano Thematic Study* that could fill the remaining gaps in the List. The systematic application of the method described in this *Volcano Thematic Study* leads to a list of the strongest remaining volcanic sites with potential for inscription.

Volcanoes are true wonders of the planet; they are central to the formation, evolution and sustenance of biological systems; they form some of our deepest and most significant cultural attachments to the land; and they attract large numbers of visitors for their aesthetic appeal. Although the primary focus of the analysis in this Study is on volcanic sites that have been inscribed on the World Heritage List under criterion (viii), these defining features of volcanoes mean that States Parties may also consider protection of the volcanic heritage value by listing them under other criteria. Focusing the *Volcano Thematic Study* solely on properties listed under criterion (viii) would miss several volcanic sites with OUV that are on the World Heritage List (such as Mount Fuji, which is listed under criteria (iii) and (iv)). There is a risk of the analysis becoming too broad, by including properties with volcanic features that are not necessarily of OUV. Although the focus of this review remains sites listed under criterion (viii), in our opinion, a broader initial view is necessary to comprehensively describe the range of volcanic heritage currently on the List.

This Study also provides advice to States Parties on the application of criterion (viii) specifically to volcanic sites. The advice includes the use of the classification system and features identified in this Study to strengthen the nomination of volcanic sites under criterion (viii). The advice focuses on the extension of the language of criterion (viii) to include consideration of volcanic sites also includes a checklist that can be used by the States Parties in their nominations as well as by nomination reviewers. The advice also describes a method, with best practice examples, for developing a comprehensive and quantitative Global Comparative Analysis for volcanic sites to support the nomination. The Global Comparative Analysis is central to the application and review process in establishing the evidence-based justification for OUV.

Mount Vesuvius, from volcanic-preserved city of Herculaneum, Italy © Dan Tormey

Although the scope of the study is the World Heritage List, the analysis in this *Volcano Thematic Study* also includes properties listed in the UNESCO Global Geoparks Programme and sites listed in the UNESCO Man and the Biosphere Programme (Biosphere Reserves). These programmes offer global recognition and may provide additional protection to natural properties. We believe that expanding the analysis to include these two other related UNESCO programmes is of benefit because it further highlights the range and diversity of values exhibited by volcanic sites:

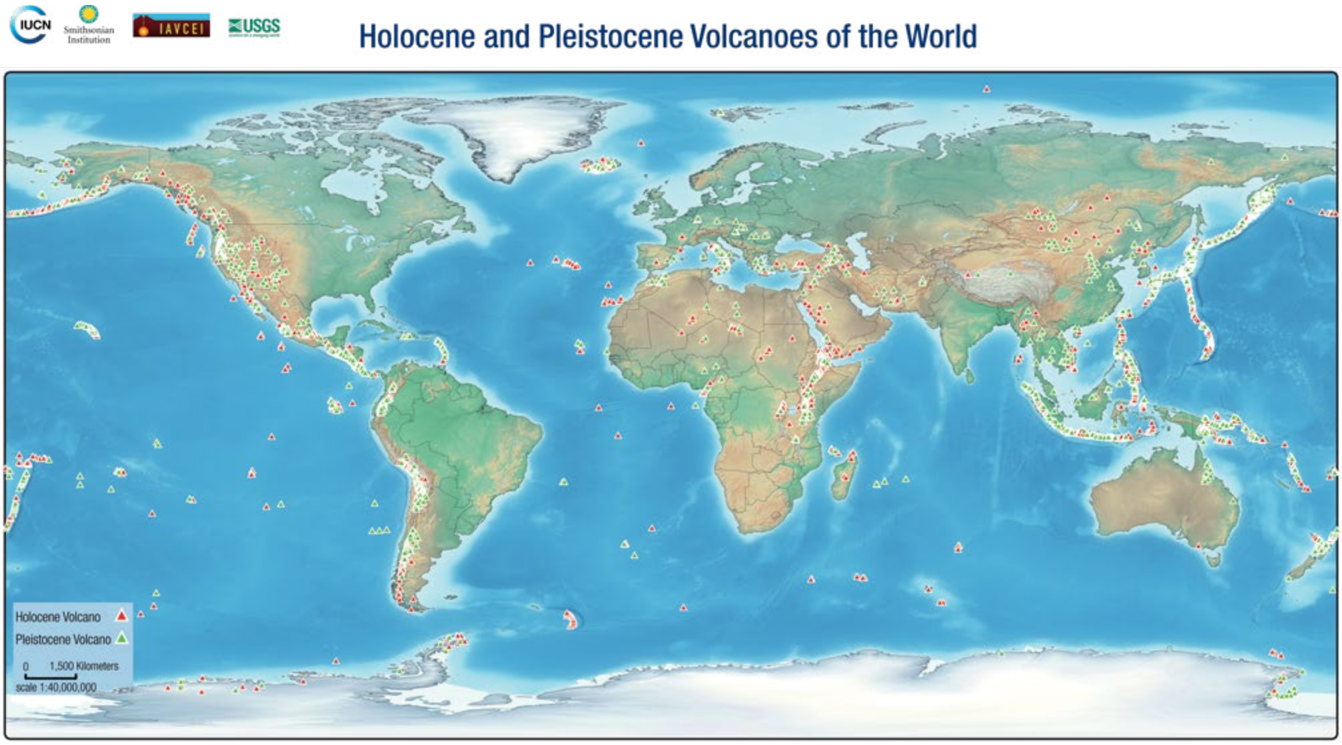


Figure 1: Map of the world's Holocene and Pleistocene volcanoes. Positional information for mapped volcanoes is from Global Volcanism Program (2013).

UNESCO Global Geoparks are well suited for sites of scientific and cultural importance with sustainable development of the volcanic resource, while Biosphere Reserves emphasise that volcanic geodiversity can support globally-significant biodiversity alongside sustainable development. Together, the three UNESCO programmes offer a broader palette of recognition that States Parties may consider for volcanic properties.

1.3 Methods used in developing the second *Volcano Thematic Study*

Appendix 1 provides a complete description of the methods used in developing this *Volcano Thematic Study*. Briefly, the methods are as follows.

1.3.1 Data and organization

This study followed a stepwise process starting with an inventory of all UNESCO World Heritage volcanic properties, UNESCO Global Geoparks and the World Network of Biosphere Reserves. The inventory included the attributes of each site, such as country, name, location, listing criteria, tectonic setting, scientific and other values represented and comments. We linked the inventory to the Smithsonian Institution Volcanoes of the World database of Holocene and Pleistocene volcanoes, which includes eruptions within approximately the last 11,700 years (Holocene) and the last 2.6 million years (Pleistocene). In addition to preparing an inventory for all World Heritage-inscribed properties, we also considered properties on the Tentative Lists identified by Member States for possible future nomination. This inventory formed the database for our analysis.

Mount Hallasan, Jeju Volcanic Island and Lava Tubes World Heritage Site, Republic of Korea © Jeju Special Self-Governing Province

World Heritage properties are nominated for inscription based on sites having OUV for at least one out of 10 criteria. Criteria (i) to (vi) are grouped as 'cultural' criteria. Criteria (vii) to (x) are grouped as 'natural' criterion. Criterion (viii) is often referred to as the 'geological criteria' (Dingwall et al., 2005).

In our inventory review of World Heritage volcanic properties, we indicate the selection criteria for which the property was inscribed (http://whc.unesco.org), the year of inscription of the property and the country and geopolitical region of the Member State. Our inventory and review included not only sites inscribed for criterion (viii), but for all World Heritage criteria: cultural (i) to (vi) as well as natural (vii) to (x). In most cases the inclusion of a specific volcanic site was clear; for example, Mount Etna (Italy), which was inscribed in 2014 solely under criterion (viii). In other cases, the volcanic feature(s) may not have even been mentioned in the inscription dossier; for example, Grand Canyon (USA), where the criteria were applied to the unique record of geological time preserved in the stratigraphic section exposed in the canyon walls but not to the Holocene Uinkaret volcanic field and Vulcan's Throne.


Volcan Descabezado Grande, Chile © Dan Tormey

A significant number of World Heritage properties with important volcanic values have been inscribed for cultural criteria alone, such as Þingvellir (Iceland) and Mt. Fuji (Japan). It could easily have been argued that these sites could have also been inscribed for criterion (viii). In fact, Þingvellir National Park is currently listed on the Tentative List for Iceland for inscription under criteria (vii) through (x).

An additional area where judgement was necessary was for World Heritage properties that are located on the flanks of or near major 'iconic' or famous volcanoes. For example, the colonial historical centers in Puebla (Mexico), Antigua (Guatemala), Quito (Ecuador), and Arequipa (Peru) are located directly adjacent to major Holocene volcanoes. While these 'proximal' volcanoes do not form part of the 'footprints' of these properties, they are significant elements of their cultural and natural landscapes and are therefore included in the study inventory.

For sites such as Pompeii-Vesuvius (Italy), Joya de Ceren (El Salvador) and Leon Viejo (Nicaragua), volcanic eruptive products display a direct and unique role in the preservation of the cultural sites and follow the requirement of criterion (iii), *"to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living, or which has disappeared."* These sites are therefore included in our inventory.

In a similar fashion, several remote oceanic island sites listed primarily for their cultural and/or biological/ecosystem values are included in our inventory because these islands are the tops of seamounts that trace the position of oceanic rifts or hot spots and are, in fact, the tops of seafloor volcanoes. These oceanic islands are of pre-Holocene age (older than 11,700 years). Without these seamount volcanoes, there would be no fringing coral reefs with their associated cultural and natural features.

We followed the practice of Wood (2009) by also including an inventory of volcano properties listed in the World Heritage Tentative List (http://whc.unesco.org/en/tentativelists/). The current Tentative List contains 19 properties of high-quality volcanic areas. These include 15 that may be inscribed under criterion (viii), including several sites that would fill gaps in the World Heritage List. We applied the same categories in our inventory of the Tentative List volcano properties as we did for the inscribed properties.

1.3.2 Definition of volcanic site

We developed five categories of volcanic features for what we considered to constitute a 'volcanic site':

1. **Holocene volcanoes:** active with eruptions in approximately the past 11,700 years (Holocene period); the Volcanoes of the World database currently contains 1,432 volcanoes with eruptions during the Holocene period;
2. **Pleistocene volcanoes (extinct volcanoes):** volcanoes with no record of Holocene activity; with well-preserved morphology (Pleistocene); approximately the past 2.6 million years. The Volcanoes of the World database currently contains 1,239 volcanoes with activity during the Pleistocene period;
3. **Eroded volcanoes/'roots of volcanoes':** included pre-Pleistocene eroded features such as dikes, sills, necks, laccoliths that form the foundations or roots of volcanoes, calderas, volcanic rift systems, oceanic spreading centers, seamounts, etc.;
4. **Volcanic rocks**: including lavas, tuffs, ash fall deposits, etc. that are closely linked to cultural sites; or
5. **Volcanic rocks in a stratigraphic section or sequence:** generally not considered in this inventory unless important in cultural history, the history of science, or are of unusual aesthetic value.

The world's volcanic estate, which can be considered the active volcanoes (Holocene volcanoes) and extinct volcanoes that preserve their form (Pleistocene volcanoes), is illustrated in Figure 1.

1.3.3 Expert consultation

An important part of the process we used in preparing this report was to engage the global community of volcano scientists in a series of 'expert consultations' to ensure that we rigorously covered the key volcanoes, volcanic features and volcanic landscapes of the various regions of the globe. This engagement had the added benefit of bringing the concepts of geoconservation of volcanic landscapes to a broad global audience not accustomed to thinking about the protection of volcanic landscapes. One result of these discussions and engagements was the establishment of the IAVCEI Commission on Protected Volcanic Landscapes in 2015.

We carried out our expert consultations through a combination of site visits to existing protected volcanic areas (National Parks, World Heritage sites, UNESCO Global Geoparks and Biosphere Reserves); correspondence with regional experts; participation in several regional meetings focused on protected volcanic landscapes, particularly in Asia and Europe; and through proactive solicitation of opinions and perspectives. We presented several invited talks about the revision of the Study at scientific meetings in Europe, Asia and the Americas. A partial listing of meetings, seminars, field visits and invited lectures is contained in Appendix 1.

1.3.4 Classification system

The classification system establishes a taxonomic basis for classifying different types of volcanic terrains and their heritage value. The classification system organises the data on volcanic features on the List and forms the framework for conducting the gap analysis and articulating an appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List.

In our deliberations, which we confirmed through consultation with our geological colleagues, we decided to make **plate tectonic setting** the primary factor in classifying World Heritage volcanic properties (Perfit & Davidson, 2000; LaFemina, 2015; Seibert et al., 2015). Plate tectonic setting met our requirements of being neither too narrow (as was a landform-type classification system) nor too broad (such as genetic systems). Plate tectonic setting provides an organising principle that is readily understood, easy to communicate on maps and graphics, and based on scientific value. The representativeness of the List for volcanic terrain is first assessed using plate tectonic setting. Additional heritage values, including consideration of educational importance, cultural/spiritual traditions, ecosystem value and aesthetic considerations, were also considered as secondary factors in aiding the determination of OUV for volcanic sites within underrepresented settings. We have used the additional consideration of the regional distribution of volcano properties on the List.

1.3.5 Gap analysis

Once the data were gathered, organised into the inventory database and sorted using our classification system, we were able to identify gaps in representation on the List. The gaps in representation are identified primarily by the plate tectonic setting of scientifically-important volcanoes, augmented by consideration of regional representation. The heritage values (biological, cultural/spiritual, aesthetic and educational) are the secondary component of the classification system that allows definition of OUV among the volcanoes within the underrepresented categories.

1.3.6 List of strongest remaining potential sites for the List

We then identify a list of underrepresented plate tectonic categories and a balanced list of the strongest remaining *potential* sites for the List. This list of potential sites is purely from the perspective of using the tool of the classification system and consultation with additional experts in volcanology and geoheritage. It is up to States Parties to consider other factors, including stakeholder support for listing, conditions of integrity within proposed boundaries of the World Heritage site, whether the property already has national protection and whether an appropriate management framework could be developed and implemented. Based upon these other factors, States Parties may choose other related volcanic sites that fill the gaps identified in representation and have suitable heritage value.

1.3.7 Biosphere Reserves and UNESCO Global Geoparks

As part of our effort to consider the international conservation status of the ‘world’s volcano estate’, we also examined the volcano properties found on the lists of Biosphere Reserves and UNESCO Global Geoparks. We applied the same categories in our inventory of these conservation programmes (see Section 4.0 and Appendix 1)

Classification system for volcanic World Heritage

2

Stromboli Volcano in eruption. Aeolian Islands, Italy © Dan Tormey

Classification systems support systematic scientific analysis, and they are communication tools: the nature of the communication in part determines the type of classification tool. Classification of volcanic landscapes for World Heritage listing must support dialogue among scientists, decision makers, local populations and other stakeholders. The classification must address scientific values, heritage values and an understanding of the regional diversity of volcanic terrain to identify the most globally exceptional volcanic sites. Perhaps most important for a UNESCO programme, classification for World Heritage status should itself be memorable and educational.

2.1 Context for classification of volcanic sites for World Heritage

In the *Geological World Heritage* study, Dingwall et al. (2005) note that there is tremendous diversity of geological and geomorphological phenomena that can be accommodated on the World Heritage List, and that the establishment of a basic classification scheme enables logical decisions to be made in preparing nominations and in site evaluations. Taxonomic listings of phenomena are commonly adopted for scientific and academic purposes, and these come in a potentially bewildering array of types in terms of their detailed structures and communication objectives. While essential for characterising themes, the classification scheme used to assist in site selection and evaluation should not be overly elaborate.

Classification must also recognize that the World Heritage List is not intended to ensure the protection of all properties of great interest, importance or value, but only for a select list of the most outstanding of these from an international viewpoint. The different elements of the classification do not all automatically require representation on the World Heritage List: sites must also meet the conditions of Outstanding Universal Value, including those for site integrity and for protection and management. Some components of the classification may be represented by very few sites because even the best sites within a taxonomic component may not satisfy integrity, protection, and management requirements. In the *IUCN Guidance for Reviewers of Earth Science nominations* (IUCN, 2009), the question is addressed as follows:

"How broad or narrow are the values put forward for the nominated property? It is helpful to take a 'taxonomic' approach to distinguishing the values of the property. (As a simplistic example, 'the world's most outstanding volcano' is a very broad value 'the world's best example of a volcanic plug' is a narrow value.) The World Heritage List is not an appropriate vehicle to collect many sites representing very specific values."

In the earlier *World Heritage Volcanoes* thematic study, Wood (2009) used a landform- and geomorphic-based classification system, although many classifications were discussed and considered in the gap analysis. This system is responsive to the wording of criterion (viii), which describes 'development of landforms' and 'significant geomorphic or physiographic features'. In our opinion this system was too narrow for use in World Heritage designation, producing far too many features that could be considered for their OUV. We also determined that a landform-based classification did not educate or clearly communicate the essential features of volcanic systems.

In addition to assessing OUV of volcanic properties, the classification system helps IUCN address the question: How does the nominated property compare with other, similar properties at the global level? The Global Comparative Analysis that all nominated properties must provide[4] requires the application of a global classification system and a comparison of the nominated property with other World Heritage properties and protected areas within the same or a similar global context.

Finally, to assist in developing a useful classification system for volcanic properties, we can learn from those used for considering sites nominated for criterion (ix) on ecological processes and criterion (x) on biodiversity. For biological sites, IUCN uses an overarching classification that is supplemented by subsidiary considerations provided in more detailed systems to assess OUV. The primary classification is the framework of the world's biogeographical provinces (Udvardy, 1975). This primary classification identifies the potential range of biogeographical provinces that may be represented on the World Heritage List. This primary subdivision to determine representativeness is then supplemented by other, internationally-recognised global classification and prioritization systems for natural habitats and ecosystems, which provide a basis for assessing OUV. These include: Key Biodiversity Areas, the IUCN/SSC Habitat Classification System, WWF's Global 200 Priority Ecoregions, Conservational International Biodiversity Hotspots and High Biodiversity Wilderness Areas, Bird Life International Endemic Bird Areas and IUCN/WWF Centers of Plant Diversity. This approach of a primary framework to test for representativeness, augmented by secondary classification components to demonstrate OUV, has proved very effective for assessing biological and ecological values of World Heritage properties. The classification system has helped ensure that natural and mixed properties on the World Heritage List cover almost all biogeographic regions, biomes and habitats of the world with a relatively balanced distribution. It provides a model for our classification system for volcanic World Heritage.

2.2 Primary classification system for volcanic World Heritage: Plate tectonic setting

In surveying and considering the range of potential classification systems, we determined that landform-type classification systems such as proposed by Wood (2009) were too narrow for our purposes, and that most genetic systems were too broad. **Plate tectonic setting**, however, provides an organising principle that is readily understood, easy to communicate on maps and graphics, and

4. Operational Guidelines, Section III.A.3, paragraph 132.3

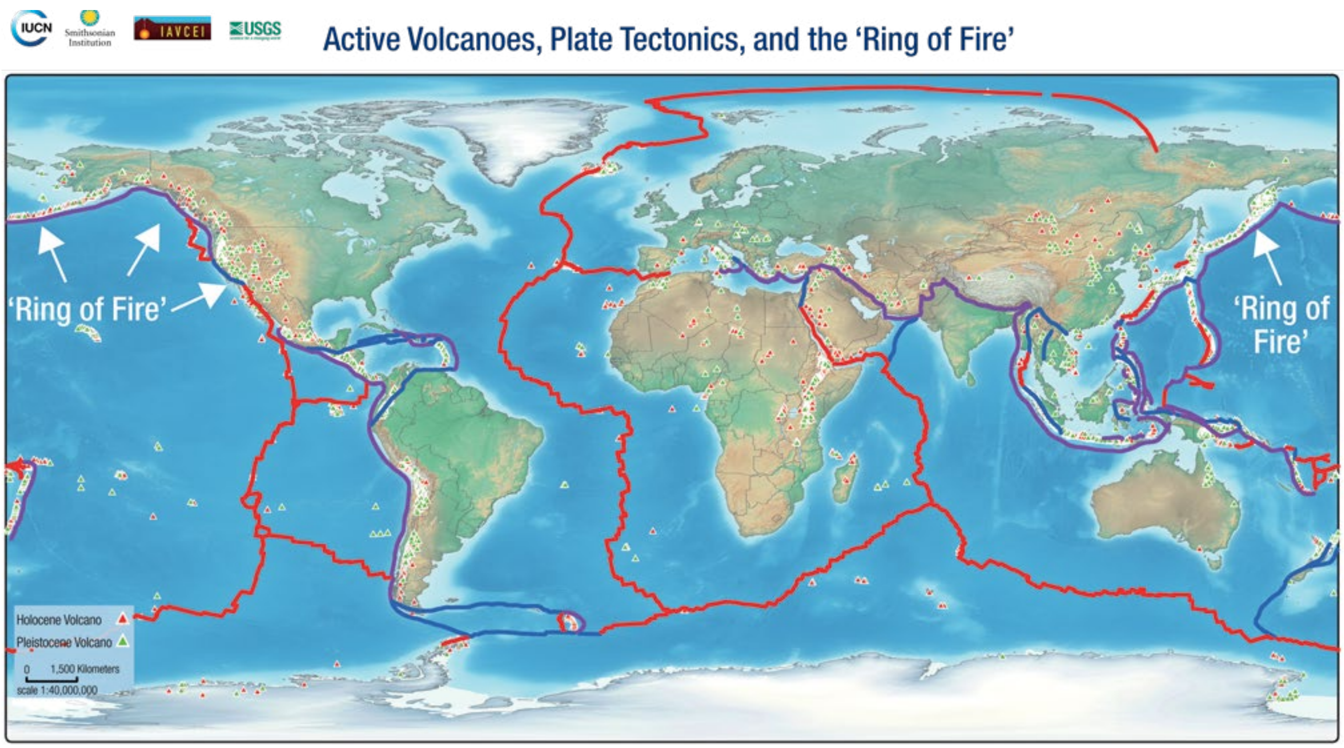


Figure 2: Map of active volcanoes of the Earth and plate tectonic boundaries. Positional information for mapped volcanoes is from Global Volcanism Program (2013).

neither too broad nor too narrow. Plate tectonics were recognized as the result of a scientific revolution that completely transformed how geologists consider the dynamic Earth, and volcanism is the visible evidence for many plate boundaries. As the primary classification component for volcanic World Heritage, plate tectonic setting is certainly highly significant, simple, memorable and is also resonant regarding educational and communication objectives.

The boundaries of the world's tectonic plates and the distribution of the world's 1,450 major active volcanoes show a strong coincidence (Figure 2). It is clear from the map that the highest densities of volcanoes coincide with plate boundaries. Such boundaries are defined by geologists as either constructive, where two plates separate (such as along the Mid-Atlantic Ridge or the East Pacific Rise), or destructive, where plates converge in regions known as subduction zones (such as those within the circum-Pacific 'Ring of Fire'). There are also volcanoes that occur within plates, typically associated with 'hotspots' over plumes of rising magma in the Earth's mantle, which are called intraplate volcanoes. Volcanoes also occur in areas of plate collision and in rare instances are associated with transform boundaries (where plates slip past one another in a horizontal motion along faults). Figure 2 also illustrates that volcanoes are not evenly distributed across the planet; large areas have no volcanic activity.

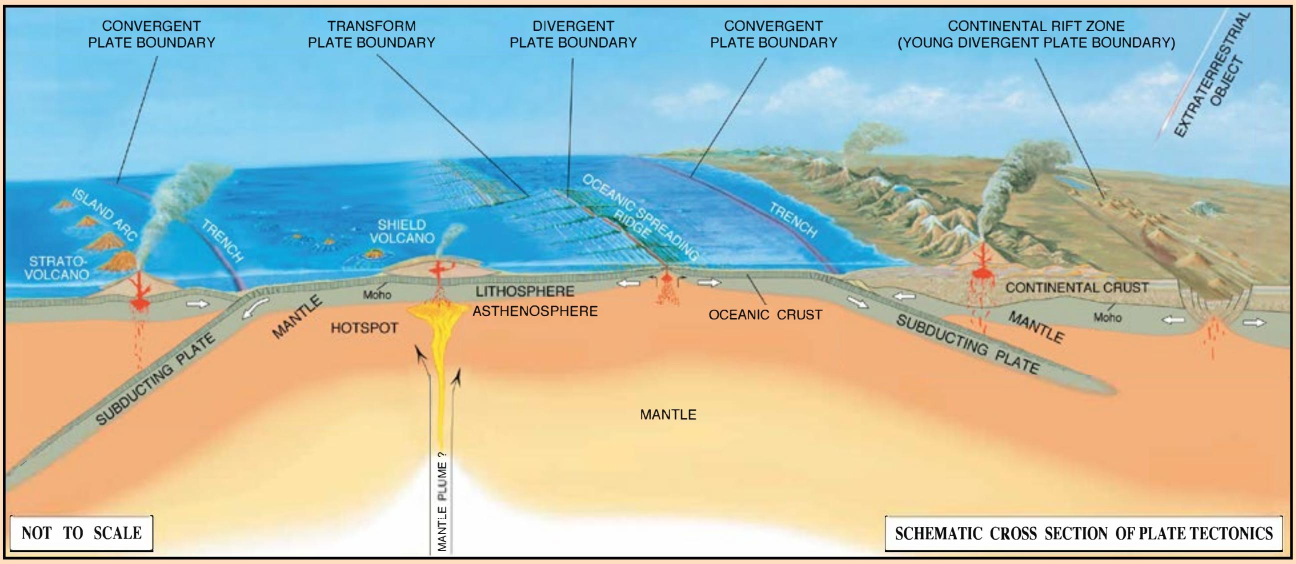
The relationship between plate tectonics and volcanism is fundamental: the mechanisms of plate tectonics influence the formation of magma in the mantle, either through decompression of hot, solid mantle material at constructive margins and mantle plumes, or the lowering of melting temperature of mantle material by the addition of volatiles (mainly water), as occurs at destructive plate margins. These different processes give rise to variations in the composition of magmatic melts and the types of eruptions. The variety of volcanic products within specific plate tectonic settings therefore represents a systematic, logical, memorable and scientific means to classify the world's volcanic geological heritage, that relates to geological values of great significance.

2.2.1 Plate tectonic components

The relationships between volcano types and tectonic setting are shown schematically in Box 5. The characteristics of volcanic rocks are closely related to the tectonic environment in which they originated, since ultimately the chemistry of magmas and volcanic constructions are related to the processes at different plate tectonic settings. Volcanoes from different plate tectonic environments are therefore distinct in terms of the composition of their source magmas, their eruptive behavior, the characteristics of their volcanic deposits and the morphology of their volcanic landforms.

The primary subdivisions of the classification system in this Study are based upon the plate tectonic setting and include (see also Box 5 and Figure 3):

Divergent Margin: This setting is produced by extension (stretching) of the crust, and it may also be associated with mantle plume activity. One product may be outpourings of basalt, but on a lesser scale and with lava more chemically diverse than that of



José F. Vigil and Robert I. Tilling

Box 5.
What is plate tectonics?

During the past 50 years, the theory of plate tectonics revolutionized earth sciences. It forms the basis of our current understanding of the structure and dynamics of our home planet. Plate tectonics assumes that the Earth's upper, rigid layer (the lithosphere) is broken into several plates that are in constant motion relative to one another. There are seven or eight major plates (depending on how they are defined) and many minor plates (often called microplates). Where plates meet, their relative motion determines the type of boundary: convergent (coming together), divergent (separating) or transform (sliding alongside). Distinctive types of earthquakes, volcanic activity, mountain building and oceanic trenches and ridges occur along these plate boundaries.

There are three types of plate boundaries. **Divergent boundaries** occur where two plates move apart from each other (Mid-Atlantic Ridge and East African Rift). **Convergent boundaries** occur where two plates slide towards each other to form either a subduction zone where one plate moves underneath the other (Andes of western South America, Japanese islands) or a collision zone (Caucasus Mountains of the Russian Federation and the Republic of Georgia). **Transform boundaries** occur where two lithospheric plates slide past each other along transform faults (San Andreas Fault in California, USA); transform boundaries rarely produce volcanoes.

Most magmas form below the lithosphere, in the Earth's mantle, and rise through the crust to either solidfy in the subsurface or erupt at the surface from a volcano. Volcanoes can also occur within a plate (intraplate), typically due to mantle hot spots or plumes that pierce the lithosphere.

Source: United States Geological Survey.

continental flood basalts. Assimilation of continental crust by the rising magma gives rift volcanoes a wider range of rock types and explosive habits than oceanic rifts, including rare types of magmas such as carbonatites and highly alkaline melts. Divergent plate boundaries can also occur in settings known as back-arc basins. Back-arc basins are rifting environments associated with some convergent margins (island and continental arcs).

Convergent Margin: Most subaerial volcanoes are located at convergent plate boundaries, also known as subduction zones. Subduction may take place where two ocean plates, or an ocean plate and continental plate, are driven against one another and one bends and sinks beneath the other. The descending plate releases volatiles (principally water) as it is heated, and these lower the melting temperature of the mantle wedge above the subducting slab. This process generates magma, which after rising to the surface of the overriding plate creates a chain of volcanoes, known as a volcanic arc. Where two ocean plates converge, the line of volcanic islands produced is called an island arc. When two continental plates converge, the area is known as a collision zone.

Intraplate: Another form of volcanism occurs where intraplate (as opposed to rift or arc) volcanoes are built on the ocean floor over hot, rising magma that may represent mantle plumes (e.g., Kilauea and the Hawaiian Islands in the USA). Intraplate mantle hotspots may also penetrate the crust of a continent, but the crustal rocks are partially melted and assimilated by the rising mantle plume, producing a wider range of magma compositions with higher silica and alkali contents. These in turn influence the eruption styles and products (e.g., Yellowstone caldera in the USA). Mantle plumes driving intraplate volcanism can also occur beneath divergent plate boundaries, forming a special case of a divergent boundary in which the magma generation rate is augmented by a mantle plume.

2.2.2 Ancient volcanic environments of Outstanding Universal Value

The plate tectonic setting is applicable to active volcanoes considered in this *Volcano Thematic Study*. Ancient volcanic environments are treated separately. These ancient settings include some of the oldest terrains on Earth (e.g., greenstone belts), economically

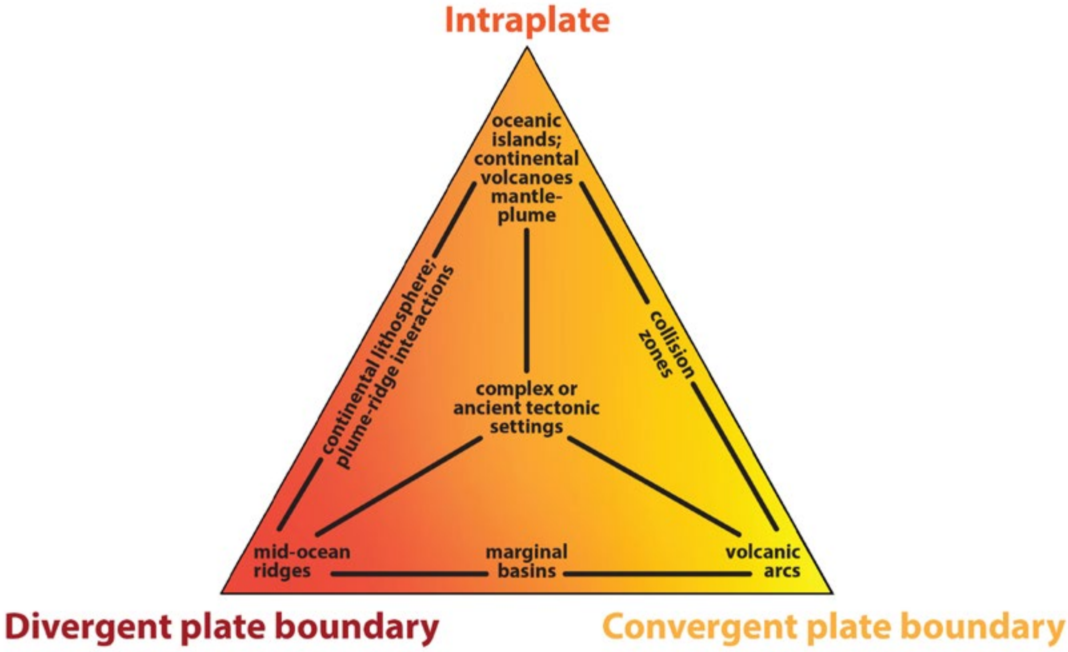


Figure 3: Diagram showing the plate tectonic settings of volcanoes (modified from Perfit & Davidson (2000) and Pearce (1996))

important areas (e.g., ancient kimberlite pipes that sample deep in the Earth's interior and deliver gem-quality diamonds) and distinctive formations of great scientific, cultural, spiritual and biological importance. Volcanic necks, dyke swarms, sills, ring dykes, cone sheets and diatremes, all of which represent parts of the underground 'plumbing systems' of former active volcanoes, may significantly contribute to the distinctiveness of ancient volcanic terrains and our scientific understanding of how volcanoes work (Figure 4). These are therefore also included in our review.

2.2.3 Regional representation

Within the context of only considering sites of Outstanding Universal Value, the regional representation of the most significant volcanic features and sites is an important factor in ensuring a representative, balanced, and credible World Heritage List. For example, 'textbook bias' can lead to overlooking volcanic sites with OUV that are not located in the developed countries where most textbook authors reside. On the other hand, we would not expect all regions to be represented equally because active volcanoes are not uniformly distributed across the globe; Figure 2 illustrates that the continental interiors generally lack volcanic activity. Therefore, those regions with a preponderance of activity are likely to have most of the listed sites and this becomes a factor in considering representation of the World Heritage List. In considering this secondary factor, we classify representation using the following regions:

- Africa
- Asia
- Europe
- Latin America
- North America
- Oceania

2.3 Secondary classification components: non-geological heritage values

The primary classification by plate tectonic setting is a scientifically-based value of geoheritage and is the primary test of representativeness of the List for volcanic geoheritage. In addition to a test of representativeness, plate tectonic setting offers the framework to assess the scientific importance of the nominated property. In his recent review, Brilha (2016) articulates that the values considered for geoheritage sites are properly *only* scientific values. However, as further described in Section 5, the relative youth and dramatic aspects of active volcanic sites compared to other geological themes lends cultural, biological and aesthetic importance to volcanic sites. The rapid growth and dramatic changes often seen for volcanic landscapes during single eruptions over a period of days to weeks to months is closer to the human memory scale that other geological themes. This immediacy leads to a deeper involvement with cultural development. The relatively rapid growth of new terrain, which rises above surrounding areas, also leads to an unusually high degree of microhabitats that in turn lead to high levels of biodiversity and endemism. Therefore, in developing the classification for use in World Heritage site listings, these related values, in addition to purely scientific values, become important considerations in assessing both representativeness and OUV among the many possible choices in the world's volcanic estate. As noted by Brilha (2016), consideration of additional values beyond scientific can increase the impact of a geoheritage area to society.

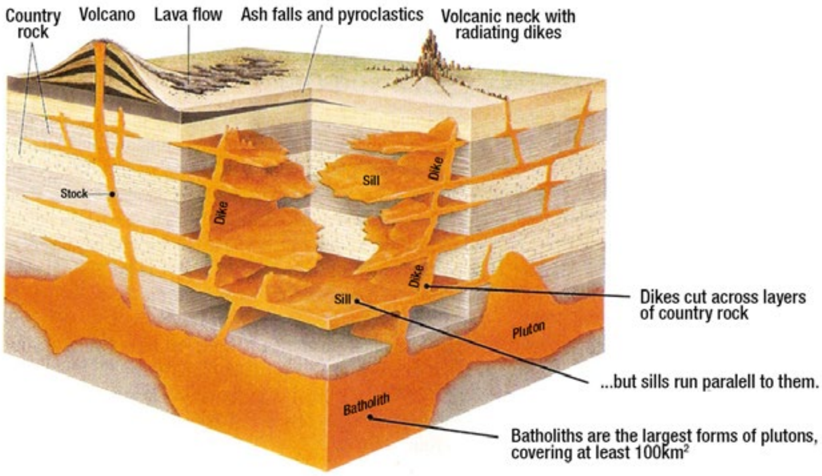


Figure 4: Diagram showing igneous intrusive forms (Press et al., 2004)

The secondary subdivisions of this Study's classification system include consideration of specific heritage values, including cultural and spiritual value (e.g., whether the volcano is iconic), biological and ecosystem values, aesthetic value and educational value. Not every volcanic site recognised for OUV under criterion (viii) must also have OUV for the secondary components. Rather, as with plate tectonic setting, one or more of the secondary factors listed here may be considered part of the measure of the nomination's heritage value. That is, among the many outstanding volcanoes associated with the Pacific ring of fire, those that have outstanding value for spiritual, ecosystem, aesthetic and educational value would be the strongest candidates to represent this component of the classification. In some cases, these secondary classification components may also display OUV and provide the basis for nomination under other criteria, in addition to criterion (viii). Each of these secondary factors is described in the following section. It is important to note that the present study does not provide guidance regarding the recognition of OUV for the criteria other than criterion (viii).

2.3.1 Cultural and spiritual value

The World Heritage Convention's Operational Guidelines for Implementation of the World Heritage Convention (UNESCO, 2017) note that attributes such as spirit and feeling do not lend themselves easily to quantification, but that they are nevertheless important indicators of character and sense of place, such as in communities maintaining traditional and cultural continuity. These values are embedded in criteria (i) through (vi) (see Section 1 for the complete wording of these criteria). For natural sites these attributes may also be part of the recognition of sites under criterion (vii) in particular.

Cultural and spiritual value is frequently an integral element to volcanic heritage because cultural and socio-economic values have emerged over time in places due to interrelations between volcanoes and society. The inclusion of cultural and spiritual value as secondary factors in classification of volcanic sites is therefore highly relevant. To fully understand OUV in relation to volcanic heritage, we need to ensure our selection criteria are capable of recognising the value systems of communities living in volcanic landscapes around the globe and the meanings and significance they give to volcanoes, as well as past associations. It should be noted that if there is a potential for OUV to be recognized for cultural and spiritual values, the International Council on Monuments and Sites (ICOMOS) is responsible for evaluation of the relevant criteria.

Borobudur Temple Compounds World Heritage Site near Merapi Volcano, Java, Indonesia © Karen Holmberg

2.3.2 Biological and ecosystem value

The most frequent associated value for which volcanic sites are listed is their outstanding biodiversity and the critical habitat which they provide as well as ecosystem processes; these values are described in criteria (ix) and (x). Biological and ecosystem values arise because volcanic landscapes are some of the most dynamic and micro-diverse landscapes on the planet, and this local geodiversity frequently supports

Grand Canyon of the Yellowstone, USA. Oil painting by Thomas Moran © U.S. Department of the Interior

some of the world's most outstanding biodiversity. Many volcanoes are geographically isolated. They 'stand alone' and are only loosely considered as part of a mountain range. The often-isolated nature of large volcanic edifices can make them sites with dramatic altitudinal and climatic variation; two features that are well suited for encouraging development of ecotones or biological diversity within a relatively small geographical footprint. This isolation may result in a high degree of biodiversity and endemism (the ecological state of a species being unique to a defined geographic location, such as an island, nation, country or other defined zone, or habitat type; organisms that are indigenous to a place are not endemic to it if they are also found elsewhere). Scientists and conservationists have long recognised this unique aspect of volcanic environments.

Another unique aspect of volcanic areas is found when volcanoes form isolated ocean islands, either as solitary volcanic cones or as a volcanic archipelago. It is usually the isolation of these volcanic sites, coupled with the high degree of biodiversity and related endemism, which first draws the attention of scientists and conservationists to these locations.

2.3.3 Aesthetic value

Criterion (vii) recognizes "superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance," and applies to most volcanic terrains and is also a frequent additional listing criterion for these properties. Volcanoes are some of the best known and most spectacular of Earth's geological features; they include aesthetically-outstanding features, such as the beautiful, soaring cone of Mount Fuji; lava plains and spectacular waterfalls of continental flood basalts (e.g., Siberian Traps, Deccan Traps, and Parana Basin Flood basalts, including Iguazu Falls); and the spectacular hydrothermal features associated with Yellowstone caldera. The beauty of these terrains stimulates the imagination and leads to memorable associations with many volcanic landscapes.

2.3.4 Educational value

There is not a separate World Heritage site listing criterion for 'educational value' and the associated value of a site regarding communication and interpretation of natural heritage to a wide audience; however, such value is implicitly part of the World Heritage criteria. As with application of all of these secondary (value) classification components, a site's educational value, in the broadest sense, can be difficult to measure precisely. The number of peer-reviewed publications about a site is often a good measure; however, cultural factors such as textbook bias, as well as site accessibility, may lead to relatively few publications on some educationally-valuable properties. In addition, the educational value may have been achieved early in the science of geology (e.g., the Siccar Point unconformity in the UK) and not received recent study. For this *Volcano Thematic Study*, we consider important criteria for outstanding educational value to include: a notable first discovery that has been subsequently used in other studies; have become 'type' eruptions (such as Icelandic, Hawaiian, Pelean, Vesuvian, Strombolian, Katmaian) or 'type' localities (e.g., Andes, East African Rift, Mid-Atlantic Ridge); or the opinion of a broad range of geologists, which may be reflected in the number of peer-reviewed publications. As a secondary value, the opinion of a broad range of geologists does not necessarily lead to OUV, but it can be considered as a secondary value along with other considerations.

Current representation of the volcanic theme on the World Heritage List

3

Semeru Volcano, Java's highest volcano, in eruption on the skyline. In the foreground is Tengger Caldera with the ribbed post-caldera cone of Batok in the center foreground and the steaming cone of Bromo in the left foreground © Lee Siebert

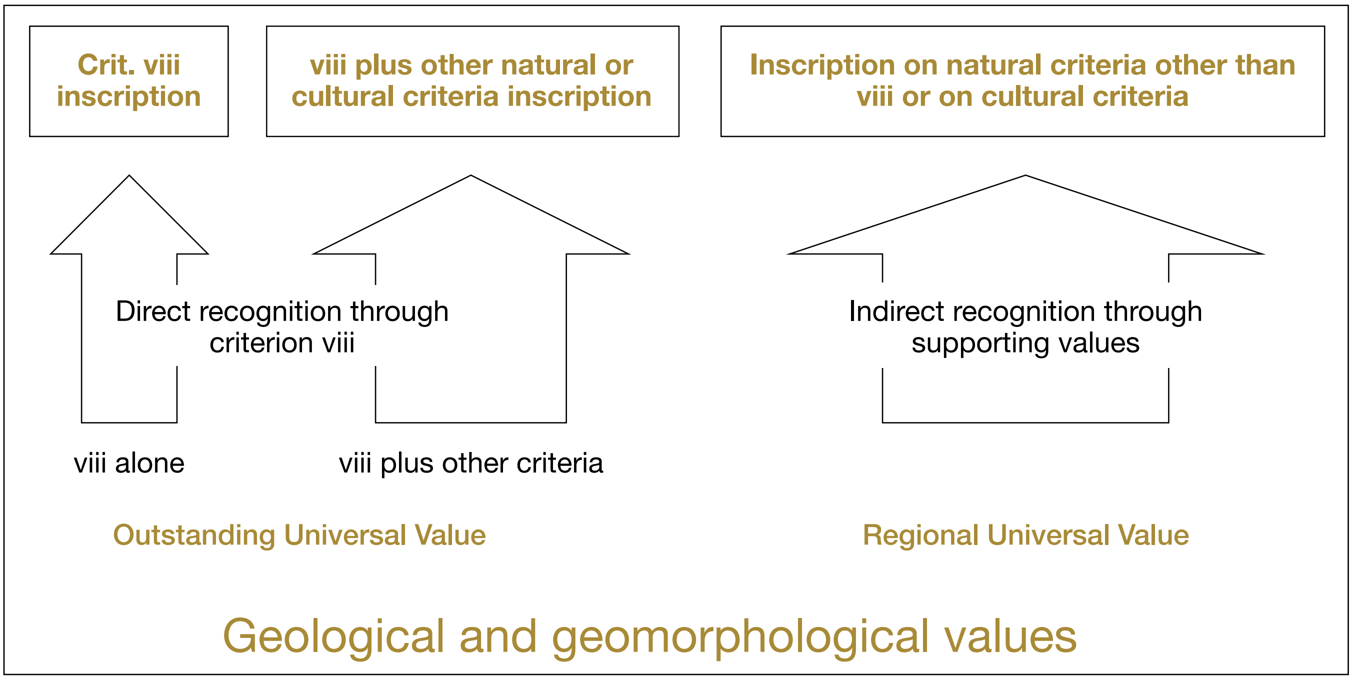


Figure 5: Direct and indirect recognition of geology and geomorphology through the World Heritage Convention (modified from Dingwall et. al., 2005)

In our application of this Study's classification system to volcanic sites on the World Heritage List, we find that the List is neither systematic in how it recognises the volcanic theme in general, nor in how it specifically recognises volcanic sites with OUV. The List currently includes 80 sites with volcanic features, but only 23 are listed under criterion (viii) (geological values). Considering the number of volcanic sites on the list to be 80 gives a false perception of over-representation; only 23 volcanic sites have been considered to have OUV for their geological attributes. The others are listed for cultural (78), biological (67) and aesthetic values (36) (see Table 1 and Table 2). Note that individual sites are frequently listed for multiple criteria. The *Geological World Heritage* report (Dingwall et al., 2005) recognises that direct recognition of geological heritage using criterion (viii) will ultimately distinguish only a relatively small number of global sites even though there is an additional benefit in identifying the supporting value of geology within World Heritage properties inscribed for biological, cultural or aesthetic values (see Figure 5, taken from Dingwall et al. (2005), their Figure 3). Dingwall et al. (2005) also note that volcanic sites that are not listed for criterion (viii) are likely to be of regional or national importance rather than Outstanding Universal Value.

Our analysis indicates, however, that several volcanoes on the World Heritage List do in fact have a strong basis for recognition of OUV for criterion (viii) but are not listed under that criterion. The recognition of OUV for volcanic sites through listing under criterion (viii) is remarkably inconsistent in the World Heritage List. Of volcanic sites on the World Heritage List that would generally be considered to have OUV by both volcanologists and the public, approximately half are not listed under criterion (viii). Larwood et al. (2013) note the supporting role played by geodiversity for sites that are inscribed for their biological and cultural values is often not fully developed in the nomination or in the management of the site because of the omission of criterion (viii).

Alternatively, some volcanic sites on the World Heritage List that would not generally be considered iconic *are* listed under criterion (viii). In these cases, the nomination included criterion (viii) in addition to other listing criteria. In retrospect, these sites may not have had 'stand-alone OUV' for volcanic features (that is, listing only under criterion (viii)), but OUV that was of regional or national importance only. Badman et al. (2008a) expand on this point, noting that in the consideration of more recent nominations, the application of the concept of OUV has become increasingly sophisticated owing to better information provided in response to more specific guidance. Similarly, use of the early inscriptions to the List as a baseline for comparison to more recent nominations have also led to more rigor in considering qualifications for OUV.

In our analysis of representation of volcanic sites on the World Heritage List, we accommodate this apparent inconsistency by first analysing the 23 volcanic properties that are listed under criterion (viii). We make no judgments regarding the strength of the basis for which each listed site displays OUV for criterion (viii); we accept it as given. To be complete in the analysis of the world's volcanic estate included under World Heritage inscription, we then augment the analysis of properties listed for criterion (viii) by considering the 57 volcanic sites that are *not* listed under criterion (viii). Although some of these sites could be reconsidered by the States Parties for future inclusion under criterion (viii), others may be of only regional or national importance, but in either case should still be protected volcanic landscapes. For those sites that have the strongest potential to qualify for listing under criterion (viii), we leave the decision to the States Party and go no further than identifying their potential.

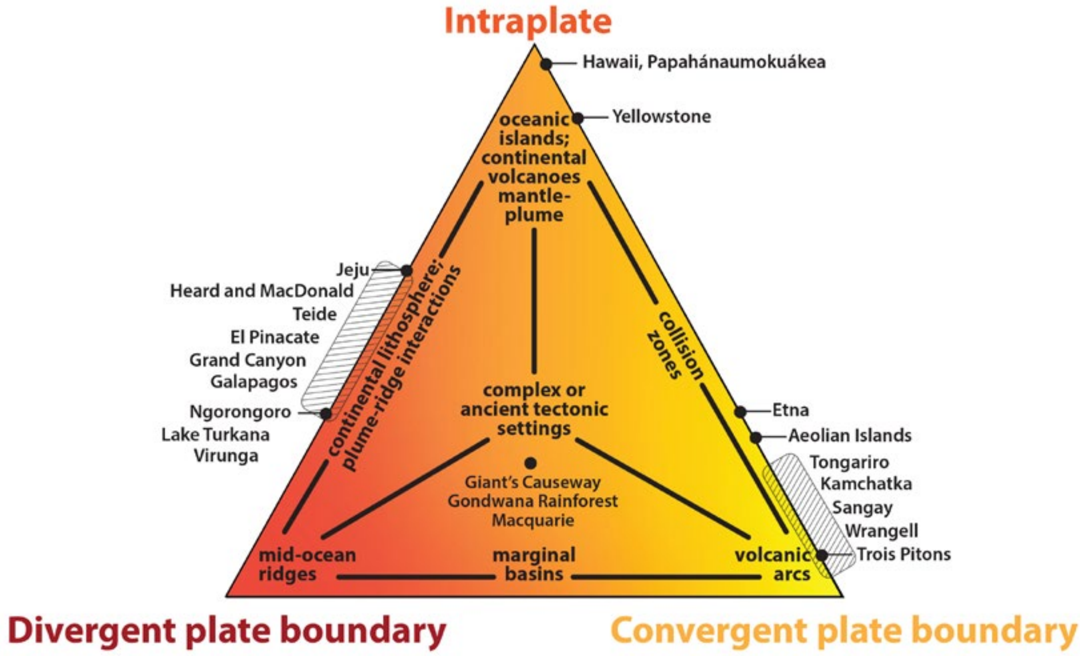


Figure 6: Diagram showing World Heritage sites with volcanic features listed for criterion (viii)

Regarding the management of volcanic World Heritage properties, if a volcanic property is not listed for criterion (viii), there is the potential that the risk of hazardous conditions (e.g., eruptions, gas emissions, fumarolic activity, landslides and other volcanic hazards) may not be adequately addressed in the site's management plan. For all World Heritage volcanic properties, regardless of whether they are recognized for criterion (viii), it is crucial to recognize potential volcanic hazards in the management plan. Nakada (2013) discusses this topic from the perspective of the educational value of incorporating hazard awareness into geoheritage sites. The World Heritage List includes some notably dangerous volcanoes. Drawing visitors to active geophysical areas carries a responsibility to monitor volcanic activity and develop risk contingency plans as essential parts of the management process for all potentially active volcanic World Heritage properties. However, if the site is not listed for criterion (viii), the management plan may not contain these hazard considerations, and the site's key volcanic features may not receive adequate emphasis or protection by the managing authority.

3.1 Primary component: plate tectonic setting

3.1.1 How representative is the World Heritage List under criterion (viii)?

The primary component of our classification system is plate tectonic setting. Figure 6 depicts the volcanic sites listed for criterion (viii) on the classification diagram, and Figure 7 depicts regional representation. Table 1 summarises volcanic sites listed for criterion (viii) on the World Heritage List according to this primary organising factor.

For the 23 volcanic sites listed for criterion (viii) on the World Heritage List, nine are from convergent margins, four are from divergent plate settings, six are from intraplate settings and four comprise ancient volcanic features.

Of these 23, only three (Mount Etna, Aeolian Islands and Hawai'i Volcanoes) are listed for criterion (viii) alone. Of the multiple listings with criterion (viii):

- 17 have outstanding biological and ecological value (listed for criteria ix or x)
- 16 have outstanding aesthetic value (listed for criterion vii)
- 14 have outstanding scientific value (defined in Section 2.3.2)
- 12 have outstanding cultural or spiritual value (listed for criteria iii, iv, v and/or vi)
- Six are considered iconic (defined in Section 1).

Mount Etna and Aeolian Islands are considered iconic convergent margin volcanoes. The World Heritage Volcanoes of Kamchatka property (Russian Federation) is an excellent representative of a transitional ocean-to-continental margin subduction environment, but there are no representatives from the significant island arc settings in the southwest Pacific Ocean or the Caribbean Sea. Continental subduction zones from the continental margin of North and South America are represented in a very limited way by Volcan Sangay (Ecuador) and parts of El Pinacate and Gran Desierto de Altar (Mexico).

Considering divergent margin volcanic provinces, Ngorongoro is considered iconic (although Ngorongoro does not include some of the most important volcanic features, such as carbonatite magmas, that are characteristic of that rifting environment). The East African and

Figure 7: Map of the World Heritage sites with volcanic features listed for criterion (viii). Positional information for mapped volcanoes is from Global Volcanism Program (2013).

Red Sea rifts are poorly represented, as are continental rift systems in general. Even though nearly half of the Earth's volcanic estate consists of submarine volcanoes in oceanic rifts, the Galápagos is the lone representative (and this includes a subridge plume).

For intraplate tectonic settings, Yellowstone, Hawai'i and the Galápagos volcanoes are considered iconic. Representation among this group is better than for convergent or divergent settings.

There are currently no representatives on the World Heritage List under criterion (viii) for back-arc basins, collision zones or continental flood basalts. Ancient volcanic features include only the Giant's Causeway, Gondwana Rainforest, and Macquarie.

Figures 6 and 7 demonstrates how few volcanic sites are on the List for criterion (viii) compared to the range of plate tectonic categories. The List includes some iconic sites that are representative of volcanism associated with Earth's plate tectonic settings. However, the List also includes volcanic systems that probably do not have stand-alone Outstanding Universal Value for geological features; their listings were primarily for biological or cultural values, with geological values added on as criterion (viii). These "add-on sites" are therefore not the best representatives of these tectonic environments. Even considering these add-on sites, the List still has several prominent gaps. These gaps, and our recommendations for filling them, are discussed in Section 4.0.

3.1.2 Does inclusion of volcanic sites not listed under criterion (viii) address the gaps?

The first place we consider for filling the gaps identified for those sites listed for criterion (viii) is World Heritage-listed sites that have volcanic features likely to display OUV that were not listed for criterion (viii). Table 2 summarises volcanic sites that were not listed for criterion (viii). Figure 8 depicts the volcanic sites listed for other than criterion (viii) on the classification diagram, and Figure 9 depicts regional representation.

Most of these sites would not likely display OUV for their volcanic features because their level of significance is regional or local only. In other words, the omission of listing for criterion (viii) for the site's volcanic features is probably correct. However, some listed sites would almost certainly display OUV under criterion (viii) and would therefore increase the representation of volcanic sites on the List for their geological values.

Among convergent margin plate tectonic settings, five of the nine listings in Table 2 are considered iconic, yet they are not listed under criterion (viii). These include Mount Fuji, Pompeii and Vesuvius (where the volcano is not included in the boundaries of the listing), Joya de Ceren (which was buried by an eruption from Laguna Caldera in El Salvador), Popocatepetl (where the volcano is also not included within the boundary) and Ujung Kulon (including Krakatau). Therefore, inclusion of the volcanic sites not listed under criterion (viii) significantly expands representation of iconic convergent margin sites on the list. This indicates some potential modifications to the current listings that could be suggested to the States Party. For convergent margin volcanic provinces, however, even the inclusion of all sites not currently listed for criterion (viii) still leaves the previously-identified gap.

Table 1: World Heritage sites with volcanic features listed under criterion (viii)

Region	Country	Name of property	Date of inscription	Criteria	Name of volcano(es)	Smithsonian Holocene (active) volcano	Plate tectonic setting
Europe	Italy	Isole Eolie (Aeolian Islands)	2000	(viii)	Cluster site including Stromboli and Vulcano	211040 and 211050	Convergent
Europe	Italy	Mount Etna	2013	(viii)	Etna	211060	Convergent
Europe	Spain	Teide National Park	2007	(vii), (viii)	Teide	383030	Intraplate
Europe	UK	Giant's Causeway and Causeway Coast	1986	(vii), (viii)	Paleocene volcanism	N/A	Ancient
Europe	Russian Federation	Volcanoes of Kamchatka	2001	(vii), (viii), (ix), (x)	Volcano cluster (inc. Bezymianny and Karymsky)	300250 and 300130	Convergent
Latin America / Caribbean	Dominica	Morne Trois Pitons National Park	1997	(viii), (x)	Morne Trois Pitons	360100	Convergent
Latin America / Caribbean	Ecuador	Sangay National Park	1983	(vii), (viii), (ix), (x)	Sangay	352090	Convergent
Latin America / Caribbean	Ecuador	Galápagos Islands	1978	(vii), (viii), (ix), (x)	Volcano cluster; Fernandina center point	353010	Divergent
Latin America / Caribbean	Saint Lucia	Pitons Management Area	2004	(vii), (viii)	Volcanic spires (Qualibou)	360140	Convergent
Latin America / Caribbean	Mexico	El Pinacate and Gran Desierto de Altar Biosphere Reserve	2013	(vii), (viii), (x)	Pinacate peaks	341001	Convergent
North America	USA	Yellowstone National Park	1978	(vii), (viii), (ix), (x)	Yellowstone caldera	325010	Intraplate
North America	USA	Papahānaumokuākea	2010	(iii), (vi), (viii), (ix), (x)	Volcanic islands of Hawaiian Archipelago	N/A	Intraplate
North America	USA	Hawai'i Volcanoes National Park	1987	(viii)	Several volcanoes	332010, 332020 and 332060	Intraplate
North America	USA	Grand Canyon National Park	1979	(vii), (viii), (ix), (x)	Uinkaret Field and Vulcans Throne	329010	Divergent
North America	USA/Canada	Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek	1979 (Extension in 1992 and 1994)	(vii), (viii), (ix), (x)	Wrangell	315020	Convergent
Africa	Democratic Republic of the Congo	Virunga National Park	1979	(vii), (viii), (x)	Nyamuragira and Nyiragongo	223020 and 223030	Divergent
Africa	Kenya	Lake Turkana National Park	1997	(viii), (x)	Central Island and South Island	222010	Divergent
Africa	United Republic of Tanzania	Ngorongoro Conservation Area	1979 (extension 2010)	(iv), (vii), (viii), (ix), (x)	Ngorongoro Crater	N/A	Divergent
Asia and the Pacific	Australia	Heard & McDonald Islands	1997	(viii), (ix)	Heard and McDonald	234010	Intraplate
Asia and the Pacific	Australia	Macquarie Island	1997	(vii), (viii)	N/A	N/A	Ancient
Asia and the Pacific	Australia	Gondwana Rainforests of Australia	1986	(viii), (ix), (x)	N/A	N/A	Ancient
Asia and the Pacific	New Zealand	Tongariro National Park	1990 (extension)	(vi), (vii), (viii)	Volcano cluster (inc. Tongariro and Ruapehu)	241080	Convergent
Asia and the Pacific	Republic of Korea	Jeju Volcanic Island and Lava Tubes	2007	(vii), (viii)	Mount Halla; more than 300 monogenetic vents	306040	Intraplate

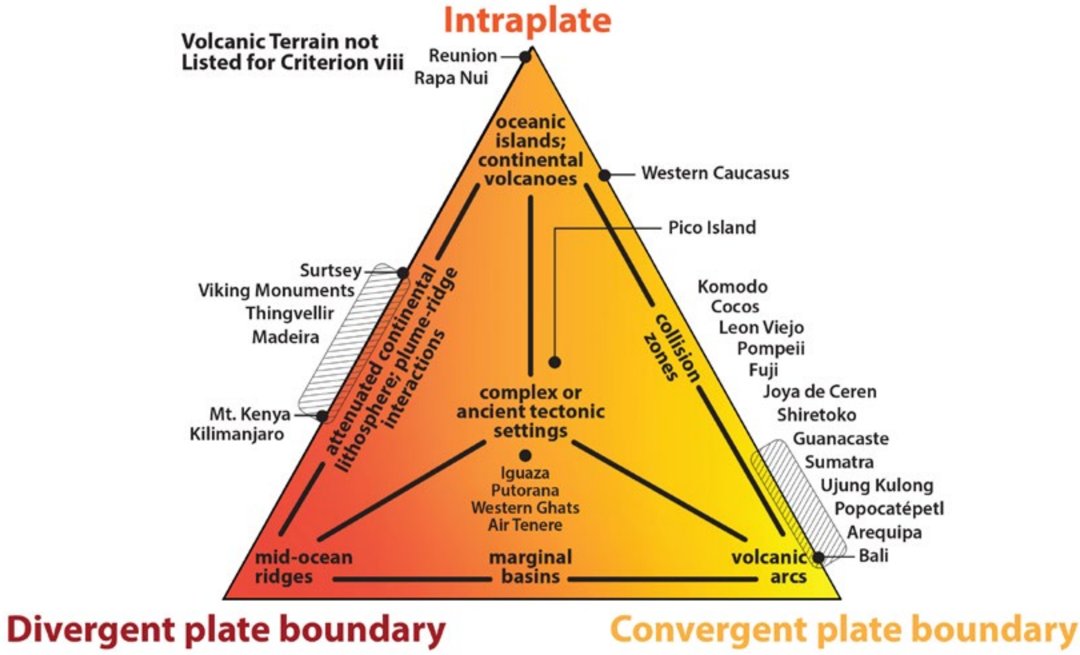


Figure 8: World Heritage sites with volcanic features listed for other than criterion (viii)

Divergent margins would also be better represented by including sites not currently listed for criterion (viii). Three iconic sites, including Surtsey (Iceland) and two from Africa's Great Rift Valley (Mount Kilimanjaro and Mount Kenya), could be listed for criterion (viii) and would enhance representation of divergent margins on the List. The lack of any submarine sites, which host more than half of the world's volcanic estate and most of the world's divergent margin volcanoes, leaves these sites unrepresented.

Intraplate volcanic sites have two additional potential representatives, Pico Island Vineyard Culture and town of Agra do Heroismo in the Azores, but neither clearly demonstrates OUV for geological features.

Continental flood basalts are currently represented by the Western Ghats of India (Deccan Traps), the Putorana Plateau of the Russian Federation (Siberian Traps) and the Iguazu National Park (Parana Basin Flood Basalts). All three are considered iconic and could display OUV. But because the geology was not central to their listings, the best-preserved areas of those volcanic provinces are not included in the World Heritage site boundaries. Although these provinces are likely to preserve areas that contain OUV for geological features, it is not clear whether the boundaries as currently drawn include such areas.

Niger's Aïr and Ténéré Natural Reserve, which contains the largest ring dike structure in the world, was not inscribed under criterion (viii), but inclusion of that criterion would enhance representation of ancient volcanic environments on the List. Entirely missing from the current List are the Bushveld of South Africa and the Great Dike of Zimbabwe; greenstone belts in Canada; the Oman or Troodos ophiolites; Devils Tower or Shiprock volcanic necks (diatremes) and dike complex in the US; and the Skaergaard intrusion in eastern Greenland.

Back-arc basins and collision zones also remain unrepresented.

3.1.3 Regional representation

World volcanoes are most abundant in convergent margin settings on land or in submarine divergent margin settings. Therefore, in considering representation by plate tectonic setting, we would not expect to see comprehensive regional representation. Figure 2 illustrates that the continental interiors generally lack volcanic activity. Thus Australia, continental Asia, eastern Europe, and southern and western Africa would not be expected to have as many volcanic sites as the Andes or Indonesia.

The most direct way to consider regional representation is to consider the degree to which areas with the greatest number of active volcanoes are adequately represented on the World Heritage List. Per country, the greatest abundance of active volcanoes is found in Indonesia (75), USA (65), Japan (58), the Russian Federation (52) and Chile (42). Of these five countries, Indonesia, Japan and Chile do not any have volcanic sites on the List for criterion (viii). There are also relatively few listed sites in North America, which has many excellent, well-studied and accessible examples of volcanoes. Considered in this way, volcano-rich regions that are unrepresented or poorly represented include the Southwest and Western Pacific, South America and North America.

Table 3 summarises representation of volcanic properties on the List by region. There is poor representation of sites in: Africa outside of East and central Africa, south-central and northern Asia, Australia and Eastern Europe, principally because these are relatively stable areas

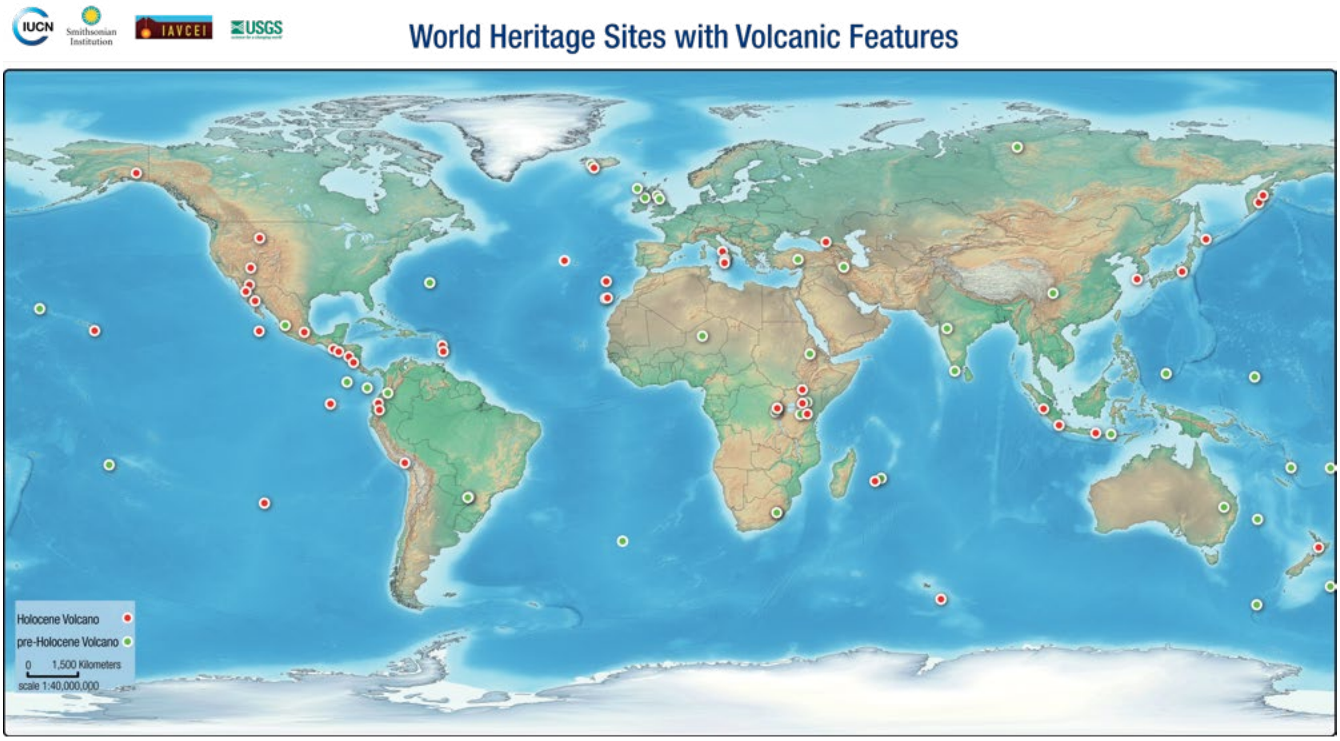


Figure 9: Map of the World Heritage sites with volcanic features. Positional information for mapped volcanoes is from Global Volcanism Program (2013).

of the Earth's crust. While there are some Holocene volcanoes on the mainland of Europe (e.g., Germany, France, Spain), the large number of volcanic World Heritage properties in this region comprise those in the Mediterranean and in overseas (mainly ocean) territories.

3.2 Secondary components and heritage values

The prevalence of other listing criteria (only 3 sites are listed solely for criterion (viii)) attests to the importance of these other heritage values in determining representatives of the world's best of the best volcanoes that should be included on the World Heritage List for their OUV. Plate tectonic setting for representativeness and scientific value, along with regional representation, are the primary classification tools used to determine whether the World Heritage List includes a representative and balanced set of volcanic properties. The secondary components represent values important to World Heritage and in practice would be used by States Parties to determine which volcanoes within underrepresented classification components would be appropriate for nomination.

In our analysis, we use the listing criteria summarised in Section 1 of this study to determine whether the value is present. The secondary subdivisions of the classification include consideration of cultural and spiritual value (listing criteria i, ii, iii, iv, v, and/or vi), biological and ecosystem value (listing criteria (ix) and (x)), aesthetic value (listing criteria vii), and educational value. The following discussion considers each of these secondary factors in the context of identifying potential gaps in representation.

3.2.1 Cultural and spiritual value

Iconic volcanoes in some sense include cultural and spiritual value or aesthetic value in the designation (Figure 10). One illustrative finding of this study is that iconic volcanoes are equally represented as listed for criterion (viii) and **not** listed for criterion (viii). The iconic nature, paradoxically, seems to have no bearing on whether a volcanic site is listed for criterion (viii). As noted above, we would suggest that nominating parties consider adding the listing for criterion (viii) for the indicated volcanic systems, although there may be other local factors that make such an addition unlikely or undesirable. Listing for cultural factors alone implies that the volcanic features will not be communicated, that IUCN will not necessarily be involved in considering the nomination and that the particular risks posed by encouraging visitation to these active volcanoes may not be addressed in the protected area's management plan.

Oldonyo Lengai, with rare carbonatite lava flow in foreground, Tanzania © Thomas Casadevall

Table 2: Volcanic sites listed as natural (or mixed natural/cultural) heritage on the World Heritage List, but not listed for criterion (viii)

Region	Country	Name of property	Date of inscription	Criteria	Name of volcano(es)	Smithsonian Holocene (active) volcano	Plate tectonic setting
Europe	France	Piton, cirques and remparts of Reunion Island	2010	(vii), (x)	Piton de la Fournaise	233020	Intraplate
Europe	Iceland	Surtsey	2008	(ix)	Surtsey	372010	Divergent
Europe	Portugal	Laurisilva of Madeira	1999	(ix), (x)	Madeira	382120	Intraplate
Europe	Spain	Garajonay National Park	1986	(vii), (ix)	La Gomera Extinct	N/A	Divergent
Europe	UK	St. Kilda	1986	(iii), (v), (vii), (ix), (x)	N/A	N/A	Ancient
Europe	UK	Gough and Inaccessible islands	1995 (extension 2005)	(vii), (x)	Inaccessible Island (Extinct) and Gough Island (Extinct)	386800	Ancient
Europe	Russian Federation	Western Caucasus	1999	(ix), (x)	Mount Elbrus, Shugo mud volcano	214010	Intraplate
Europe	Russian Federation	Putorana Plateau	2010	(vii), (ix)	N/A	N/A	Flood Basalt
Latin America / Caribbean	Brazil / Argentina	Iguazu / Iguacu National Park	1984 / 1986	(vii), (x)	N/A	N/A	Flood Basalt
Latin America / Caribbean	Colombia	Malpelo Fauna and Flora Sanctuary	2006	(vii), (ix)	N/A	N/A	Ancient
Latin America / Caribbean	Costa Rica	Cocos Island National Park	1997 (extension 2002)	(ix), (x)	Isla del Coco	345811	Convergent
Latin America / Caribbean	Costa Rica	Area de Conservacion Guanacaste	1999 (extension 2004)	(ix), (x)	Rincon de la Vieja	345020	Convergent
Latin America / Caribbean	Mexico	Islands and Protected Areas of the Gulf of California	2005	(vii), (ix), (x)	Tortuga and San Luis	341011 and 341003	Divergent
Latin America / Caribbean	Mexico	Archipiélago de Revillagigedo	2016	(vii), (ix), (x)	Barcena	341020	Divergent
Africa	Democratic Republic of the Congo	Kahuzi-Biega National Park	1980	(x)	Mount Kahuzi (extinct) and Mount Biega	N/A	Ancient
Africa	Ethiopia	Simien National Park	1978	(vii), (x)	N/A	N/A	Ancient
Africa	Kenya	Mount Kenya National Park / Natural Forest	1997	(vii), (ix)	Mt Kenya	N/A	Divergent
Africa	Kenya	Kenya Lake System in the Great Rift Valley	2011	(vii), (ix), (x)	Mengai; hot springs and geysers	222060	Divergent
Africa	Niger	Air and Ténéré Natural Reserves	1991	(vii), (ix), (x)	Ring dyke	N/A	Ancient

Region	Country	Name of property	Date of inscription	Criteria	Name of volcano(es)	Smithsonian Holocene (active) volcano	Plate tectonic setting
Africa	United Republic of Tanzania	Kilimanjaro National Park	1987	(vii)	Kilimanjaro	222150	Divergent
Africa	Lesotho / South Africa	Maloti-Drakensberg Park	2003	(i), (iii), (vii), (x)	N/A	N/A	Ancient
Asia and the Pacific	Australia	Lord Howe Island Group	1982	(vii), (x)	Extinct island volcano	N/A	Ancient
Asia and the Pacific	China	Mount Emei Scenic Area, including Giant Buddha Scenic Area	1996	(iv), (vi), (x)	N/A	N/A	Ancient
Asia and the Pacific	Indonesia	Tropical Rainforest Heritage of Sumatra	2004	(vii), (ix), (x)	Gunung Kerinci	261170	Convergent
Asia and the Pacific	Indonesia	Ujung Kulon National Park	1991	(vii), (x)	Krakatau	262000	Convergent
Asia and the Pacific	Indonesia	Komodo National Park	1991	(vii)	Satonda and other extinct volcanic islands	N/A	Ancient
Asia and the Pacific	Japan	Shiretoko	2005	(ix), (x)	Shiretoko-lozan	285090	Convergent
Asia and the Pacific	New Zealand	New Zealand Sub-Antarctic Islands	1998	(ix), (x)	Antipodes Island	335010	Ancient
Asia and the Pacific	India	Western Ghats	2012	(ix), (x)	N/A	N/A	Flood Basalt
Asia and the Pacific	Palau	Rock Islands Southern Lagoon	2012	(iii), (v), (vii), (ix), (x)	Volcanic island	N/A	Ancient

Table 3: Volcanic properties listed as cultural heritage (criteria i-vi) only

Region	Country	Name of property	Date of inscription	Criteria	Name of volcano(es)	Smithsonian Holocene (active) volcano	Plate tectonic setting
Europe	UK	Old and New Towns of Edinburgh	1995	(ii), (iv)	N/A	N/A	Ancient
Europe	UK	Historic Town of St. George and Related Fortifications, Bermuda	2000	(iv)	City built on volcanic island	N/A	Ancient
Europe	UK	Frontiers of the Roman Empire	2005	(ii), (iii), (iv)	Whin Sill	N/A	Ancient
Europe	Portugal	Landscape of the Pico Island Vineyard Culture	2004	(iii), (v)	Pico	382020	Intraplate
Europe	Portugal	Central zone of the town of Agra do Heroismo in the Azores	1983	(iv), (vi)	Pico	382020	Intraplate
Europe	Italy	Archaeological Areas of Pompei, Herculaneum and Torre Annunziata	1997	(iii), (iv), (v)	Vesuvius	211020	Convergent

Region	Country	Name of property	Date of inscription	Criteria	Name of volcano(es)	Smithsonian Holocene (active) volcano	Plate tectonic setting
Latin America and the Caribbean	Chile	Rapa Nui National Park	1995	(i), (iii), (v)	Easter Island	356011	Intraplate
Latin America and the Caribbean	El Salvador	Joya de Ceren Archaeological Site	1993	(iii), (iv)	Loma Caldera and San Salvador	343050	Convergent
Latin America and the Caribbean	Nicaragua	Ruins of Leon Viejo	2000	(iii), (iv)	Momotombo	344090	Convergent
Latin America and the Caribbean	Ecuador	City of Quito	1978	(ii), (iv)	Rucu Pinchicha and Guagua Pinchicha	352020	Convergent
Latin America and the Caribbean	Guatemala	Antigua, Guatemala	1979	(ii), (iii), (iv)	Agua, Acatenago and Fuego	342100, 342080 and 342090	Convergent
Latin America and the Caribbean	Mexico	Historical city of the City of Puebla	1987	(ii), (iii)	Popocatepetl	341090	Convergent
Latin America and the Caribbean	Mexico	Earliest 16th century Monasteries on the slopes of Popocatepetl	1994	(ii), (iv)	Popocatepetl	341090	Convergent
Latin America and the Caribbean	Peru	Historical city of the City of Arequipa	2000	(i), (iv)	Nevado Chachani, El Misti and Pichu	354007, 354010 and 354004	Convergent
Asia and the Pacific	Iran (Islamic Republic of)	Takht-e Soleyman Archaeological Site	2003	(i), (ii), (iii), (iv), (vi)	N/A	N/A	Ancient
Africa	Mauritius	Le Morne Cultural Landscape	2008	(iii), (vi)	N/A	N/A	Ancient
Asia and the Pacific	Japan	Fujisan, sacred place and source of artistic inspiration	2013	(iii), (vi)	Fuji	283030	Convergent
Europe	Iceland	Þingvellir National Park	2004	(iii), (vi)	N/A	N/A	Divergent
Asia and the Pacific	Indonesia	Cultural Landscape of Bali Province: the Subak System as a Manifestation of the Tri Hita Karana Philosophy	2012	(ii), (iii), (v), (vi)	Batur caldera	264010	Convergent
Asia and the Pacific	Micronesia (Federated States of)	Nan Madol: ceremonial centre of eastern Micronesia	2016	(i), (iii), (iv), (vi)	Volcanic island	N/A	Convergent
Asia and the Pacific	Fiji	Levuka historical Port Town	2013	(ii), (iv)	City built in vicinity of eroded volcanic crater	N/A	Ancient
Europe	France	Taputapuatea	2017	(iii), (iv), (vi)	Volcanic island	N/A	Ancient

Region	Country	Name of property	Date of inscription	Criteria	Name of volcano(es)	Smithsonian Holocene (active) volcano	Plate tectonic setting
Europe	Turkey	Göreme National Park and the rock sites of Cappa-docia	1985	(i), (iii), (v), (vii)	Cappadocia ash flow tuff	N/A	Ancient
Latin America and the Caribbean	Colombia	National Archaeo-logical Park of Tierradentro	1995	(iii)	Volcanic tuff	N/A	Ancient
Asia and the Pacific	India	Ellora Caves	1983	(i), (iii), (vi)	Basalts of Deccan traps	N/A	Flood Ba-salts
Asia and the Pacific	Vanuatu	Chief Roi Mata's Domain	2008	(iii), (v), (vi)	Volcanic islands	N/A	Convergent
Latin America / Caribbean	Mexico	Agave Landscape and Ancient Indus-trial Facilities of Tequila	2006	(ii), (iv), (v), (vi)	Tequila	N/A	Convergent

Table 4: Volcanic World Heritage sites by geopolitical region

World regions (UN Macroregions)	Number of volcanic World Heritage sites for any listing criteria	Number of volcanic World Heritage sites listed for criterion (viii)
Africa	11	3
Asia and Pacific	21	5
Europe	22	5
Latin America	21	5
North America	6	5

Furthermore, the World Heritage List does not contain many of the volcanoes that might be commonly recognised by the public. Numerous iconic or world-renowned volcanoes (cultural, spiritual, or aesthetic value) are not included on the List, including Santorini (Thera), Greece; Paricutin, Mexico; Mount Mayon, Philippines; Mount Saint Helens and Crater Lake, USA; Laki, Iceland; Mt Pelée, Martinique; and Tambora, Indonesia. Although not inscribed specifically, Vesuvius is represented by the Pompeii, Herculaneum and Torre Annunziata archaeological World Heritage property, which lies on the slope of, but does not include, this volcano. If there is a potential for OUV for cultural and spiritual value, then ICOMOS supports UNESCO in their consideration of these criteria.

3.2.2 Biological and ecosystem value

These criteria seem to be well recognised in the listings of volcanic sites, and we would encourage the continued inclusion of this factor in future volcanic listings. As described earlier, the isolated and diverse nature of volcanic terrain frequently leads to high degrees of endemism; therefore, volcanic geodiversity frequently supports OUV from biological and ecological habitats.

3.2.3 Aesthetic value

IUCN currently interprets the definition of criterion (vii) as including two distinct ideas: (1) superlative natural phenomenon and (2) exceptional natural beauty and aesthetic importance – and that properties can meet this criterion by addressing either one or the other or both. Superlative natural phenomenon for example can be addressed as “the world’s highest elevation active volcano”. Exceptional natural beauty, however, can be quite subjective and difficult to apply. IUCN has published guidance on the application of criterion (vii) to natural sites (Mitchell et al., 2013), and some land management agencies have developed objective criteria for developing assessments of aesthetic value, but considering the application of these tools is outside the scope of this *Volcano Thematic Study*. We would recommend making the assessment of Outstanding Universal Value for this criterion more objective. In any case, aesthetic value is well recognised in the listing of volcanic sites, and we would encourage the continued inclusion of this factor in volcanic listings. As described earlier, the isolated and diverse nature of volcanic terrain frequently leads to high aesthetic value of volcanic sites, including diversity of views and dramatic setting.

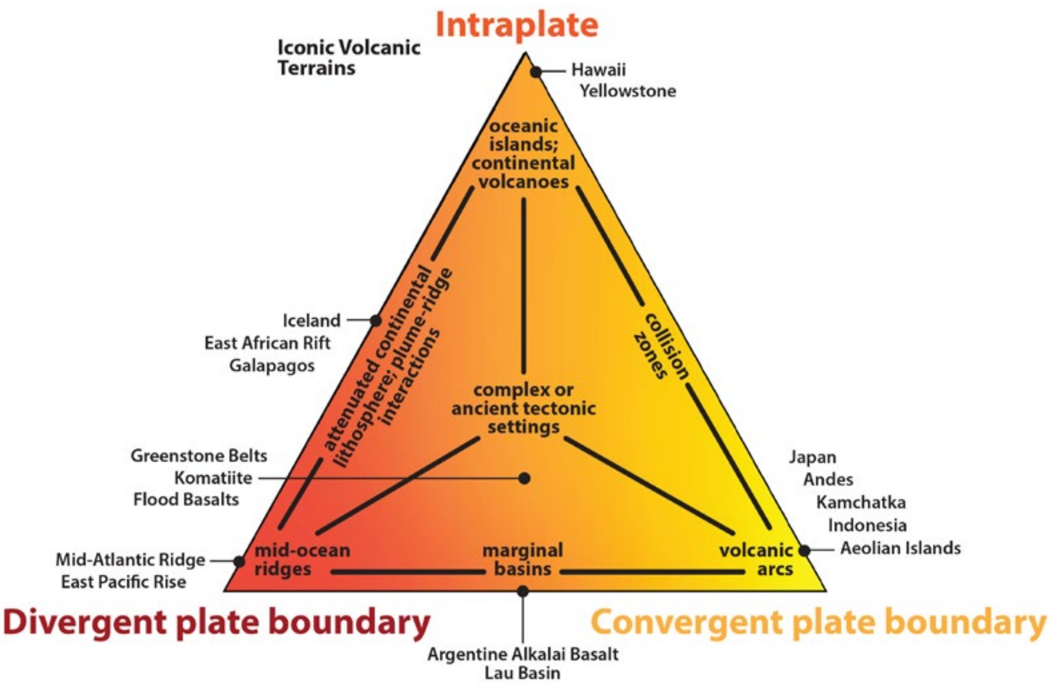


Figure 10: Diagram of iconic volcanic terrains

3.2.4 Educational value

Educational value appears to be well represented among the volcanic sites listed for criterion (viii). Of the 21 sites, 14 have outstanding educational value considering that each is the notable site of a first discovery, a type eruption style, or in the opinion of a breadth of scientific opinion (which may be represented by the published literature, being mindful of textbook bias discussed in Section 2.3.2).

Batur caldera, part of the Cultural Landscape of Bali Province World Heritage Site, Indonesia © Thomas Casadevall

Identification of the strongest remaining sites with potential for inscription

4

Lava lake, Erta Ale Volcano, Ethiopia © Jens-Wolfram Erben

The World Heritage Committee requested IUCN *"to revisit and update its thematic study on 'World Heritage Volcanoes' to clearly articulate a short and appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List ... "*[5] Based on our analysis of the World Heritage List, we have determined that volcanic sites listed for criterion (viii) do not well represent the volcanic geoheritage classified by plate tectonic setting and heritage value. This section uses the gaps identified by our classification system to determine the strongest remaining areas and sites with potential for inscription that would result in appropriately balanced representation of the volcanic theme on the List.

Of central importance to our findings is the recognition that the areas and sites identified in this Study as having potential for inscription are illustrative and advisory only; they are by no means pre-approved for inscription on the List. It is up to States Parties to consider other factors, including stakeholder support for listing, conditions of integrity within proposed boundaries of the World Heritage site and whether an appropriate management framework can be developed. Based on these and other factors, States Parties may choose other related volcanic sites, different from those identified in this Study, that fill the gaps identified in representation and demonstrate Outstanding Universal Value. Similarly, we do not propose that each of the sites described in this Section, although strong candidates with potential for inscription, will be inscribed on the List. Wood (2009) also included some of the sites identified in this Study. IUCN notes that this Study replaces Wood (2009) as the guidance on what has potential for listing.

We first summarise the gaps in the List for volcanic sites listed for criterion (viii) as described in Section 3.1 including the iconic sites currently on the List, but not inscribed for criterion (viii). We follow a systematic process in developing the list of sites that are not currently on the List, and that may be considered to fill these gaps, as follows:

1) Volcanic sites on States Parties' Tentative Lists that may demonstrate OUV for criterion (viii); or
2) Volcanic sites identified through our own experience and knowledge of the scientific literature and extensive outreach to experts in volcanology and geoheritage conducted for this study through presentations and discussions at professional society meetings and in follow-up communications.

4.1 Gaps in current representation under criterion (viii)

There are currently significant gaps in representation of volcanic sites listed for criterion (viii). Figure 11 provides an indication of the gaps in plate tectonic setting representation.

Figure 11 indicates that the Andes of western South America, the most prominent example of continental arc volcanism, is poorly represented. The high volcanoes of Ecuador and the Chilean and Argentine Lake District contain numerous candidates for representing this province as well as outstanding caldera systems, including Cerro Galan in Argentina and Chile's Laguna del Maule region. The western and southwestern Pacific island arc settings of Japan, Philippines and Indonesia, which include several volcanoes with potential OUV, are also unrepresented on the List.

Collision zones between continents are not well represented on the List. The collision between the Arabian Plate and the Eurasian Plate includes active volcanism in Anatolia, Turkey (including the iconic Mount Ararat), Armenia and Georgia, none of which have been listed.

The four divergent margin volcanoes on the current World Heritage List include three iconic volcanoes or locations. However, the Mid-Atlantic Ridge (including Iceland's iconic volcanoes) and the Red Sea Rift region are both poorly represented. Submarine volcanic systems, discussed later in this study, are dominantly rift systems and are also not represented.

Back-arc basins are unrepresented, although there are outstanding examples in Argentina and the southwest Pacific.

Intraplate volcanism is well represented by the iconic Hawaiian Volcanoes National Park and the Yellowstone caldera (both in the USA).

The two ancient volcanic terrains on the current List contain no continental flood basalts, greenstone belts, komatiites, ring dikes or subvolcanic feeder and storage systems, despite the importance of these terrains in creating and remaking the early continents and as components of most of the planet's major mass extinctions.

4.2 Inclusion of sites on States Parties' Tentative Lists to improve representation

States Parties are required to develop Tentative Lists of properties considered for nomination to the World Heritage List. These tentative lists represent current thinking of States Parties with respect to filling the gaps in representation with properties that may demonstrate OUV. We followed the practice of Wood (2009) by also including an inventory of volcano properties listed in the World Heritage Tentative List[6]. The current Tentative List contains 19 properties of high-quality volcanic areas including 15 that may be nominated for inscription under criterion (viii), including several sites which would fill gaps in the World Heritage List. See Annex 1 for an inventory of the Tentative List volcano properties considered in this Study.

5. IUCN Decision 37 COM 8B.15 adopted at its 37th session in Phnom Penh, 2013
6. whc.unesco.org/en/tentativelists/

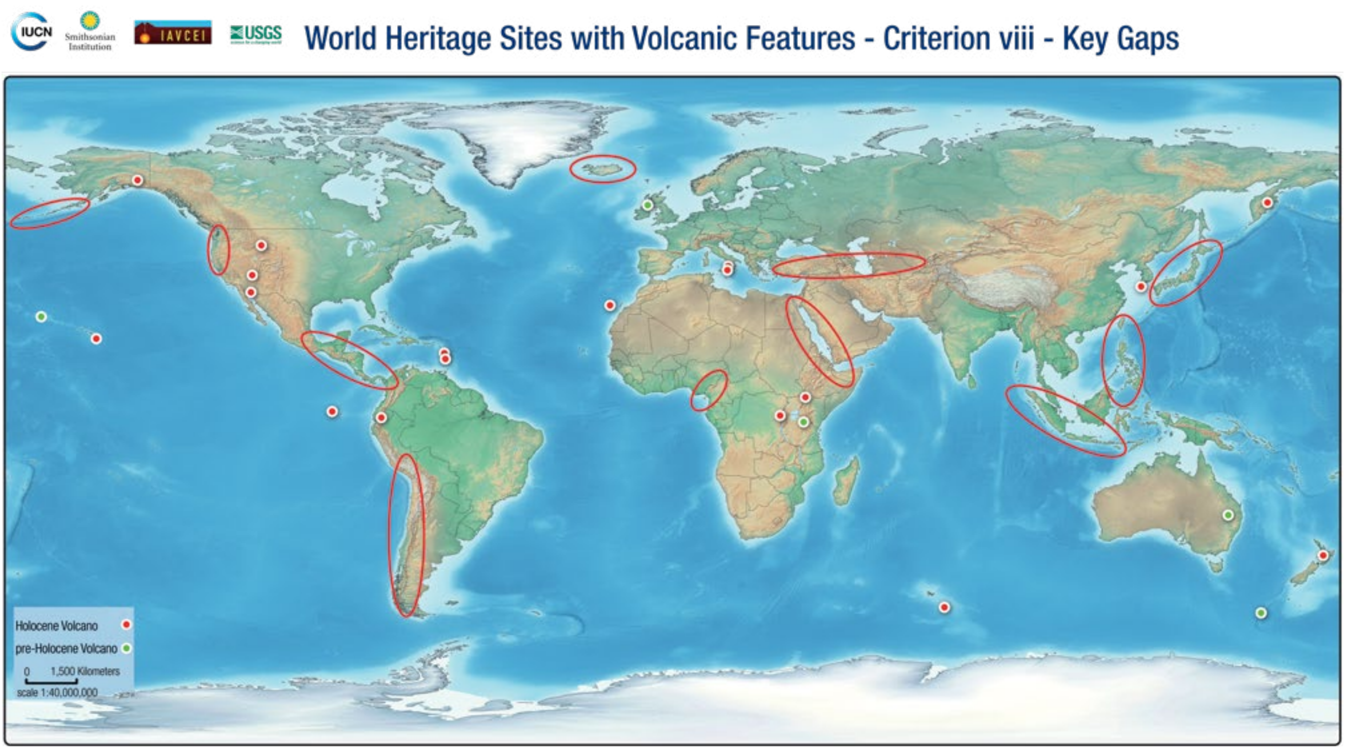


Figure 11: Map showing gaps in plate tectonic and regional representation of the World Heritage List. Positional information for mapped volcanoes is from Global Volcanism Program (2013).

4.3 Sites with potential for inscription that would create a representative List for the Volcanic Theme

Based on the above analysis, and following extensive study, review of the scientific literature and extensive outreach to professional societies and other experts in volcanology and geoheritage, the study identifies a limited list of several volcanic sites with strong potential for inscription on the World Heritage List. The sites include some on the Tentative List. The sites do not repeat our list of sites currently on the World Heritage List, but not inscribed for criterion (viii). Following the example of the *World Heritage Desert Landscapes* thematic report (Goudle & Seely, 2011), we present the sites in each region in two categories:

(i) iconic sites with clear high potential to meet criterion (viii), and

(ii) additional sites that may be further considered for the potential to meet criterion (viii), but where justification of the criteria would require further study.

The presentation of sites in this section, with a focus on criterion (viii), is not exhaustive and has not attempted to analyse whether these suggested locations meet the necessary conditions of integrity or their level of protection and management to have the possibility of nomination. States Parties may alternatively consider evaluating the options of nomination as UNESCO Global Geoparks or Biosphere Reserves in the event they do not fully exhibit OUV, or if these other designations are better adapted to the goals of the States Party, and the communities associated with each site, than is World Heritage. This topic is taken up in detail in Section 5. In all cases States Parties are recommended to seek advice from UNESCO and IUCN prior to beginning work on nominations for sites covered in the present study.

The recommended sites for consideration, by relevant region, are as follows:

Africa

High Likelihood:

Erta Ale, Ethiopia has earth's longest-lived lava lake, which places the volcano in a more or less continuous state of eruption since 1906. Erta Ale fills an important gap in continental rifting sites. It is a scientifically-important volcano owing to its central location in the rift system, and for its lava lake. Erta Ale is in Ethiopia's Afar Depression, part of the East African Rift system, and includes a triple junction of rifts in this location. It is a basaltic shield volcano located in the barren Danakil depression, and consists of nested, steep-walled craters, with associated fissure systems with recent fissure eruptions from the northern flank of this exceptionally active volcano. The name means "gateway to hell" in the local Afar language. The management plan would need to address access to the location, in one of the most inhospitable places on Earth for travel.

Worthy of Consideration:

Oldonyo Lengai, Tanzania is an iconic African rift site with, among other features, abundant carbonatite magmas distinctive of this area. The volcanic ash deposits preserve key features of human evolution such as a human trackway. It also has outstanding biodiversity.

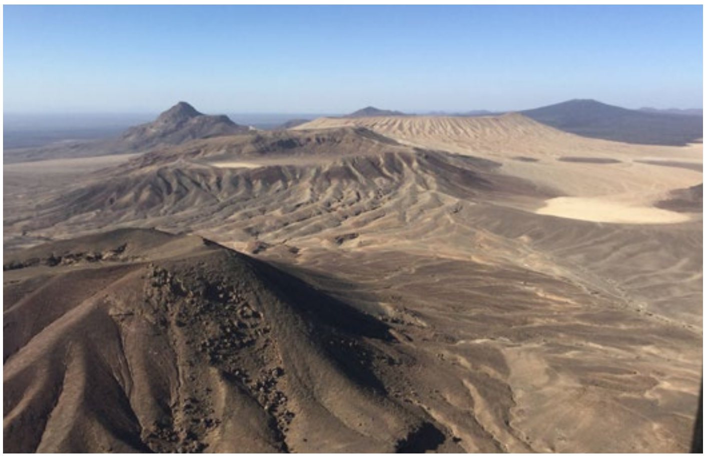
It helps fill important gaps in divergent margin settings of the continents. If Oldonyo Lengai were to be nominated for criterion (viii), it may be considered as an extension of the Ngorongoro World Heritage Site property.

The Cameroon Line is located in the Gulf of Guinea, and is an outstanding example of a hot spot trace that migrates from oceanic to continental plates on the mainland of Africa (crossing Equatorial Guinea, Sao Tome and Principe, Nigeria and Cameroon). As such it preserves an unusually broad range of magma types and is important to our scientific understanding of hotspot magmatism because it serves as a natural laboratory for the interaction of the underlying plume with overlying crust. The area fills gaps in representation of hot spot magmatism, and is also in a geographically-underrepresented region of West Africa.

Arab states:

High Likelihood:

The Harrats of Saudi Arabia are part of one of Earth's longest rift zones, and the location is woven into a culturally-significant triangle between Al Madinah, Makkah and Jeddah, along major pilgrimage routes. They are located near the prominent Red Sea Rift, and form an independent volcanic alignment; it would help fill the gap in continental rift magmatism. The basaltic volcanic fields, known as harrats, are the centerpiece portion of the long rift zone, and are located in the western regions of the Kingdom of Saudi Arabia. The presently-active harrats are the current expression of approximately 10 million years of volcanism, spectacularly preserved by the arid climate.



Harrat Khaybar, Saudi Arabia © U. S. Geological Survey photo by Juliet Ryan-Davis

Latin America and Caribbean:

High Likelihood:

The Chilean/Argentine Lake District (Zona Sur) is a spectacularly beautiful region of classic cone volcanoes in a biodiverse area of lakes and rivers in northern Patagonia. The area is in an underrepresented continental convergent margin volcanic arc area, and provides some of the world's best, and best-studied, representatives of cordilleran arc magmatism. Although many lovely volcanoes and lakes can be found in the world, the Lake District is blessed with an abundance of volcanoes, lakes, and rivers. The snow-covered Andes volcanoes form a constant backdrop to vistas of clear blue or even turquoise waters, as at Lago Todos los Santos. Hundreds of rivers descend from the southern Andes to form lakes that then drain to the ocean through major outlet rivers. The rivers that descend from the Andes rush over volcanic rocks, forming numerous white-water sections and waterfalls. The vegetation, including many ferns in the shady areas, is a lush green. Some sections still consist of old-growth forests. The area would be an excellent serial nomination for both countries in order to include the range of features that demonstrate Outstanding Universal Value.

Osorno Volcano and Rio Petrohue, Chile/Argentina Lake District © Dan Tormey

Back-Arc Magmatism of Western Argentina: continental back-arc volcanism is unrepresented on the World Heritage list, and the volcanic fields of Western Argentina are the world's best example of this plate tectonic setting. They lie parallel to the Andean volcanic arc, and include such iconic localities as Payun Matru and Pale Ike.

The Payún Matrú volcanic field in Argentina includes a massive Hawaiian-style shield of Cerro Payún Matrú; one lava from from Payun Matru is Earth's longest known Quaternary lava flow at 181 km. Satellite to the edifice are more than 300 eruptive centers erupted from fissure systems that extend across the entire shield volcano. At least 30 lava domes and basaltic lava flows were erupted contemporaneously with the basaltic fissure eruptions. Oral traditions include knowledge from the time of the latest eruption.

The iconic basalt field of Pale Ike, located well south of Payun Matru and straddling the Chile-Argentina border north of the Straits of Magellan, is a classic back-arc locality with important inclusions of mantle rocks in some of the lavas. The southernmost of the Patagonian basaltic plateau lavas, Pali-Aike contains lake-filled maars and basaltic scoria and spatter cones with associated young lava flows. The distribution of maars and cones indicates that eruptions occurred along regional fissures. Ash and other deposits from Pali Ike are important for age constraints on human migration through the Americas to the southern tip of land.

Payun Matru is on Argentina's Tentative List.

Cerro Galan, Argentina is a large and exceptionally well-preserved caldera system in the Andes of Argentina. It is an underrepresented area of cordilleran arc magmatism, and is an excellent representative of caldera-forming activity that creates continental crust. It is in the remote northwestern Catamarca Province of Argentina and was discovered in 1975 using satellite images. Galan is part of a chain of silicic volcanic centers lying east of the volcanic arc, and the whole region has been subject to substantial ignimbrite-forming volcanism.

Cerro Galan is on Argentina's Tentative List.

Cotopaxi Volcano, Ecuador is an iconic, stunningly beautiful Andean volcano and is the world's highest-elevation active volcano. Cotopaxi would fill a gap in representation for continental volcanic arc volcanoes. Symmetrical, glacier-clad Cotopaxi stratovolcano is Ecuador's best-known volcano and one of its most active. The steep-sided cone is capped by nested summit craters. Deep valleys scoured by lahars radiate from the summit of the andesitic volcano, and large andesitic lava flows extend to its base. The modern conical edifice has been constructed since a major collapse sometime prior to about 5000 years ago. Pyroclastic flows have accompanied many explosive eruptions, and lahars have frequently devastated adjacent valleys. The most violent historical eruptions took place in 1744, 1768, and 1877. Pyroclastic flows descended all sides of the volcano in1877, and lahars traveled more than 100 km into the Pacific Ocean and western Amazon basin. While the last significant magmatic eruption of Cotopaxi took place in 1904, the volcano produced several large steam and ash eruptions in 2015.

Cotopaxi Volcano summit crater at 5,897m, Ecuador © Dan Tormey

Caribbean volcanic systems, consisting of the Lesser Antilles island arc along the eastern margin of the Caribbean Sea, is a stunningly beautiful chain of tropical islands whose volcanic eruptions have led to 30,000 fatalities over the last 200 years. A Caribbean nomination would fill an important gap in island arc systems, and emphasize the combination of beauty and hazards that characterize many volcanic regions. The Lesser Antilles island arc chain stretches 850 km from Grenada in the south to Saba in the north and includes 21 potentially active volcanoes spread across 11 islands. Most of the islands have a single active volcano, while others have multiple, with the island of Dominica having nine active volcanoes. Volcanic activity in the Caribbean has created some of the most beautiful islands in the world, which also have demonstrated the destructive power of volcanoes. There are several volcanoes that have the potential for Outstanding Universal Value of this combination of volcanic features, including Montserrat and the Soufriere Hills volcano (massive eruptions in 1995 which devasted the southern two thirds of the island); or Mount Pelée and the 1902 eruption which killed 30,000 people when a dramatic eruption swept through the town of St. Pierre. This area could serve as an international serial nomination, or Mount Pelée (the most lethal of the eruptions, and with a type eruption, Pelean, named after it) could be a single representative.

Worthy of Consideration:

Atitlan, Guatemala and Masaya, Nicaragua would improve representation in cordilleran arc magmatism. Volcán Atitlán is one of several prominent conical stratovolcanoes in the Guatemalan highlands and forms a dramatic backdrop to Lake Atitlán, one of the scenic highlights of Guatemala. Masaya is one of Nicaragua's most unusual and most active volcanoes. It lies within the massive Pleistocene Las Sierras pyroclastic shield volcano, filled on its northwest end by more than a dozen vents that erupted along a circular, 4-km-diameter fracture system. Masaya has been frequently active since the time of the Spanish Conquistadors, when an active lava lake prompted attempts to extract the volcano's molten "gold."

Maule Silicic Center, Chile may be earth's largest active silicic magmatic system, capable of a massive "super-volcano" eruption. It lies within an underrepresented category of continental arc volcanic systems.

El Tatio thermal field, Chile is one of the largest hydrothermal manifestations on the planet. The volcanic features include a wide range of hydrothermal expressions, and the lava flows include a unique magnetite lava flow.

Galeras and Nevado del Ruiz, Colombia. Both of these volcanoes had deadly eruptions: Nevado del Ruiz had a small eruption on November 13, 1985 that, through glaciovolcanic interaction, produced an enormous lahar that buried and destroyed the town of Armero causing an estimated 25,000 deaths and was the deadliest lahar in recorded history. Galeras volcano, the most active volcano in Columbia, erupted in 1993, resulting in the deaths of six scientists and three tourists.

Ilopango Caldera, El Salvador lies immediately east of the capital city of San Salvador. The latest eruption and caldera collapse resulted from the massive 5th century Terra Blanca Joven eruption, which produced widespread pyroclastic flows and devastated early Mayan cities. If this site were to be nominated it would be as an extension of the World Heritage Site Joya de Ceren, which like Pompeii and Herculaneum, preserves a record of life encapsulated in a volcanic ash flow.

Asia and Pacific Region:

High Likelihood:

Mayon Volcano, Philippines: Mayon is an iconic strato-volcano of Philippine archipelago with a long history of eruptions producing ash clouds and pyroclastic eruptions. Mayon would fill an unrepresented arc volcano along the western Pacific Ring of Fire.

Beautifully symmetrical Mayon, which rises above the Albay Gulf NW of Legazpi City, is the Philippines' most active volcano. The structurally simple edifice has steep upper slopes that are capped by a small summit crater. Historical eruptions date back to 1616 and range from Strombolian to Plinian eruptive styles, with cyclical activity beginning with basaltic eruptions, followed over the longer term by andesitic lava flows. Pyroclastic flows and mudflows have commonly swept down the many ravines that radiate from the summit and have often devastated populated lowland areas. A violent eruption in 1814 killed more than 1,200 people and devastated several towns. Mayon continues active in 2018.

Mount Mayon volcano, located within Albay Biosphere Reserve, Philippines © UNESCO MAB gallery

Mayon volcano is located within the Albay UNESCO Biosphere Reserve.

Changbaishan, China/Paekdu, Democratic People's Republic of Korea: One of the world's largest known Holocene explosive eruptions took place at Changbaishan/Paekdu Volcano about 1,000 CE, depositing rhyolitic and trachytic volcanic ash as far away as northern Japan and forming the present 5 km wide caldera. The volcano straddles the China / DPRK border and lies within a regionally under-represented region where the tectonic setting is poorly understood. Minor historical eruptions have been recorded since the 15th century. The volcano and its scenic crater lake are revered as an important feature in the cultural history of the Korean peninsula. The 850-m-deep summit caldera is filled by scenic Lake Tianchi (Sky Lake). A large Korean-speaking population resides near the volcano on both sides of the border.

The volcano is partially located within the Changbaishan UNESCO Biosphere Reserve, China, and also in the Paekdu UNESCO Biosphere Reserve, Democratic People's Republic of Korea.

Mount Changbaishan/Mount Paekdu Volcano, China/Democratic People's Republic of Korea © Kayla Iacavino

Auckland volcanic field, New Zealand: The 140 km^3 Auckland volcanic field of late Pleistocene to late Holocene in age, lies at the southern end of the Northland Peninsula and is overlain by Auckland, New Zealand's largest city. The Auckland volcanic field fills an under-represented category of convergent plate boundary volcanism in the southwestern Pacific region.

More than 50 maars, tuff rings, small lava shields, and scoria cones have formed in the Auckland field over the past 140,000 years in an elliptical region nearly 30 km long in its largest (N-S) direction. The Auckland volcanic field has produced dominantly intraplate alkali basaltic rocks, forming the northernmost of a group of Quaternary volcanic fields of the Auckland Intraplate Province. Of the 19 eruptions known to have occurred within the past 20,000 years, only one eruptive center is known to have been active during the Holocene. The Rangitoto eruption, about 600 years ago, was the largest of the Auckland volcanic field and created the 6-km-wide Rangitoto Island, which consists of multiple scoria cones that cap a low shield volcano with a broad apron of lava flows.

The Auckland volcanic field is on the UNESCO Tentative List for New Zealand.

Kermadec islands, New Zealand: The Kermadec islands are a volcanic island arc, southwestern Pacific, formed at the convergent boundary where the Pacific Plate subducts under the Indo-Australian Plate. Inclusion of the Kermadec islands would help fill the gap in southwestern Pacific island arc volcanism.

The subducting Pacific Plate created the Kermadec Trench, an 8 km deep submarine trench, to the east of the islands. The islands lie along the undersea Kermadec Ridge, which runs southwest from the islands towards the North Island of New Zealand and northeast towards Tonga (Kermadec-Tonga Arc). The four main islands of the Kermadec arc are the peaks of volcanoes that rise from the seabed to project above sea level. There are several other volcanoes in the chain that do not reach sea level.

The submarine Kermadec island arc form New Zealand's largest Marine Reserve and host remarkable biodiversity of marine life, as well as numerous hydrothermal vents clustered around submarine volcanoes.

The Kermadec islands are on New Zealand's Tentative List.

Tambora Caldera, Indonesia: The 1815 eruption of Tambora Volcano was the largest known explosive eruption of the past 200 years and is credited for the "year without a summer" in 1816, shortening the growing seasons in the northern hemisphere of Europe, North America, and Asia. Tambora caldera of the Indonesian archipelago fills an under-represented portion of the western Pacific Ring of Fire. The massive Tambora stratovolcano forms the entire 60-km-wide Sanggar Peninsula on northern Sumbawa Island. The largely trachybasaltic-to-trachyandesitic volcano grew to about 4,000 m elevation before forming a caldera more than 43,000 years ago. Late-Pleistocene lava flows largely filled the early caldera, after which activity changed to dominantly explosive eruptions during the early Holocene. The eruption of an estimated more than 150 km^3 of tephra formed a 6-km-wide, 1,250-m-deep caldera and produced global climatic effects. Minor lava domes and flows have been extruded on the caldera floor at Tambora during the 19th and 20th centuries.

Tambora Volcano, Indonesia © Iwan Setiyawan/KOMPAS

Toba Caldera, Indonesia: The 35 x 100 km Toba caldera is the Earth's largest Quaternary caldera and was formed during four major Pleistocene ignimbrite-producing eruptions beginning at 1.2 million years ago. Toba caldera of the Indonesian archipelago fills an under-represented portion of the western Pacific Ring of Fire. The youngest of the caldera-forming eruptions produced the Young Toba Tuff (YTT) about 74,000 years ago. The YTT represents the world's largest known Quaternary eruption, ejecting about 2,500-3,000 km^3 (dense rock equivalent) of rhyolitic pyroclastic deposits and airfall ash from vents at the NW and SE ends of present-day Lake Toba. Resurgent doming formed the massive Samosir Island and Uluan Peninsula structural blocks.

Toba Caldera and the large lake Toba offer a stunning scenic landscape and is home to a rich cultural heritage as expressed in building architecture and handicrafts.

Iconic volcanoes of Japan: The Japanese archipelago is largely of volcanic origin and contains more than 80 Holocene volcanoes. The entire archipelago could be considered as the classical island arc produced by subduction and many of the volcanoes of the archipelago are considered iconic including Sakurajima, Aso, Unzen, and Fuji-san.

Despite this status, no volcanoes of the Japanese archipelago have been listed for criterion (viii). However, the island arc volcanoes do have outstanding cultural and biological heritage connected with the volcanic landscapes including Mount Fuji-san which has been inscribed for its cultural importance.

Worthy of Consideration:

Kuwae Caldera, Vanuatu: The largely submarine 6 x 12 km Kuwae caldera occupies the area between Epi and Tongoa islands and is the site of one of the largest eruptions of the past millennium. The Kuwae caldera occupies an under-represented region of the western Pacific Ring of Fire.

Native legends and radiocarbon dates from pyroclastic-flow deposits have been correlated with a 1452 CE ice-core peak thought to be associated with collapse of Kuwae Caldera. The submarine volcano Karua lies near the northern rim of Kuwae caldera and is one of the most active volcanoes of Vanuatu. It has formed several ephemeral islands since it was first observed in eruption during 1897. Its last eruption was in 1974.

Mount Popa, Myanmar: Mount Popa is a Holocene volcano in an unusual plate tectonic setting that includes an unrepresented collision zone as well as convergent margin. It is a large, steep-sided composite cone that rises above a surrounding lava plateau. Local legends describe an eruption in 442 BCE.

Mount Popa is a sacred site with a monastery built atop the Taung Kalat lava dome.

Pinatubo, Philippines: The June 1991 eruption of Pinatubo was the second largest eruption of the 20th century. The 1991 eruption attracted world-wide attention from the scientific community and is especially notable for the atmospheric impacts of the eruption. Pinatubo lies in an under-represented portion of the Philippine archipelago island arc along the western Pacific Ring of Fire.

Prior to 1991 Pinatubo Volcano was a relatively unknown, heavily forested lava dome complex located 100 km NW of Manila with no records of historical eruptions. The 1991 eruption ejected massive amounts of tephra and sulfur gases in to the atmosphere and produced voluminous pyroclastic flows, forming a small, 2.5-km-wide summit caldera whose floor is now covered by a lake. Caldera formation lowered the height of the summit by more than 300 m.


A lake partially fills the 1991 Pinatubo crater, Philippines © Dan Tormey

Tephra and sulfur gases produced by the 1991 eruption were injected into the stratosphere and circulated the globe in a week and produced measurable cooling of the atmosphere in the Northern hemisphere for several years following the eruption. The eruption also caused large disruptions to regional air traffic for several weeks owing to dispersal of volcanic ash. Although the eruption caused hundreds of fatalities and major damage with severe social and economic impact, successful monitoring efforts greatly reduced the number of fatalities. Widespread lahars that redistributed products of the 1991 eruption have continued to cause disruption to the environment and infrastructure.

Taal Caldera, Philippines: Taal Volcano is one of the most active volcanoes of the Philippine archipelago. Though not topographically prominent, its prehistorical eruptions have greatly changed the topography of SW Luzon island. The 15 x 20 km Talisay (Taal) caldera is largely filled by Lake Taal. Observations and studies of the explosive 1966 eruption revolutionized understanding about the mechanisms and dynamics of pyroclastic explosive processes and the identification of "base surge" as an important process in explosive eruptions worldwide.

The proximity of Taal Caldera to metro Manila makes it important for educational and public awareness opportunities.

Rinjani, Lombok Island, Indonesia: Rinjani Volcano on the island of Lombok rises to 3726 m, second in height among Indonesian volcanoes only to Sumatra's Kerinci Volcano. Rinjani Volcano would fill an under-represented segment of the Indonesian island arc.

Rinjani lies along the eastern margin of the 6 x 8.5 km, oval-shaped Samalas Caldera, formed during one of the largest Holocene eruptions globally in 1257 CE. The western half of the caldera contains a scenic 230-m-deep lake. Rinjani's most recent eruption was in 2016. In 2018 a large earthquake on Lombok caused significant damage and loss of life to local villages on the slopes of Rinjani.

The Samalas caldera forms the core of the recently (2018) designated Rinjani-Lombok UNESCO Global Geopark.

Banda archipelago, Indonesia: The Banda archipelago – also known as the Spice islands – forms part of the Sunda-Banda island arc, an under-represented convergent plate boundary. The islands were a magnet for traders seeking the wealth of the spice trade and they occupied a key position in global exploration of the 15th and 16th centuries.

The archipelago consists of 10 small volcanic islands including the active volcanic island of Banda Api, the NE-most volcano in the Sunda-Banda arc.

The Banda archipelago is on the World Heritage Tentative List for Indonesia.

Europe and North America:

High Likelihood:

Icelandic volcanic systems: Iceland is iconic volcanic terrain, the part of the planet where the mid-Atlantic ridge surfaces as a major island. Iceland is central to scientific understanding of how earth processes work, particularly oceanic rifts and interactions with subridge plumes. Mid-ocean ridges are unrepresented on the World Heritage List, and Icelandic volcanic systems would fill this important gap in an outstanding way. Iceland includes the entire range of currently active mid-ocean rift features, including large rift systems with historically-important eruptions (such as the Laki fissure flow that led to several years of no summer and famine conditions worldwide); the world's largest and best expressed subglacial landforms (tindar ridges and tuya peaks); rootless vents of all known types (no other place on earth has such complete and excellent exposures of the effects of lava flows over various types of water and ice); and, where the rift also includes a major mantle plume, the development of large central-vent volcanoes that include the entire magma series from basalt to rhyolite. Iceland also includes some of the best-exposed subvolcanic features on earth; as one goes east from the current centers of volcanic activity, one proceeds deeper into the volcanic plumbing system. Some of these feeder systems are unique to Iceland because such a well preserved and active part of the mid-ocean ridge is rare. There is little to no vegetation on these outstanding examples of volcanic features, making them a pure expression of criterion (viii).


Volcanic vent from the Laki fissure eruption, Iceland © Dan Tormey

The Icelandic volcanoes associated with Vatnajokull and Torfajokull are on Iceland's Tentative List.

Santorini Caldera, Greece: Santorini caldera, site of the Late-bronze age Minoan eruption, one of the largest eruptions of historical time, is one of the most iconic and historical important volcanoes of Antiquity. Santorini (Thera), with its steep-walled caldera rim draped by whitewashed villages overlooking an active volcanic island in the center of a caldera bay, is one of the scenic highlights of the Aegean. The volcanic complex of Santorini is the most active part of the South Aegean Volcanic Arc, an under-represented volcanic arc which marks the subduction of the African tectonic underneath the Aegean subplate of the Eurasian tectonic plate.

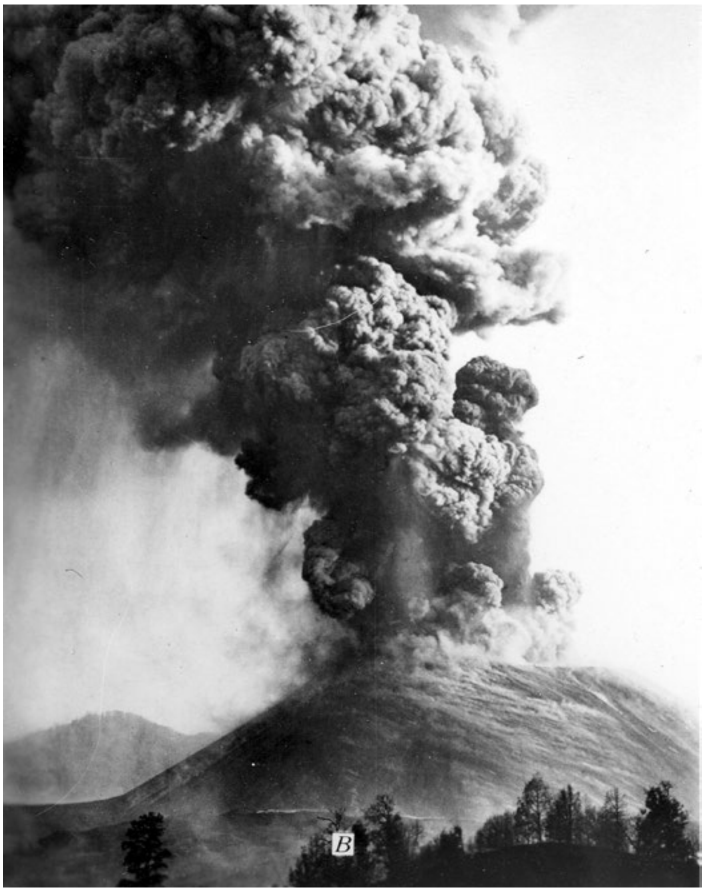
The circular island group is composed of overlapping shield volcanoes cut by at least four partially overlapping calderas. The youngest caldera formed about 3600 years BP during the Late-Bronze-Age Minoan eruption that forced abandonment of the thriving Aegean Sea island and inspired the legend of Atlantis. Post-Minoan eruptions beginning in 197 BCE constructed a series of lava domes and flows that form two islands near the center of the caldera. A submarine eruption took place in 1650 CE outside the caldera NE of Thera. The latest eruption produced a small lava dome and flow in 1950, accompanied by explosive activity.

Mount Saint Helens, USA: Modern volcano science is often said to have started with the May 18th, 1980 eruption of Mount Saint Helens. The volcano, frequently referred to as the "Fuji of North America" is located in the Cascade and is part of the under-represented Cascade Volcanic Arc, a segment of the Pacific Ring of Fire that includes over 160 active volcanoes. This volcano is well known for its ash explosions and pyroclastic flows.

The May 18th eruption was unusually well monitored and observed and subsequently studied by scientists from around the world. Our understanding of several important eruptive processes such as volcano sector collapse, the dynamics of pyroclastic surge and flows, the mechanics of debris flows and mudflows, and degassing of continental strato volcanoes all originated with observation and studies of the 1980 eruption. With 57 fatalities, the 1980 eruption was the deadliest and most economically destructive volcanic event in the history of the United States.

In 1982 the landscape around the volcano was protected as the Mount St. Helens National Volcanic Monument to preserve the volcano and allow for the eruption's aftermath to be scientifically studied.

Paricutin Volcano, Mexico: Paricutin cinder cone lies in the *Michoacán-Guanajuato volcanic field of the* Trans-Mexican volcano belt. While Paricutin is but one of more than 1400 vents



Paricutin Volcano, Mexico © U.S. Geological Survey

in the Michoacan-Guanajuato field, it is forever embedded in the global popular culture as the “volcano which grew up in the corn field” and is the centerpiece of the iconic “birth of a volcano story”. Thanks to nearly continuous observation by geologists during its 9 year eruptive history from 1943 through 1952, Paricutin is often considered the first modern study of an on-going eruption.

The Michoacán-Guanajuato volcanic field contains over 1400 vents, including the historically active cinder cones of Parícutin and Jorullo, covering a 200 x 250 km wide area of Michoacán and Guanajuato states in west-central México. Cinder cones are the predominant volcanic form, but small shield volcanoes, lava domes, and maars and tuff rings are also present. The shield volcanoes are mostly Pleistocene in age, and have morphologies similar to small Icelandic-type shield volcanoes, although the Michoacán-Guanajuato shields have higher slope angles and smaller basal diameters. Jorullo, which was constructed in the 18th century, and Parícutin, which grew above a former cornfield during 1943-52, are the two best known of the roughly 1000 small volcanic centers scattered throughout the volcanic field.

Worthy of Consideration

The Caucasus Mountains are iconic collision zone volcanoes; this tectonic environment is not represented by a site listed for criterion (viii). The Western Caucasus World Heritage Site contains Mount Elbrus (as described in Section 3.1.2). Mount Ararat (Turkey) and Mount Kazbek (Georgia) are also iconic volcanoes that could be considered individually or part of an international serial nomination. The stratovolcano Mount Ararat, also known as Agri Dagi, has global cultural significance for interactions with Bronze Age civilizations and as the reputed resting place of Noah’s Ark. Mount Kazbek is in the greater Caucasus and after Mount Elbrus is the highest volcanic peak in the range. It is known as the mythical location where Prometheus was chained on the mountain in punishment for having stolen fire from the gods and having given it to mortals.

Tres Virgines, Baja California, Mexico is a volcanic complex including the Aguajito caldera and three strato volcanoes set in a desert environment to produce an aesthetically outstanding area. The volcanic area includes an active geothermal area. The volcanic complex lies within the Gulf of California rift environment.

The Tres Vírgenes volcanic complex contains the only large stratovolcanoes in Baja California. The roughly 1940-m-high complex rises above the Gulf of California in the east-central part of the peninsula. Three volcanoes, El Viejo, El Azufre, and La Vírgen were constructed along a NE-SW line and are progressively younger to the SW. The youngest volcano, La Vírgen, is an andesitic stratovolcano with numerous dacitic lava domes and lava flows on its flanks. A major plinian explosive eruption from a SW-flank vent was radiocarbon dated at about 6500 years ago.

Tres Virgines is located within the El Vizcaino, a UNESCO Biosphere Reserve property.

Crater Lake Caldera, Oregon, USA: The spectacular 8 x 10 km Crater Lake caldera in the southern Cascades of Oregon formed about 6850 years ago as a result of the collapse of a complex stratovolcano known as Mount Mazama. Scientific studies have documented the pre-caldera geology showing that the Mount Mazama complex is nearly 500,000 years old.

The explosive eruptions triggering formation of the 8-10 km wide caldera were among Earth’s largest known Holocene eruptions, distributing tephra as far away as the midcontinent area of the USA and into Canada and producing pyroclastic flows that traveled 40 km from the volcano. The widespread Mazama ash layer serves as a prominent time marker for a wide variety of archaeological and ecosystem studies.

Crater Lake caldera, with Wizard Island, USA © Thomas Casadevall

The deep blue waters of North America’s second deepest lake, at 600 m, fill the caldera to within 150-600 m of its rim. Post-caldera eruptions within a few hundred years of caldera formation constructed a series of small lava domes on the caldera floor, including the partially subaerial Wizard Island cinder cone, and the completely submerged Merriam Cone. The latest eruptions produced a small rhyodacitic lava dome beneath the lake surface east of Wizard Island about 4200 years ago.

Crater Lake forms the centerpiece of the Crater Lake National Park.

Katmai Caldera, Alaska, USA: The largest eruption of the 20th century occurred at Mount Katmai, Alaska in April 1912. The eruption produced a large 3 x 4 km caldera which resulted from the voluminous eruption of Novarupta volcano. Prior to 1912, Mount Katmai was a compound stratovolcano with four NE-SW-trending summits, most of which were truncated by caldera collapse in that year. Two or more large explosive eruptions took place from Mount Katmai during the late Pleistocene. Most of the two overlapping pre-

1912 Katmai volcanoes are Pleistocene in age, but Holocene lava flows from a flank vent descend the SE flank of the SW stratovolcano into the Katmai River canyon. A small lake on the caldera floor started to form following the 1912 eruption and post-1912 glaciers have formed within Katmai caldera.

The Katmai caldera has been the subject of more than a century of scientific studies which have lead to much improved understanding of how volcanic calderas form, as well as a type eruption, Katmaian, named after it.

Mount Katmai forms the centerpiece of Katmai National Park and has also been recognized as a UNESCO Biosphere Reserve.

Iguazu National Park World Heritage Site, Argentina/Brazil © Ko Hon Chiu Vincent

Ancient volcanic sites

There are several volcanic sites that are not currently or were not recently active but which preserve the subsurface magmatic feeder and storage systems (the roots of volcanoes) or represent the significant role of volcanism in the growth and evolution of continents and/or have contributed to mass extinctions. These include the greenstone belts in Australia, Canada and South Africa (the earliest preserved continental crust was volcanic in origin); the Oman and Troodos ophiolites (ancient volcanic oceanic crust deposited on the continents); Devils Tower and Shiprock volcanic necks in the US; the scientifically classic Skaergaard intrusion in eastern Greenland (roots of volcanoes); and the Bushveld Complex of South Africa and the Great Dike of Zimbabwe (complex subvolcanic settings). These sites could all potentially display OUV for criterion (viii).

4.4 Antarctica:

Mount Erebus is the southernmost active volcano on the planet. It periodically has a long-lived lava lake. It is a centerpiece to the culture of polar exploration. It is not covered by the World Heritage Convention because Antarctica is not the territory of any State Party, but from the perspective of the values needed to meet criterion (viii) it would otherwise have high likelihood for inscription, if it were able to be nominated.

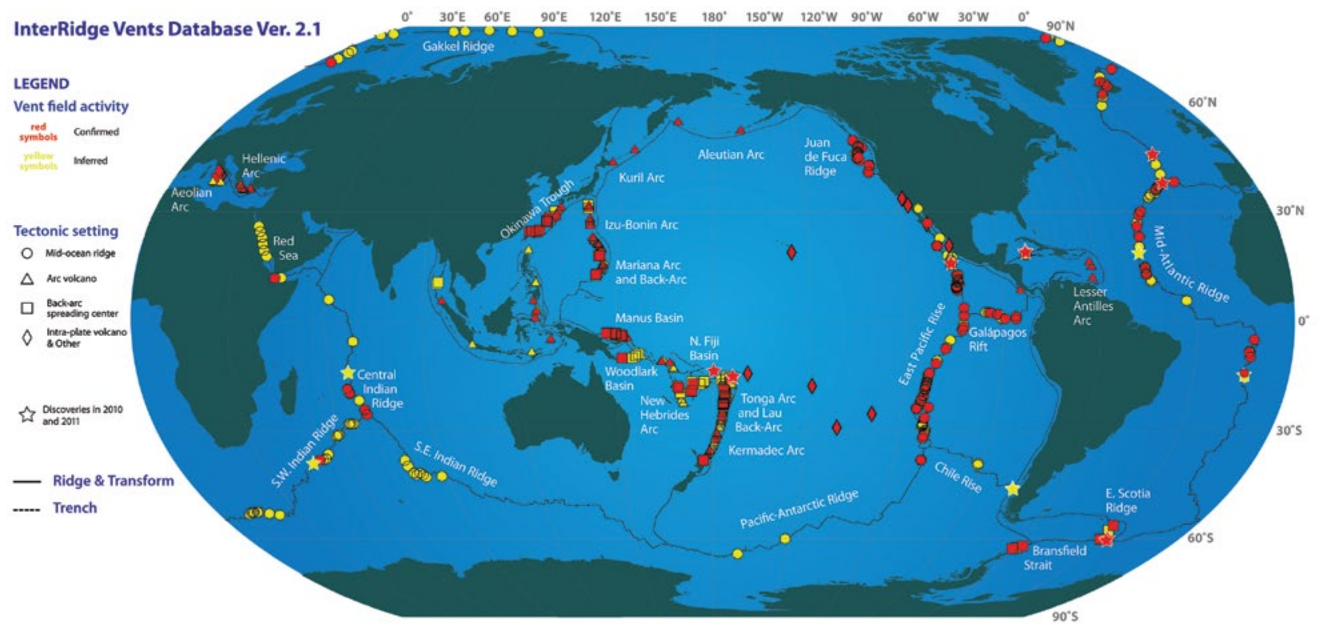
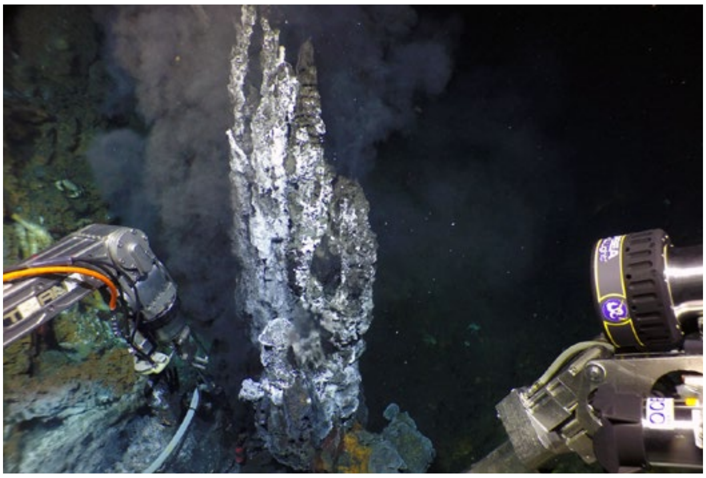


Figure 12: Distribution of submarine hydrothermal vent fields. These represent a subset of the world's volcanic estate on the ocean floor. (Beaulieu et al., 2015)

4.5 Gaps in representation of submarine volcanic heritage

Purely submarine volcanic features are not included on the World Heritage List. However, 70% of the Earth's surface is covered by water and is effectively a submarine environment. Much of the Earth's active tectonism, including spreading centers, ridges, transform faults and subduction-related trenches, are submarine (Figure 12). Bathymetric studies of the sea floor have revealed that it is dotted with volcanoes, which recent studies (Hillier & Watts, 2007; Wessel et al., 2010; Kim & Wessel, 2011) estimate could number over three million, 39,000 of which rise to more than 1,000 m above the ocean floor. With the increase in sea-floor mining and other potentially destructive practices, some of these volcanic terrains are at risk.



Submarine volcanic hydrothermal system (black smoker from East Pacific Rise) © WHOI-National Deep Submergence Facility, NSF, WHOI-MISO Facility, Cruise AT42-06 participants.

Several marine reserves include areas of submarine volcanism and hydrothermal vent activity, but by and large the volcanic features in these submarine environments are not represented in lists of UNESCO-protected properties. The World Heritage Convention does not address sites in areas beyond national jurisdiction (Freestone et al., 2016). We suggest that the submarine volcanic estate has areas and features that deserve discussion and possible protection and inclusion under one or more of the UNESCO protected-landscape programmes.

One impediment to managing and protecting these submarine environments is that often there are no States Parties to claim jurisdiction and management responsibility over the large majority of them. “Sixty-four per cent of the world’s ocean – and nearly half of the surface of the Earth – is outside the legal powers of traditional national governance systems.” (Worboys et al., 2015). Thus, such properties fall more appropriately under ‘Law of the Sea’ jurisprudence. However, several submarine volcanoes representing submarine extensions of terrestrial volcanic systems (Loihi, Kick-em-Jenny, Oshima) do fall within territorial jurisdictions. The UNESCO/IUCN publication *World Heritage on the High Seas: An Idea Whose Time Has Come* (Freestone et al., 2016) discusses this topic primarily from the perspective of biological world heritage, but many of the concepts therein also apply to geoheritage.

This *Volcanic Thematic Study* considers the absence of submarine volcanism from the World Heritage List to be a substantial gap in representation of the Earth’s volcanic systems. We identify this gap in this Study; however, we also recognise that filling this gap will depend upon additional international agreement and governance frameworks, and this represents a further reason to explore the extension of the application of the World Heritage Convention to the High Seas.

Parallel UNESCO programmes to preserve volcanic heritage

5

Mount Hallasan, Jeju Island, Republic of Korea © Jeju Special Self-Governing Province

Three UNESCO conservation programmes highlight natural landscapes, including those with significant and important volcanic features: the World Heritage List, UNESCO Global Geoparks and Biosphere Reserves. These Internationally Designated Areas (IDAs) represent the highest attainable stature in terms of international recognition (Schaaf & Clamote-Rodrigues, 2016). Each of the three programmes has different goals, mechanisms and process for designation of properties and different degrees of required management protection, in the case of volcanic features, sites and landscapes. However, they all share the common feature that their sites, reserves and parks are distributed globally (Figures 13 and 14; Tables 5 and 6) and that they encounter similar challenges in terms of landscape management, potential hazard identification and planning needs.

All three programmes ultimately offer benefits to the management of the world's volcanic estate, and for many outstanding volcanic sites (such as those presented in Section 4.4: Sites with potential for inscription), nomination as a UNESCO Global Geopark or Biosphere Reserve may be a better choice for States Parties. In addition, some volcanic areas may benefit from multiple listings, including a World Heritage Site centerpiece, and associated UNESCO Global Geoparks or Biosphere Reserves that allow for greater amounts of sustainable development activities on the periphery of the World Heritage Site. For these reasons, we include these other programmes in this *Volcano Thematic Study*.

In the case of World Heritage properties, their management focuses on the preservation of those features to ensure they remain unimpaired for future generations. In the case of both UNESCO Global Geoparks and Biosphere Reserves, the management of these properties focuses on resource conservation while also allowing sustainable development of the geological features. As part of all three types of UNESCO designations, management plans are developed that must address the protection of the values provided by the volcanic landscapes, and typically are led by communities rather than a States Party.

Promoting sustainable economic development is a key, underlying premise for both Biosphere Reserves and UNESCO Global Geoparks. Biosphere Reserves are natural sites that seek to reconcile the conservation of biological and cultural diversity with economic and social development through partnerships between people and nature. As such, they are ideal to test and demonstrate innovative approaches to sustainable development on both a local and an international scale through the Man and the Biosphere Programme. Geoparks are unified areas of geological heritage that promote geoheritage, the role of the geologic setting in the growth and development of community and cultural values, and enhance awareness of geological hazards, such as volcanoes, earthquakes and tsunamis, among local communities while adopting standards for the sustainable use of natural resources and 'green tourism'. UNESCO Global Geoparks undertake their activities within the framework of the UNESCO Global Geoparks Network approved in November 2015.

A small number of protected volcanic landscapes have multiple UNESCO designations. For example, Jeju Island, Republic of Korea is designated as a World Heritage property, a Biosphere Reserve and a UNESCO Global Geopark. Hawai'i Volcanoes National Park and Yellowstone National Park in the USA and Galápagos Islands, Ecuador are designated as both World Heritage properties and Biosphere Reserves.

While the goals and criteria for inclusion of a property or community differ between the three UNESCO programmes, each designation offers a means and a mechanism to protect the unique conservation values for which the property is designated. There are sites on the Tentative List and identified in Section 4.4 of this Study that may be better considered as a UNESCO Global Geopark or Biosphere Reserve from the outset of the nomination process. Dingwall et al. (2005) make a similar recommendation and add that national or regional protection may also be the most appropriate.

5.1 Biosphere Reserves

The concept of Biosphere Reserves originated with UNESCO's Man and the Biosphere (MAB) Programme in 1974, and the Biosphere Reserve network was launched in 1976. The network is a key component in MAB's objective of achieving a sustainable balance between the goals of conserving biological diversity, promoting economic development and maintaining associated cultural values.

Biosphere Reserves are geographical areas that are representative of the planet's diversity of habitats. Including both land and/or marine ecosystems, these areas are characterised as sites that are not exclusively protected (such as national parks) but which also house human communities who live from sustainable activities that do not endanger the ecological value of the sites. Biosphere Reserves have three functions: the conservation of ecosystems and genetic variation; the promotion of sustainable economic and human development; and to serve as examples of education and training on local, regional, national and international issues of sustainable development. (http://www.unesco.org/new/en/santiago/natural-sciences/man-and-the-biosphere-mab-programme-biosphere-reserves/).

As of April 2018, 58 of the 669 (8.7%) Biosphere Reserves feature important or significant volcanic sites (Figure 14; Table 5). For Biosphere Reserves, there is no requirement that identifies or highlights the reserve's geological setting or geological or geodiversity values. The primary criterion for Biosphere Reserves is that the property has "… unique biodiversity …". Of the 669 (2018) current Biosphere Reserves, many are designated due to the unique biological diversity found on mountains – particularly on isolated

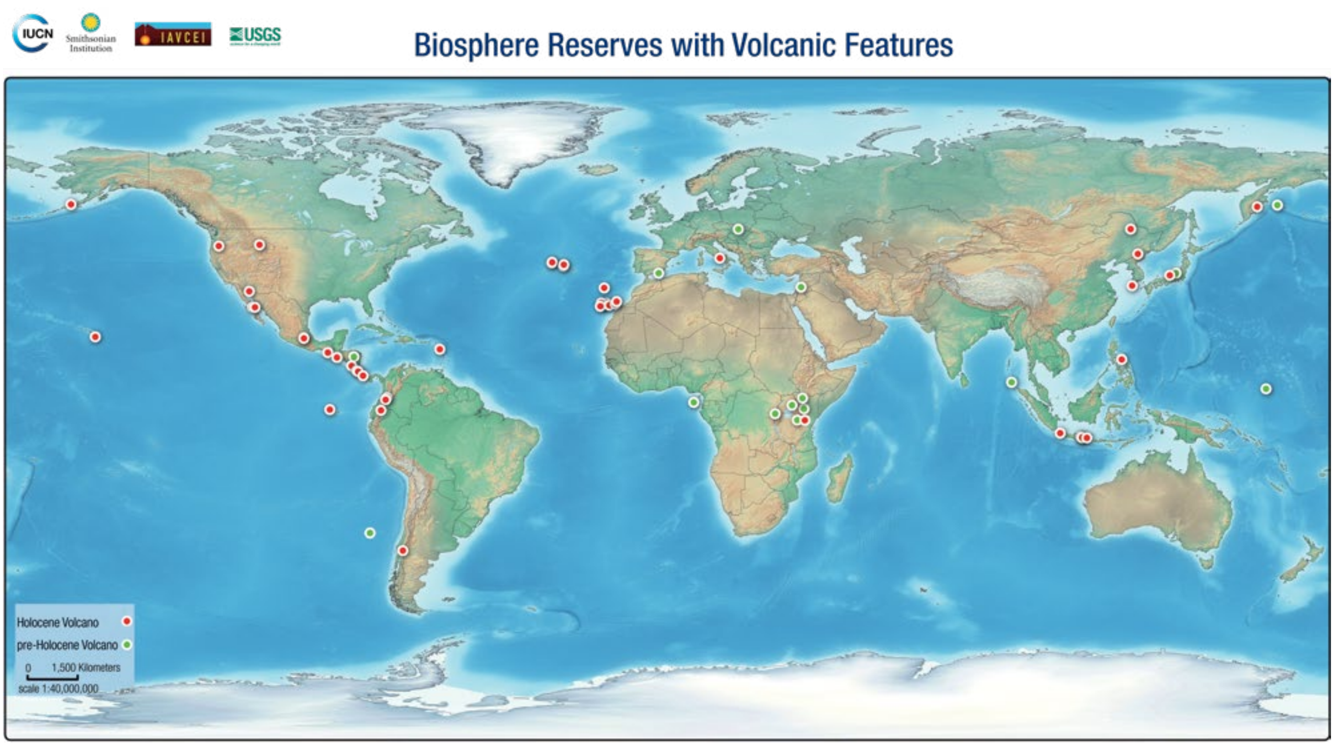


Figure 13: Map of Biosphere Reserves with volcanic features. Positional information for mapped volcanoes is from Global Volcanism Program (2013).

mountains – where elevation change is accompanied by commensurate changes in, and high degrees of endemism in, flora and fauna. Several such isolated mountains are remote volcanoes or volcanic ranges that because of their unique geographical and climatological locations offer unique habitats or ecotones for plants and animals. The result is that while these landscapes are protected and managed primarily for their biodiversity, they also are considered protected volcanic landscapes and are therefore included in this review. In addition, a small number of Biosphere Reserves are also designated as World Heritage sites, such as Hawai'i Volcanoes National Park, USA and Galápagos Islands, Ecuador. Several Biosphere Reserves are also designated as UNESCO Global Geoparks, including Lanzarote, Spain; Azores, Portugal; Wudalianchi, China; and Kilimanjaro, Kenya.

5.2 UNESCO Global Geoparks

In 2015 UNESCO added a third programme, the UNESCO Global Geoparks Programme, which aims to conserve the natural environment. Landscapes with geological heritage of international value, including volcanic features, may be accepted under the UNESCO Global Geoparks Programme where they are managed by local communities to promote geoconservation and sustainable development. The UNESCO Global Geoparks Programme began as the Global Geoparks Network in 2000. As described by UNESCO, "UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development." A UNESCO Global Geopark uses its geological heritage, in connection with all other aspects of the area's natural and cultural heritage, to enhance awareness and understanding of key issues facing society, such as using Earth's resources sustainably, mitigating the effects of climate change and reducing natural disaster-related risks. By raising awareness of the importance of the area's geological heritage in historical and modern societies, UNESCO Global Geoparks give local people a sense of pride in their region and strengthen their identification with the area. The creation of innovative local enterprises, new jobs and high-quality training courses generates new sources of revenue through geotourism, while the geological resources of the area are protected. (UNESCO Global Geoparks website, 2017).

As of April 2018, 35 of 140 Geoparks (25%) are volcanic themed or contain prominent volcanic geosites and/or landscape-scale features (Figure 14; Table 6). Eight are in China, five in Japan, three each in Spain and the Republic of Korea (ROK) and two each in Hungary, Iceland and Indonesia. The ages of the geological formations in these geoparks range from 2.7 Ba to presently active.

Twenty of the 35 UNESCO Global Geoparks are considered "active" volcanic systems that have experienced activity within the past 11,700 years. Eight UNESCO Global Geoparks with post-Holocene volcanic features are also included in this analysis owing to their uniqueness. For example, the Troodos ophiolite complex of Cyprus is an exceptionally well-exposed cross section through an oceanic spreading center. The Sesia Val Grande in Italy is likewise an exceptionally well-preserved cross section of the Earth's upper crust exposing the roots of a large caldera. Other pre-Holocene volcanic features exposed in Spain's Cabo de Gata Global

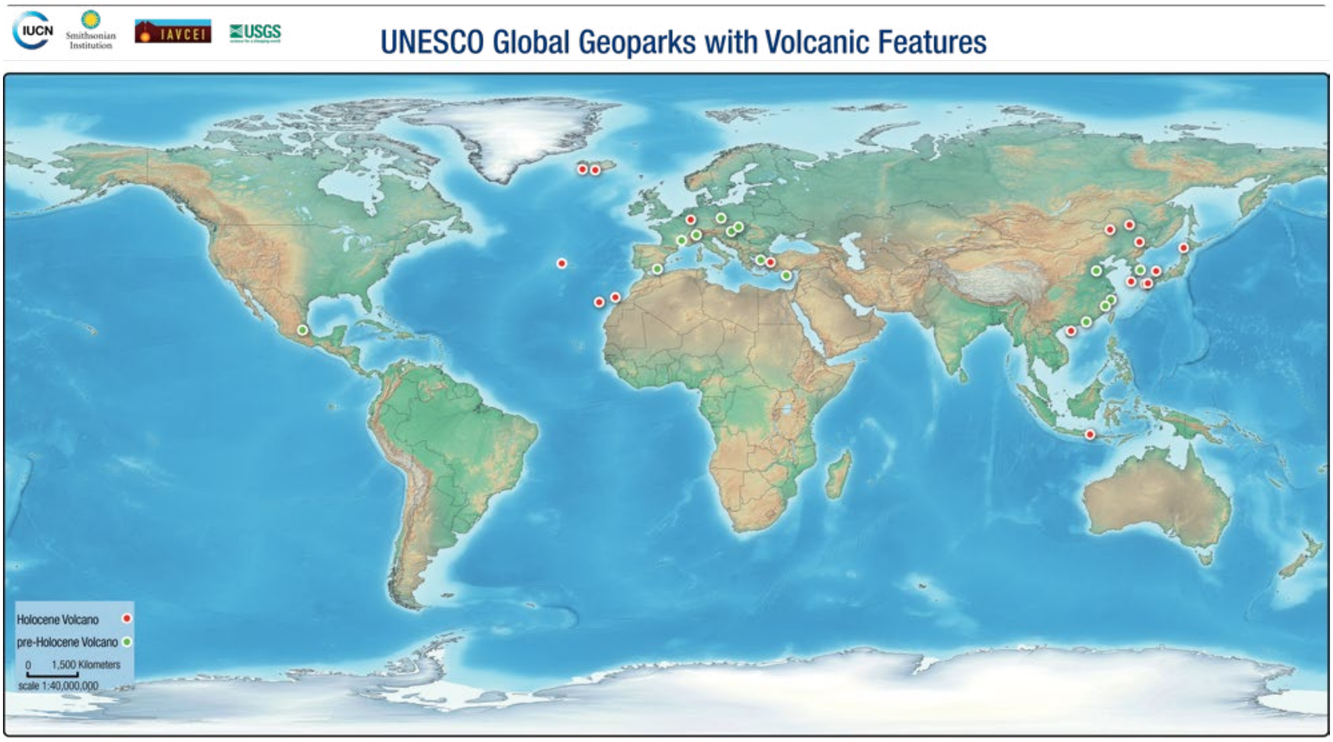


Figure 14: Map of UNESCO Global Geoparks with volcanic features. Positional information for mapped volcanoes is from Global Volcanism Program (2013).

Geopark and France's Monts d'Ardeche Global Geopark show an unusually rich display of constructional volcanic landforms. Two UNESCO Global Geoparks are also Biosphere Reserves (Wudalianchi, China and Jeju, Republic of Korea).

As noted by UNESCO, "UNESCO Global Geoparks, together with the other two UNESCO site designations Biosphere Reserves and World Heritage Sites, give a complete picture of celebrating our heritage while at the same time conserving the world's cultural, biological and geological diversity, and promoting sustainable economic development. While Biosphere Reserves focus on the harmonized management of biological and cultural diversity and World Heritage Sites promote the conservation of natural and cultural sites of OUV, UNESCO Global Geoparks give international recognition for sites that promote the importance and significance of protecting the Earth's geodiversity through actively engaging with the local communities."[7]

Lonquimay Volcano in the Chilean Lake District, with Araucaria tree in the foreground. Lonquimay lies within the Araucarias Biosphere Reserve and the Kütralkura UNESCO Global Geopark, Chile © Thomas Casadevall

7. www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/frequently-asked-questions/difference-between-unesco-global-geoparks-biosphere-reserves-and-world-heritage-sites/

Guidance for use of criterion (viii) in future volcanic theme nominations to the World Heritage List

6

Sete Cidades Caldera, São Miguel, Azores, Portugal © José Brilha

Dramatic structural changes to the Halemaumau crater and summit region, Kilauea caldera, Hawai'i, August 2018 © U.S. Geological Survey

6.1 Application of criterion (viii) to volcanic theme nominations

Criterion (viii) was written generally enough to encompass the wide range of geological heritage that might be considered for inclusion on the World Heritage List:

Criterion (viii): be outstanding examples representing major stages of Earth's history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features

Most geological themes encompass millions or billions of years of Earth history. Volcanic sites, by their nature, only preserve the most recent geological time frames. Active volcanoes encompass the last 11,700 years (with activity beginning as early as 2–3 Ma before present) of the 4.56 billion years of Earth history. Our guidance for applying criterion (viii) to consideration of volcanic sites reflects this distinctive attribute by addressing heritage values of cultural and spiritual, biological, aesthetic, and educational values.

We first discuss the development of a checklist to apply the general language of criterion (viii) to provide greater specificity for the volcanic theme. We then present an annotated outline for development of a Global Comparative Analysis for application to the volcanic theme as well as some concluding remarks. We note that in all cases it is advisable for States Parties to seek early advice from UNESCO and IUCN on any specific site they consider may warrant World Heritage status, before beginning work towards a nomination. We also repeat the caveat that in addition to meeting criteria, all sites nominated under criterion (viii) must also meet the relevant conditions of integrity, and requirements for protection and management.

6.1.1 Application of criterion (viii) to the volcanic theme

The classification system described in Section 2 provides the core of the guidance to determine underrepresented plate tectonic settings, regions, and other components described above.

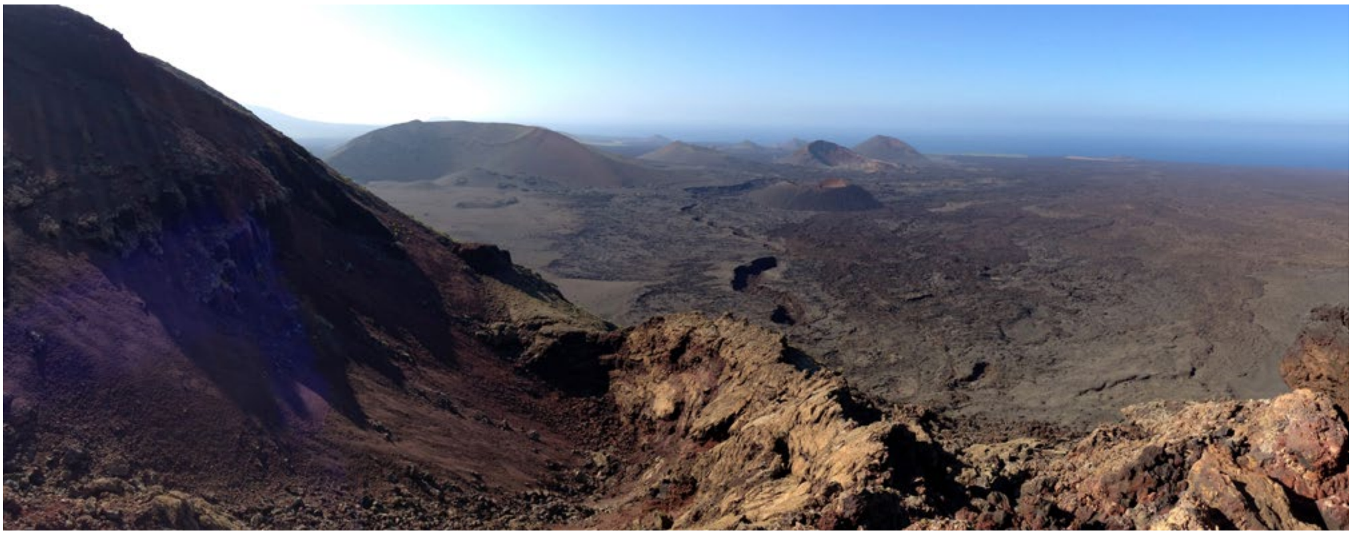
Outstanding Universal Value must be demonstrated on the core geological values, and on whether the nominated property is in an underrepresented plate tectonic category. Once a case for OUV under criterion (viii) is established, States Parties would then consider the secondary components (values) that express the relatively unique role that volcanic heritage plays in cultural, biological, aesthetic, and educational values. These secondary considerations assist in selecting which sites within an underrepresented plate tectonic setting would be the best representative.

The following checklist is inspired by that of Wells (1996). It is intended to be used as a checklist by States Parties and reviewers of nominations for inscription on the World Heritage List to ensure the range of advice provided in this *Volcanic Thematic Study* is considered.

6.1.2 IUCN volcanic site evaluation checklist under criterion (viii)

Primary considerations of site representation:

1. What tectonic setting does the site represent? Is the setting currently underrepresented on the World Heritage List?
2. Does the site provide a narrow range of geological values or a broad range of geological values? Prefer a broad range.
3. How unique is the site in providing scientific values; for example, is the site a 'type locality' for study or are there similar areas that are alternatives?
4. Is the site the only key location where major scientific advances were (or are) being made that have made a substantial contribution to the understanding of volcanoes and volcanic processes on Earth?



Timanfaya National Park, Lanzarote, Canary Islands, Spain © Thomas Casadevall

5. Are there comparable sites elsewhere that contribute to the understanding of the total 'story' that is also provided by the nominated site?
6. How international is the level of interest in the site?
7. Is the site in a regionally underrepresented area?

Secondary considerations of other heritage value represented by the site:

8. Are there other features of cultural and/or natural value (cultural and spiritual value, biological and ecosystem value, aesthetic value) associated with the site? Are these other features present at a significant level that would provide greater heritage value for the nominated volcanic property compared to other volcanoes in the province? Consider the wording of each potential listing criteria provided in Section 1 of this Thematic Study (Introduction).
9. Does the site provide outstanding educational value and opportunities?

6.1.3 Guidance for global comparative analysis

OUV is a comparative determination; there is no absolute measure that would allow consideration in isolation from all other comparable sites. Determination of the best of the best requires Global Comparative Analysis by States Parties. The Global Comparative Analysis would build on the analysis in this *Volcano Thematic Study*, and consider current representation of the plate tectonic setting and the region on the World Heritage List. A Global Comparative Analysis provides essential information in considering the merits of a site nominated for its volcanic values.

For such an important element of an application, there is little guidance for States Parties. We have prepared desktop reviews of more than 25 nomination applications since 2009 and have identified characteristics of the most effective Global Comparative Analyses. The following is an annotated outline from these studies that we have extended based upon the analysis and advice provided in this *Volcano Thematic Study*.

6.1.4 Annotated outline of global comparative analysis for volcanic properties

We suggest States Parties use the following outline to help them prepare a robust global comparative analysis for their site.

- Define key elements of OUV represented by the site. This description establishes the basis for comparison.
- Consider first a very broad range of volcanic systems that may have any common components to the site. The goal is to demonstrate the work of considering global sites for comparison, regardless of their protected status.
- Identify other areas in the world that share each of the key elements of OUV. For example, consider a site with the elements of OUV that include volcanic shield volcanoes and subsidiary volcanic cones in a rifting environment; extensive sand dunes in a volcanic desert setting; and desert ecosystems with a high degree of biodiversity in a volcanic desert setting. The analysis should identify for comparison other sites with any of the attributes, not only those sites with all of them: shield volcanoes, subsidiary cones, rifting environment, other volcanic sites with extensive sand dunes, and other volcanic sites with desert ecosystems and a high degree of biodiversity.
- Narrow the broad list of sites to those that may have characteristics of OUV comparable to the nominated site.
- Describe each of the sites on the narrow list in a qualitative manner to provide an overview of the features and values at each site. Include common features that can be compared quantitatively across the sites for comparison.
- For each key feature displayed by the nominated property, provide a quantitative ranking of how well expressed that feature

is for each of the sites considered in the Global Comparative Analysis. The method of quantification will vary based upon the key feature, but at a minimum provide a three-level quantification (high-medium-low). Brilha (2016) provides guidance on developing objectives for quantitative analysis, comparison criteria, scoring mechanisms, and providing weighting factors to emphasise those criteria that are most important in the comparison as well as lessons learnt in applying quantitative methods to large and small data populations.

- Identify whether the sites are inscribed on the World Heritage List or are UNESCO Global Geoparks or Biosphere Reserves. All comparable sites on any of these lists must be included in the narrow list for Global Comparative Analysis.
- It is vitally important to show the work, in a technical annex if necessary, of each step of the analysis, starting from the long list of potentially-comparable sites around the world. In this way, reviewers of the nomination can evaluate the quality and comprehensiveness of the Global Comparative Analysis.
- Use the Global Comparative Analysis to rank and evaluate the nominated site in the context of the classification presented in this Volcano Thematic Study.

6.2 Conclusions

UNESCO requested IUCN *"to revisit and update its thematic study on World Heritage Volcanoes to clearly articulate a short and appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List ...* "[8] Based upon our analysis of the World Heritage List, volcanic sites listed for criterion (viii) do not well represent the volcanic geoheritage organised by plate tectonic setting and heritage value. The classification system presented in this Study identifies plate tectonic settings and regions that are underrepresented and emphasises that for the volcanic theme, the geoheritage value is typically entwined with other heritage values including cultural, biological, aesthetic and scientific. The Study emphasises to States Parties and nomination reviewers the importance of these elements in considering future nominations for inscription to the List for the volcanic theme. Section 4.4 presents a list of outstanding volcanic sites to be considered for inscription.

To advise States Parties on nominations for volcanic sites, the Study provides a checklist that extends the clarity of application of criterion (viii) to the volcanic theme. Because a Global Comparative Analysis is central to considerations of representativeness, and of demonstration of Outstanding Universal Value, the Study provides an annotated outline and guidelines for such an analysis, encouraging quantification to the extent supported by the data in the Global Comparative Analysis.

Because the request for this Study specified articulation of a short and appropriately balanced list of the strongest remaining candidates for inscription on the List, candidate sites are listed in Section 4.4. However, these candidate sites are advisory and illustrative; they are by no means pre-approved. It is up to States Parties to consider other factors, including stakeholder support for listing.

8. IUCN Decision 37 COM 8B.15 adopted at its 37th session in Phnom Penh, 2013

Author biographies

Dr Thomas Casadevall has been a Scientist Emeritus with the United States Geological Survey (USGS) in Denver, Colorado, USA since 2008. His scientific interests focus on mineral resources related to volcanic environments; on active volcanism and the related hazards to people and aviation operations; and on geologic heritage with an emphasis on protected volcanic landscapes. He currently leads the US Geoheritage and Geoparks Advisory Group and has undertaken the revision of the IUCN thematic study on World Heritage Volcanoes.

From 1996 to 2008, Tom served in the Office of the Director, USGS with terms as Regional Director for the Western Region (1996–1997), as Acting Director of the USGS (1998), as Deputy Director (1999–2000) and as Regional Director, Central Region (2000–2008). From 1978 to 1996 he worked as a geologist with the USGS Volcano Hazards Program while stationed at the Hawaiian Volcano Observatory, the Cascades Volcano Observatory, the Alaskan Volcano Observatory and in Denver, Colorado. From 1989 to 1996 he led the USGS project 'Volcanic Hazards and Aviation Safety'. From 1985 to 1988 he was Advisory Volcanologist to the Volcanological Survey of Indonesia and resided in Java, Indonesia. In 1977–1978 he taught geology of volcanic environments at the Escuela Politecnica Nacional in Quito, Ecuador. From 1969–1972 he worked as a mineral exploration geologist with the Bear Creek Mining Company and from 1972 to 1974 as a production geologist for the Sunnyside Gold Mine in Silverton, Colorado.

Dr Casadevall holds an M.A. (1974) in Geology and a Ph.D. (1976) in Geochemistry from the Pennsylvania State University. He holds a B.A. (1969) from Beloit College in Anthropology and Geology.

Role on the *Volcano Thematic Study*: Dr Casadevall led the *Volcano Thematic Study* team and was the direct report to IUCN on the project. He gathered the team and worked with the members to develop the objectives and scope of the study, prepare summary discussions of the World Network of Biosphere Reserves, work with the team on all phases of the study and lead the extensive outreach programme to professional societies, IUCN and numerous groups dedicated to preserving geoheritage. One result of these discussions and engagements was the establishment of the IAVCEI Commission on Protected Volcanic Landscapes in 2015. He carried out our expert consultations through a combination of site visits to existing protected volcanic areas (National Parks, World Heritage sites, UNESCO Global Geoparks and Biosphere Reserves, correspondence with regional experts, participation in several regional meetings focused on protected volcanic landscapes – particularly in Asia and Europe – and though pro-active solicitation of opinions and perspectives. He also presented several invited talks about the revision of the *Volcano Thematic Study* at scientific meetings in Europe, Asia and the Americas.

Dr Dan Tormey is President of Catalyst Environmental Solutions Corporation, an environmental consultancy in the USA. He has a Ph.D. in Geology and Geochemistry from MIT and a B.S. in Civil Engineering and Geology from Stanford. Dr. Tormey's graduate work included experimental petrology of mid-ocean ridge basalts, mapping of subvolcanic intrusions in eastern Iceland, and extensive mapping, sampling, analysis, and interpretation of Andean volcanoes from the Atacama Desert to Patagonia, and particularly in central Chile. Dr Tormey has worked on behalf of IUCN in world heritage since 2009, having conducted 24 desktop reviews of nominations from States Parties to the World Heritage List, and one field mission. In addition to co-authoring this *Volcano Thematic Study*, Dr Tormey is also co-author on IUCN and WCPA's *Best Practice Guidelines on Geoheritage Conservation in Protected Areas* to be published in 2019. Dr Tormey actively pursues volcanology research around the world, including submarine systems, as well as terrestrial systems in the USA, Italy, Armenia, Georgia, Indonesia, the Philippines and more than 30 years in the Andes of South America.

His research spans geology and geochemistry; interactions between geophysical variables that affect risk assessment, risk preparedness and contingency planning; community outreach, education and communication; relations between geodiversity and biodiversity; and geoheritage. Dr Tormey is an expert in environmental policy and environmental impact assessment of energy, water and land management issues, including evolving strategies for climate change adaptation action plans. He was named by the National Academy of Sciences to the Science Advisory Board for Giant Sequoia National Monument; to the California Council on Science and Technology for issues related to hydraulic fracturing; is a Distinguished Lecturer and recipient of the award for Environmental and Social Responsibility for the Society of Petroleum Engineers; is lead scientist for Cruz del Sur, an emergency response and contingency planning organisation in Chile; was an Executive in Residence at California Polytechnic University San Luis Obispo; is a Fellow of the Explorers Club; and is a Professional Geologist in California.

Role on the *Volcano Thematic Study*: Dr Tormey served as the principal writer of the *Volcano Thematic Study* and prepared posters and abstracts in support of the expert solicitation process. He developed the classification system, provided gap analysis, developed guidance to States Parties on the extension of the use of criterion (viii) to volcanic sites, and developed the Global Comparative Analysis guidance. He worked with the team to develop the objectives and scope of the study, and prepared summary discussions of UNESCO Global Geoparks.

Dr Jessica Roberts was educated in the UK, receiving her Bachelor's degree in Applied Geography from Bournemouth University and her Master's degree in Geological Hazard Assessment from the University of Portsmouth. Her Ph.D. from the University of York, focused on Galeras volcano in Colombia, exploring how indigenous values of volcanic landscapes can be used to inform volcanic risk management practices. Jessica has also carried out field studies of active volcanic systems in Iceland, Italy and Dominica. She currently works as a freelance environmental social science consultant and lecturer, working to better understand the interface between society and their environment.

Role on the *Volcano Thematic Study*: For the initial IUCN World Heritage Volcano study (Wood, 2009) Dr Roberts was the research assistant who compiled and analysed data about the World Heritage Volcanoes. For the current report she once again served as the data master to update data tables for World Heritage sites and add volcanic sites found in biosphere reserves and Global Geoparks. Dr Roberts also participated in the literature review for our iconic volcano discussions, helped guide discussions on how to catalogue volcanic geoheritage and worked to re-frame and orient the present study as it evolved from the earlier IUCN report (Wood, 2009).

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Annex I. Methods used in conducting the *Volcano Thematic Study*

Methods for preparing the revised edition of the Volcano Thematic Study

To address the remit from IUCN to ***" … revisit and update its thematic study on 'World Heritage Volcanoes'" to clearly articulate a short and appropriately balanced list of the strongest remaining volcanic sites with potential for inscription on the World Heritage List … "*** we followed a stepwise process starting with an inventory of all World Heritage volcanic properties, World Network of Biosphere Reserves and UNESCO Global Geoparks. Our inventory database was prepared using Excel software that could be expanded and easily updated as new information became available and as we added additional fields to assist in our analysis. The current inventory database contains more than 11,000 data fields for the four principal categories of the inventory. These are: World Heritage sites with volcanic features, World Heritage sites listed on the World Heritage Tentative List as of April 2018; Biosphere Reserves; and UNESCO Global Geoparks.

The inventory included each site's attributes, including country, name, location, listing criteria, tectonic setting, other values represented (including scientific value) and comments. We linked the inventory to the Smithsonian Global Volcanism Program (http://volcano.si.edu/) database of Holocene volcanoes with record of eruptions within the last 11,700 years and Pleistocene volcanoes with records of eruptions dating back 2.5 million years. This inventory formed the database for our analysis.

In parallel with the inventory, we evaluated the taxonomic basis for classifying the World Heritage volcanic properties. In the original *World Heritage Volcanoes* thematic study, Wood (2009) relied primarily on the geomorphic expression of the volcanic feature (the landform) as the primary basis for classification. This was supplemented by using several secondary considerations including eruption type, tectonic setting, chemical composition of eruptive products and plate tectonic setting.

Following our deliberations and consultations with our geological colleagues, we decided to make **plate tectonic setting** the primary factor in classifying the World Heritage volcanic properties (Perfit & Davidson, 2000; LaFemina, 2015; Seibert et al., 2015). Plate tectonic setting met our requirements of being neither too narrow (as was a landform-type classification system) nor too broad (genetic systems). Plate tectonic setting, however, provides an organising principle that is readily understood, easy to communicate on maps and graphics, and neither too broad nor too narrow. Plate tectonic setting is an organising principle that is based upon scientific value; plate tectonics is the result a scientific revolution that completely transformed how geologists consider the dynamic Earth, and volcanism is the visible evidence for many plate boundaries. As the primary classification component for volcanic World Heritage, plate tectonic setting is certainly memorable and educational.

Additional heritage values, including consideration of scientific importance, cultural/spiritual, ecosystem importance and aesthetic considerations, were also considered as secondary factors in aiding our evaluation of the 'representativeness' of a given property. In general, the primary classification component of plate tectonic setting provides a measure of which areas remain underrepresented on the List while the heritage values (including scientific heritage) enhance selection of properties that are the best of the best volcanic terrains.

In addition to preparing an inventory for all World Heritage-inscribed properties, we also considered properties on the **Tentative Lists** identified by Member States for possible future nomination.

Inventory of all World Heritage properties

Our first step in preparing an updated thematic study was to assemble an inventory of all World Heritage properties inscribed through 2017. This required us to review all World Heritage properties where volcanoes as well as volcanic rocks and volcanic structures were found. This process resulted in a slight expansion of the list compared to the one prepared for the original Wood (2009) study.

Sites with multiple volcanic vents and eruptive centers

While several World Heritage volcano properties have a single volcano or volcanic edifice as its focus, many volcanic World Heritage properties host more than one volcano, or volcanic systems with multiple volcanoes, such as Hawai'i Volcanoes National Park (USA), which contains three active volcanoes and was inscribed in 1987 for criterion (viii). In our inventory, if a property contains 'clusters' consisting of more than one Holocene volcano such as Tongariro (New Zealand), Kamchatka (Russian Federation), Galápagos (Ecuador), Hawai'i (USA), Aeolian Islands (Italy) and Virunga (Rwanda), we group these as a single volcanic property. In addition, properties composed of multiple 'monogenetic' volcanic centers such as Grand Canyon (USA), Pinacate (Mexico) and Pico Azores (Portugal) are likewise identified as a single volcanic center.

Change in the Smithsonian system of Volcano Number identification

In the original *World Heritage Volcanoes study*, Wood (2009) used an earlier system of volcano numbers to identify volcanic systems in World Heritage properties. In 2013, the Smithsonian's GVP announced new and permanent unique identifiers (Volcano Numbers, or VNums) for volcanoes documented in the **Volcanoes of the World (VOTW) database** maintained by GVP and accessible at www.volcano.si.edu. In this revision of the *Volcano Thematic Study*, we have used the new and permanent unique identifiers established by the Smithsonian as the authoritative system for volcanic site identification.

The International Association for Volcanology and Chemistry of Earth's Interior (IAVCEI), The World Organization of Volcano Observatories (WOVO) and the Global Volcano Model (GVM) have sanctioned the Smithsonian GVP to assign official names and numbers to the world's volcanoes. The purpose of the numbers is to prevent ambiguity regarding the name and location of volcanoes that may have non-unique names or that are known by multiple names. The original VNums were based on a system developed in the 1950s for the IAVCEI Catalog of Active Volcanoes of the World (CAVW). GVP policy had been to embed significant geographical, historical and age information within the numbers. As a result, GVP often changed VNums, most frequently to accommodate newly-recognised volcanoes in a particular geographical region, which over time undermined the goal of preventing ambiguity.

After moving VOTW to a new database platform, the Smithsonian programme developed a new VNum system. During this process GVP staff considered the needs of the International Civil Aviation Organization (ICAO) and other stakeholders who wished to have numbers compatible with modern computing systems. Holocene, Pleistocene and Tertiary volcanoes all fall under the new, unified numbering system, allowing interoperability between VOTW and new databases under development globally (e.g., WOVOdat, LaMEVE). Letters and characters (hyphens and equals signs) have been eliminated. Secondary numbers have been added to designate subfeatures associated with each volcano. None of the new numbers start with 0 or 1 to avoid confusion with the legacy system. While a connection remains to the previous system, the geographic link to CAVW regions and subregions is no longer mandatory (volcano.si.edu/gvp_vnums.cfm).

Holocene volcanoes

More than half of the properties containing World Heritage volcanoes' host a record of volcanic activity from the Holocene geological period and can be found in the catalogue of the Smithsonian Global Volcanism Program. The Smithsonian database assigns a unique Volcano Number – a six-digit identifier – to each Holocene volcano in a World Heritage volcanic property.

For sites with Holocene volcanic activity, this process of assigning a Volcano Number was clear cut. However, the list of World Heritage volcanic properties also includes a small number of locales that host pre-Holocene volcanic activity, including Iguazu (Brazil and Argentina) and the western Ghats (India), and therefore have no corresponding Volcano Number.

World Heritage selection criteria

One challenge we faced in conducting this study was defining what constitutes a 'volcanic site'. We therefore developed the following five categories of volcanic features that establish what one is.

Categories of volcanic features considered in this review of volcanic sites:

1. Holocene volcanoes: active with eruptions in the past 11,700 years (Holocene period); Smithsonian Global Volcanism Program database currently contains 1,443 volcanoes with eruptions during the Holocene period.
2. Pleistocene volcanoes (extinct volcanoes): volcanoes with no record of Holocene activity; with well-preserved morphology (Pleistocene); approximately the past 2.5 million years. The Smithsonian Global Volcanism Program database currently contains 1,236 volcanoes with activity during the Pleistocene period.
3. Eroded volcanoes (roots of volcanoes): included pre-Pleistocene eroded features such as dikes, sills, neck, laccoliths. Forming foundations or roots of volcanoes, calderas, volcanic rift systems, oceanic spreading centers, seamounts, etc.
4. Volcanic rocks: including lavas, tuffs, ash fall deposits, etc. which are closely linked to cultural sites.
5. Volcanic rocks in a stratigraphic section or sequence: generally, not considered in this inventory unless important in cultural history, the history of science, or of unusual aesthetic value.

World Heritage properties are nominated for inscription based on sites having Outstanding Universal Value (OUV) for at least one out of ten criteria. Criteria (i) to (vi) are traditionally grouped as cultural criteria. Criteria (vii) to (x) are grouped as natural criteria. Criterion (viii) is often referred to as the "geological criterion" (Dingwall et al., 2005).

In our inventory database of World Heritage volcanic properties, we indicate the selection criteria for which the property was inscribed (http://whc.unesco.org), the year each property was inscribed and the country and geopolitical region of the Member State (See Table of World Heritage volcanic properties). Our inventory included not only sites inscribed for criterion (viii) but for all World Heritage criteria: cultural (i) to (vi) as well as natural (vii) to (x). In some cases the inclusion of a specific volcanic site was clear; for example, Mount Etna (Italy), which was inscribed in 2014 for criterion (viii). In other cases the volcanic feature(s) may not have even been mentioned in the inscription dossier, such as occurred for the Grand Canyon (USA), where the criteria were applied to the unique

Table 5: Important volcanic sites currently listed on the World Heritage Tentative List

Country	Property Name	Year Listed	Criteria	Comments
Latin America				
Argentina	La Payunia, Llancanelo y Payun Matru	2011	(vii), (viii)	back arc, caldera (Malargue)
Guatemala	Atitlan caldera	2002	(viii)	caldera / Los Chicayos tuff
Nicaragua	Volcan Masaya	1995	(viii)	caldera / shield volcano
Asia and Pacific (including Pacific Coast of Russian Fed.)				
China	Wudalianchi Scenic Spots	2001	(viii), (ix)	monogenetic field
China	Yandang Mount	2001	mixed	Cretaceous volcanism
China	Volcanic landscape, Changbai Mt.	2017	(vii), (viii), (ix), (x)	important caldera / bndy DROK
DROK	Mount Chilbo	2000	(vii), (viii), (ix)	Paekdu Vol. Zone
Japan	no volcanoes for viii			
Russian Fed.	Commander Islands	2005	(vii), (viii), (ix), (x)	extinct volcanoes; submarine volcanic ridge; already Biosphere Reserve
Indonesia	Banda Islands	2015	(iv), (vi), (x)	Holocene, archipelago
Philippines	Mayon Volcano Natural Park	2015	(vii), (x)	Holocene, 273030; named Bio. Reserve in 2016
Philippines	Mount Malindang Range Natural Park	2006	(vii), (ix), (x)	Holocene, 271071
New Zealand	Auckland Volcanic Fields	2007	(ii), (iii), (iv), (v), (viii)	Holocene, classic monogenetic field
New Zealand	Kermadec Islands and Marine Reserve 2007	2007	(vii), (viii), (ix), (x)	Holocene, submarine features
North America				
United States	no volcanos or volcanic features			
Mexico	no volcanos or volcanic features			
North Atlantic and Europe				
Iceland	Thingvellir National Park	2011	(vii), (viii), (ix), (x)	
Iceland	Myvatn and Laxa	2011	(viii), (ix), (x)	
Iceland	Torfajokull Volcanic System	2013	(vii), (viii)	
Iceland	Vatnajökull	2011	(vii), (viii), (ix)	
Greece	Petrified Forest of Lesvos	2014	(iv), (vii), (viii), (x)	a UNESCO Global Geopark
Africa and Arab states				
Kenya	Hell's Gate National Park	2010	(viii)	Suswa volcano

record of geological time preserved in the stratigraphic section exposed in the canyon walls but not to the Holocene Uinkaret volcanic field also present within the national park boundaries.

A significant number of World Heritage properties with important volcanic values have been inscribed for cultural criteria alone, such as Thingvellir (Iceland) and Fujisan (Japan). It could easily have been argued that these sites could have also been inscribed for criterion (viii). (In fact, Thingvellir National Park is currently listed on the Tentative List for Iceland for inscription under criteria (vii) to (x)).

An additional area where we had to use our judgment was for World Heritage properties which were located on the flanks of or near to major "iconic" or famous volcanoes. For example, the colonial historical centers in Puebla (Mexico), Antigua (Guatemala), Quito (Ecuador), Arequipa (Peru), and Pompeii – Vesuvius (Italy) are located directly adjacent to major Holocene volcanoes. While these "proximal" volcanoes do not form part of the "footprints" of these properties, they are significant elements of the cultural and natural landscapes for these properties and are therefore included in our inventory.

For sites such as Joya de Ceren (El Salvador) and Leon Viejo (Nicaragua), volcanic eruptive products display a direct and unique role in the preservation of the site and follow the requirement of criterion (iii) *".. to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living, or which has disappeared."* Similarly, these sites are included in our inventory.

Meetings:

Yogyakarta – IAVCEI COV	8 September 2014
Prague – IUGG	June 2015
Iceland – ProGEO	September 2015
Spain, Volcandpark II	December 2015
Jeju – Jeju Forum, Republic of Korea	May 2016
Puerto Varas – IAVCEI COV-9	November 2016
Portland – IAVCEI Assembly	August 2017
Naples – COV-10	September 2018

IAVCEI Commission on Protected Volcanic Landscapes – established 2015

Seminars, field visits, on-site discussions:

Batur Global Geopark	September 2014
Iceland Volcanological Agency	September 2015
Reykeyanes and Katla Geoparks	September 2015
Geological Survey of Spain	December 2015
Lanzarote Global Geopark	December 2015
Wudalianchi Global Geopark	May 2016
Azores Global Geopark	June 2016
Kutral-kura Aspiring Geopark, Chile	November 2016
USGS CVO, HVO observatory seminars	2015, 2016, 2017
IUCN WCPA Geoheritage Specialist Group, Vilm, Germany	April 2018
UNESCO Global Geopark Conference, Italy	September 2018
SUGeo (Mexican Geopark Coordinating Body), Mexico City	January 2019
University of Rhode Island Graduate School of Oceanography	April 2019
Woods Hole Oceanographic Institution, Massachusetts	April 2019

Universities – invited lectures on Protected Volcanic Landscapes:

Minho, Portugal	June 2016
Geneva	November 2017
Colorado	February 2018

In a similar fashion, several remote oceanic island sites listed primarily for their cultural and or biological/ecosystem values are included in our inventory as these islands are in fact the tops of sea mounts which trace the position of oceanic rifts and are in fact the tops of seafloor volcanoes. These oceanic islands are of pre-Holocene age (older than 11,700 years). But without these sea mount – volcanoes there would be no fringing coral reefs with associated cultural and natural features.

Tectonic classification of Holocene and older volcanoes

In this revision of the Study, we have adopted plate tectonic setting as our primary taxonomic method for assessing how representative a World Heritage volcano property is. In our review of World Heritage volcano properties, we have relied on the Smithsonian GVP database**,** which lists the tectonic setting of each Holocene and Pleistocene volcano. We have also used the map in Simkin et al., (2006) to verify the assigned tectonic setting.

For geologically older World Heritage volcano properties, we have made assignments of tectonic setting based upon our experience with the area or the literature, or we have refrained from making such assignments if we did not have enough information. For example, for the Air Tenere (Niger), Giant's Causeway (UK) and Takhte-Soleyman (Iran) World Heritage properties we have refrained from assigning a tectonic setting for this reason.

Graphical presentation of tectonic setting

For comparative and illustrative purposes, we have elected to use the widely accepted triangular diagram (ternary diagram) developed by Perfit & Davidson (2000) to display where the various Holocene volcanoes fit in a graphical portrayal of their tectonic setting. In their original use of this diagram, Perfit & Davidson (2000) plotted magma chemistry for a selection of volcanoes in a variety of tectonic settings. We have chosen to plot specific examples on the diagram to illustrate the general relationship between the World Heritage volcano properties and their tectonic settings. The placement of each example was made using our best judgment and has been confirmed through discussion with Dr Michael Perfit (personal communication, 2017).

Our primary focus is on using the ternary diagram to aid in identifying where a 'gap' might occur in the representation of a potential World Heritage volcano.

Regional distribution

In our inventory of World Heritage volcano properties, we have assigned a geographical region for each property based upon a slightly modified scheme of the UN Regional Groups, which include:

- Africa and Arab states
- Asia-Pacific (including the Kamchatka and Aleutian volcanoes) and Oceania
- Latin America and Caribbean
- Europe
- North America

Gap analysis

In addition to mapping World Heritage volcano properties according to their tectonic settings, we have used a second criteria – regional distribution of World Heritage volcano properties – to identify where a potential gap in coverage might exist. When taken together, the combination of tectonic setting and geopolitical region offer a first-order view of where World Heritage volcano properties occur and where possible gaps in their distribution exist. This allows us to identify a "… short and appropriately balanced list of the strongest remaining volcanic sites …" as requested in our remit for this revision.

World Heritage Tentative Lists

We followed the practice of Wood (2009) by also including an inventory of volcano properties listed in the World Heritage Tentative List (http://whc.unesco.org/en/tentativelists/). The current Tentative List contains 19 properties of high-quality volcanic areas, including 15 to be inscribed under criterion (viii), including several sites which would fill gaps in the World Heritage List. We applied the same categories in our inventory of the Tentative List volcano properties as we did for the inscribed properties (Table 4).

Expert consultation

An important part of the process we used in preparing this report was to engage the Global community of volcano scientists in a series of "expert consultations" to ensure that we rigorously covered the key volcanoes, volcanic features, and volcanic landscapes of the various regions of the globe. This engagement had the added benefit of bringing the concepts of geoconservation of volcanic landscapes to a broad global audience not accustomed to thinking about the protection of volcanic landscapes. One result of these discussions and engagements was the establishment of the IAVCEI Commission on Protected Volcanic Landscapes, established in 2015.

We carried out our expert consultations through a combination of site visits to existing protected volcanic areas (National Parks, World Heritage sites, UNESCO Global Geoparks, and Biosphere Reserves), correspondence with regional experts, participation in several regional meetings focused on protected volcanic landscapes – particularly in Asia and Europe – and though pro-active solicitation of opinions and perspectives. We presented several invited talks about the revision of the VTS at scientific meetings in Europe, Asia, and the Americas.

We relied principally on the Smithsonian Institution Global Volcanism Program as the authoritative source of information (location, eruptive history, tectonic setting, and physical volcanology) about Holocene and pre-Holocene volcanoes and volcanic areas. Prior to this study, the Smithsonian Global Volcanism Program Database did not include mention of landscape protection and conservation affecting the world's important volcanic resources. Because of this study, the Smithsonian GVP has agreed to include mention of how and under what auspices the world's important volcanic landscapes are protected and conserved.

Consultations and discussions including presentation of progress and results as our work proceeded. A partial listing of meetings, seminars, field visits and invited lectures is contained in Table XXX.

Volcano Thematic Study team:

To carry out this work, the team has conducted numerous phone conference calls, email exchange, and several face-to-face meetings (below) since constituted in 2015.

April 2016	(Jessica, Dan, and Tom)
September 2016	(Jessica and Tom)
October 2017	(Dan and Tom)
February 2018	(Jessica and Tom)
March 2018	(Dan and Tom)
December 2018	(Dan and Tom)
April 2019	(Dan and Tom)

Annex II. The *Volcanic Thematic Study* Inventory Database

Background

The inventory database is a key product of the *Volcanic Thematic Study*, a comprehensive, global assessment of protected volcanic geoheritage sites. The Study is the culmination of a two-year process to identify and review sites of volcanic geoheritage conservation around the world. To undertake this task the inventories of three key geoheritage designations were examined: World Heritage, UNESCO Global Geoparks and Biosphere Reserves.

Driving the design of the Study database was an aim to capture the geographic distribution, geological processes and landscape features of each World Heritage volcanic site around the world. Once populated, the amassed database would provide a tool with which the investigating team could undertake a gap analysis of volcanic geoheritage conservation and use to examine the regional distribution of sites and the inventory of characteristics protected by them.

Table 6: Theme – site demographics

Question	Directions for populating the database
Name of Property	Name as listed on the official online list of conservation designation*
Country	Country listed on official site description on official online list of conservation designation*
Region	Region as defined by UN
Name of volcano(es)	Holocene volcanoes only Name as listed by Smithsonian GVP**
Smithsonian Holocene (active) volcano number	Holocene volcanoes only Volcano Number as listed by Smithsonian GVP**
Longitude	pre-Holocene volcanoes and volcanic features only Longitude as listed by Smithsonian GVP**
Latitude	pre-Holocene volcanoes and volcanic features only Latitude as listed by Smithsonian GVP**
Site description	Key features as listed in site description on official online site of conservation designation*

* World Heritage: www.unesco.org |Global Geoparks: www.unesco.org |Biosphere Reserves: www.unesco.org
** Smithsonian Institution – Global Volcanism Program: https://volcano.si.edu

Table 7: Theme – conservation status

Question	Options	Direction for populating the database
Conservation designation	World Heritage-inscribed UNESCO Global Geopark, Biosphere Reserve	Tick one option only. If the site has more than one designation add an additional row and duplicate the data for each additional designation.
Date of inscription	N/A	Date of inscription as listed on the official online list of conservation designation*
World Heritage sites only		
World Heritage selection criteria	Criteria: (i), (ii), (iii), (iv), (v), (vi), (vii), (viii), (ix), (x)	Using the site information listed on the official online list of World Heritage sites include all criteria site was inscribed for*
Heritage type	Natural, Cultural, Mixed	Using the site information listed on the official online list of World Heritage sites include all criteria site was inscribed for*

* World Heritage: www.unesco.org | Global Geoparks: www.unesco.org | Biosphere Reserves: www.unesco.org

Table 8: Theme: geological processes

Question	Options	Direction for populating the database
Tectonic setting	Convergent subduction zone Backarc basin Collision zone Divergent / rift system Subridge plume / hotspot Intraplate / hotspot Continental flood basalts	Include one option only. Refer to the science literature for guidance including Smithsonian GVP database.
Eruption style	Icelandic Hawaiian Strombolian Vulcanian Plinian Pelean Surtseyan Phreatomagmatic	Include as many options as applicable. Refer to the science literature for guidance.

Table 9: Theme: landform features

Question	Options	Direction for populating the database
Volcanic landform features within the site	Monogenetic fields incl. cinder cones and scoria cones. Maars, tuff rings and diatremes. Polygenetic fields. Calderas. Ignimbrite. Stratovolcanoes. Sector collapse. Shield volcanoes. Lava dome. Lava flow. Lava tube. Glacial. Flood basalt. Hot springs, fumaroles and crater lake. Necks (roots of volcano). Columnar basalt. Roots of caldera. Noteworthy ancient volcanic feature.	Include as many options as applicable. Refer to specialist knowledge, the site description on the official designation website, the Smithsonian GVP website and additional peer-reviewed literature for guidance.

The Study reviews and expands upon an earlier study undertaken by Woods (2009) that focused on meeting the same research aim. However, although a database was constructed for this earlier study, it did not meet the objectives of this updated study and was therefore not used. The original database manager for the 2009 study was however re-recruited for the new study to encourage consistency. Whilst the Wood report focused largely on landform features, it was decided that the revised study would present a taxonomic classification process that would require a more in-depth examination and therefore a greater bank of data points.

The database design process:

The database was designed primarily as a tool for the assessment team to amass the required data and aid in its analysis. Its function was designed to serve three key objectives:

1. To capture the full inventory of the global volcanic geoheritage estate;
2. To facilitate a gap analysis of sites, their history and their characteristics; and
3. To provide the foundations for the development of a public resource tool.

The database was constructed using Microsoft Excel software chosen because of its usability and ubiquity. However, despite these strengths, Excels limitations centre on not having the same ability as other software to offer a real-time editing service that enables multiple users to collaborate on a file at the same time. Therefore one challenge faced by this choice was the generation of a new file with every reiteration of the database that was shared within the team. To mitigate against loss of data or replication of tasks, a rigorous system of file organisation was therefore put into place.

An initial workshop in 2016 attended by all three of the assessors identified the different data fields required for the study. These were then converted into a worksheet that consisted of four key data themes under which several different fields were assigned.

1) Site demographics

Data fields assigned: The name of the property, region, country situated in, names of volcanoes within the site, Smithsonian volcano number, volcano longitude and latitude and a brief description of the site's key features.

2) Conservation status

Data fields assigned: Conservation designations awarded to each site and year of inscription. For World Heritage sites: selection criteria met and whether it was inscribed for its 'Natural', 'Cultural' or 'Mixed' heritage.

3) Geological processes

Data fields assigned: The tectonic setting of each site and the eruption style(s) of any volcano(es) within it.

4) Landform features

Data fields assigned: The different geological landforms located within the boundaries of each site.

A guide for filling each in each data field was devised, either providing direction for where to source the data from or a selection of response options that could be selected, as shown in Tables 1–4.

Populating the database:

The population of the database was undertaken during a series of consecutive phases.

Phase 1:

a) Each of the three authors was assigned one of the three conservation designations: World Heritage, UNESCO Global Geoparks and Biosphere Reserves.

b) Using the criteria listed below, each site was individually evaluated for whether the site qualified to be included in the assessment.

Criteria for inclusion:

i) Site of active volcanism

ii) Site of ancient volcanism

iii) Volcanic features remain, or primarily preserved as strata within a section

The assessors reviewed each site, making their decision based upon their specialist knowledge, site descriptions listed on the UNESCO website, information within the Smithsonian GVP website and additional peer-reviewed literature.

Phase 3:

a) A summary list of the sites was undertaken, including relative data on: volcanoes situated within the sites, tectonic setting, style of eruptions, other heritage values (cultural, biological, aesthetic, and scientific) and volcanic landform features.

b) This initial list was then divided up by region.

c) A two-stage period of peer review and expert elicitation was undertaken.

    I. Each region's list was shared with both a volcanology expert and a geoheritage expert from each region for peer review.

    II. The initial data were also presented at a series of volcano and geoheritage global conferences and working group meetings between workshop one and workshop two to undertake peer review and expert elicitation.

Phase 4:

a) A second week-long workshop was conducted 12 months after the first. This workshop had four key aims:

    1) To re-review the initial list agreed in workshop one, ensuring that all sites fit the criteria set.

    2) To assess all newly inscribed sites for all three designations and add these to the spreadsheet.

    3) To review all feedback gained through the peer-review process.

        i. Re-reviewing sites where necessary; and

        ii. Reviewing additional sites where missed.

b) A second draft of the database was finalised, from which three individual spreadsheet workbooks were created (one for each individual designation).

Output:

The Study database hosts all the data gathered and generated by our comprehensive global assessment of all World Heritage sites, UNESCO Global Geoparks and Biosphere Reserves undertaken during a two-year period.

At this point the database currently comprises:

- One master spreadsheet of all assessment data for all three designations;
- Three individual spreadsheet workbooks – one for each designation; and
- A data bank consisting of:
  - » 218 individual site records inputted (51x data points per site) and
  - » A total of 11,118 individual data points.

Database functionality for user's centres around the following three tasks, all of which have enabled the Study's gap analysis.

a) Site analysis: reviewing all data for individual sites;

b) Frequency analysis: calculating the number of individual sites with shared characteristics; and

c) Regional analysis: Regional comparison of site numbers and characteristics.

Future development and recommendations:

The Study database should be updated at regular intervals to ensure that all new sites and expansions are reviewed and their data included. Amendments should also be made to capture any sites whose status has been rescinded. This will facilitate future gap analyses and utilization of the database as a tool to answer additional research questions.

The design of the database and the methodology for populating it can also be applied for non-volcanic geoheritage such as cave and karst, although the list of landforms would need to be altered.

Although the Study database was initially designed as a research tool specifically for this *Volcano Thematic Study*, Its design can easily be adapted into a practical learning tool for other users if it were to become publicly available. The addition of a series of search tools would be required to implement this.

Annex III. Biosphere Reserves and UNESCO Global Geoparks with volcanic features

Biosphere Reserves and UNESCO Global Geoparks

As part of our effort to consider the state of the world's volcano estate, we also examined the volcano properties included in UNESCO's Biosphere Reserve and geopark programmes. We applied the same categories in our inventory of these conservation programmes as we did for World Heritage properties. (See Table 5 and 6.)

Table 10: Biosphere Reserves with volcanic features

Region	Country	Name of property	Date of inscription / designation	Name of volcano(es)	Smithsonian Holocene Volcano Number	Latitude	Longitude
Europe	Italy	Somma Vesuvio and Miglio d'oro	1997	Vesuvius	211020		
Europe	Portugal	Corvo Island	2007	Monte Gorde	382002		
Europe	Portugal	Graciosa Island	2007	Graciosa	382040		
Europe	Portugal	Flores Island	2009	Flores	382001		
Europe	Portugal	Santana Madeira	2011	Madeira	382120		
Europe	Slovakia	Polana	1990	N/A	N/A	48.65	19.48
Europe	Spain	La Palma (Canary Islands)	1983	La Palma	383010		
Europe	Spain	Lanzarote (Canary Islands)	1993	Timanfaya	383060		
Europe	Spain	Cabo de Gata-Nijar (Canary Islands)	1997	N/A	N/A	36.7	-2.2
Europe	Spain	Isla de El Hierro (Canary Islands)	2000	El Hierro	383020		
Europe	Spain	Gran Canaria (Canary Islands)	2005	N/A	383040		
Europe	Spain	Fuerteventura (Canary Islands)	2009	N/A	383050		
Europe	Spain	La Gomera (Canary Islands)	2012	N/A Shield volcano 3 Ma	N/A	28.11	-17.21

Region	Country	Name of property	Date of inscription / designation	Name of volcano(es)	Smithsonian Holocene Volcano Number	Latitude	Longitude
Europe	Spain	Macizo de Anaga (Canary Islands)	2015	N/A	N/A	28.55	16.20
Europe	Portugal	Fajas de São Jorge (Azores)	2016	Sao Jorge island; Pico da Esperanca	382030		
Europe	Russian Federation	Kronotskiy	1984	Kronotskiy	300200		
Europe	Russian Federation	Commander Islands	2002	N/A	N/A	55.21	166.00
Latin America and the Caribbean	Guadeloupe	Archipel de la Guadeloupe (Caribbean)	1992	La Soufriere	360060		
Latin America and the Caribbean	Chile	Juan Fernandez	1977	N/A	N/A	33.77	-80.77
Latin America and the Caribbean	Chile	Araucarias	1983	Llaima and other stratovolcanoes	357110		
Latin America and the Caribbean	Colombia	Cinturo Andino	1979	Huila and Purace	351050 and 351060		
Latin America and the Caribbean	Costa Rica	Cordillera Volcanica Central	1988	Multiple volcanoes, Poas, Irazu	345040 and 345060		
Latin America and the Caribbean	Ecuador	Archipiélago de Colón (Galápagos)	1984	Fernandina as center point; Multiple active volcanoes are included within this biosphere reserve incl. Pinta, Marchena, Genovesa, Wolf, Ecuador, Darwin, Santiago, Fernandina, Santa Cruz, Santa Fe, Cerro Azul	353010		
Latin America and the Caribbean	Ecuador	Sumaco	2000	Sumaco	352040		
Latin America and the Caribbean	El Salvador	Apaneca-llamatepec	2007	Izalco volcano	343030		

Region	Country	Name of property	Date of inscription / designation	Name of volcano(es)	Smithsonian Holocene Volcano Number	Latitude	Longitude
Latin America and the Caribbean	Nicaragua	Bosawas	1997	Cerro Saslaya, extinct stratovolcano	N/A	14.00	-85.00
Latin America and the Caribbean	Nicaragua	Ometepe	2010	Maderas and Concepcion	344120		
Latin America and the Caribbean	Panama	La Amistad	2000	Baru	346010		
Latin America and the Caribbean	Mexico	El Vizcaino	1993	Las Virgenes	341010		
Latin America and the Caribbean	Mexico	Alto Golfo de California	1993	Pinacate peaks	341001		
Latin America and the Caribbean	Mexico	Islas del Golfo de California	1995	Tortuga	341011		
Latin America and the Caribbean	Mexico	La Primavera	2006	Sierra la Primavera pre-Holocene	341820	20.62	-103.52
Latin America and the Caribbean	Mexico	Volcan Tacana (border of Mexico and Guatemala)	2006	Tacana	341130		
Latin America and the Caribbean	Mexico	Las Volcanes	2010	Popocatépetl and Iztaccihuatl	341090 and 341082		
Africa	Kenya	Mount Kenya	1978	Mount Kenya	N/A	-0.16	37.33
Africa	Kenya	Mount Kulal	1978	Mount Kulal, eroded, extinct volcano	N/A	2.75	36.93
Africa	Kenya	Amboseli	1991	Kilimanjaro	222150		
Africa	Kenya	Mount Elgon	2003	Mount Elgon	N/A	0.85	34.06
Africa	Rwanda	Volcans Biosphere Reserve	1983	Contiguous to Virunga National Park, DRC	N/A	-1.50	29.50
Africa	Sao Tome and Principe	Isla of Principe	2012	Principe (inactive)	N/A	1.60	7.38
Africa	United Republic of Tanzania	Serengeti-Ngorongoro	1981	Ngorongoro	N/A	-3.23	35.48

Region	Country	Name of property	Date of inscription / designation	Name of volcano(es)	Smithsonian Holocene Volcano Number	Latitude	Longitude
Asia and the Pacific	China	Chaingbaishan	1979	Mount Changbaishan	305060		
Asia and the Pacific	China	Wudailianchi	2003	Wudalianchi	305030		
Asia and the Pacific	Democratic People's Republic of Korea	Paekdu	1989	Mount Paekdu	305060		
Asia and the Pacific	Micronesia (Federal States of)	Utwe	2005	Kosrae	N/A	5.28	162.95
Asia and the Pacific	India	Great Nicobar	2013	N/A	N/A	7.05	93.76
Asia and the Pacific	Indonesia	Cibodas	1977	Mount Gede and Mount Pangrango	263060		
Asia and the Pacific	Indonesia	Bromo Tengger Semeru-Arjuno	2015	Tengger, Semeru, Arjuno-Welirang	263300, 263310 and 263290		
Asia and the Pacific	Philippines	Albay	2016	Mayon	273030		
Asia and the Pacific	Indonesia	Balambangan	2016	Kawah Ijen	263350		
Asia and the Pacific	Japan	Mount Hakusan	1980	Mount Hakusan	283050		
Asia and the Pacific	Japan	Shiga Highland	1980	N/A	N/A	36.70	138.46
Asia and the Pacific	Republic of Korea	Jeju	2002	Mount Halla	306040		
North America	USA	Yellowstone National Park	1978	Yellowstone	325010		
North America	USA	Hawaiian Islands	1980	This property has many active volcanoes inc. Kilauea, Mauna Loa and Haleakala	332010, 332020, 332060		
North America	USA	Aleutian Islands	1976 withdrawn 2017	Property has more than 40 volcanoes; Pavlof	312030		
North America	USA	Three Sisters	1976 withdrawn 2017	Three Sisters	322070		
Arab States	Syrian Arab Republic	Lajat	2009	N/A	N/A	32.92	36.55

Region	Country	Name of property	Date of inscription	Name of volcano(es)	Smithsonian Volcano Number	Latitude	Longitude
Europe	Cyprus	Troodos	2015	N/A	N/A	34.97	32.84
Europe	Czech Republic	Bohemian Paradise	2002 (2015)**	N/A	N/A	50.58	15.11
Europe	Hungary	Bakony-Balaton	2012 (2015)**	Tapolca Basin lavas; Pliocene	N/A	46.97	17.92
Europe	Hungary & Slovakia	Novohrad-Nograd	2010 (2015)**	Miocene to Pleistocene	N/A	48.16	19.81
Europe	France	Monts d'Ardeche	2014 (2015)**	Ardeche young volcanoes inc. Jaujac	N/A	44.63	4.25
Europe	Germany	Vulkaneifel	2000 (2015)**	Ulmener maar, Holocene	210010		
Europe	Iceland	Katla	2011 (2015)**	Katla volcano	372030		
Europe	Iceland	Reykjanes	2015	Reykjanes volcano	371020		
Europe	Italy	Sesia Val Grande	2013 (2015)**	N/A	N/A	45.98	8.34
Europe	Greece	Lesvos Island	2004 (2015)**	N/A	N/A	39.20	25.85
Europe	Portugal	Azores	2013 (2015)**	Use Pico as centerpoint for 11 Holocene volcanic centers	382020		
Europe	Spain	Cabo de Gata-Nijar	2005 (2015)**	El Fraile	N/A	36.78	-2.23
Europe	Spain	Lanzarote and Chinijo Islands	2015	Timanfaya	383060		
Europe	Spain	El Hierro	2014 (2015)**	Hierro	383020		
Europe	Turkey	Kula	2013 (2015)**	Kula	213000		
Latin America / Caribbean	Mexico	Comarca Minera	2017	Older volcanic rocks of Trans-Mexican Belt	N/A	20.14	-98.67

Table 11: UNESCO Global Geoparks with volcanic features

For column showing Date of inscription, the two dates and the double asterisks (**) indicate that the property was originally inscribed in Global Geopark Network on the first date (year) and then added to the UNESCO Global Geopark Network in 2015.

Region	Country	Name of property	Date of inscription	Name of volcano(es)	Smithsonian Volcano Number	Latitude	Longitude
Asia and the Pacific	China	Arxan	2017	"35 Quaternary volcanoes" – monogenetic field	305011		
Asia and the Pacific	China	Leiqiong	2006 (2015)**	"38 cones and craters" – monogentic field	275011		
Asia and the Pacific	China	Wudalianchi	2004 (2015)**	Wudalianchi	305030		
Asia and the Pacific	China	Yandangshan	2005 (2015)**	Mount Yandangshan caldera; Cretaceous volcanism	N/A	28.35	121.10
Asia and the Pacific	China	Jingpoho	2006 (2015)**	Jingboho volcano	305040		
Asia and the Pacific	China	Hong Kong	2011 (2015)**	Cretaceous volcanism	N/A	22.35	114.37
Asia and the Pacific	China	Mount Taishan	2006 (2015)**	Paleozoic volcanism	N/A	36.26	117.07
Asia and the Pacific	China	Ningde	2010 (2015)**	Cretaceous volcanism	N/A	26.65	119.52
Asia and the Pacific	Indonesia	Batur	2012 (2015)**	Batur	264010		
Asia and the Pacific	Indonesia	Rinjani-Lombok	2018	Rinjani	264030		
Asia and the Pacific	Japan	Unzen	2009 (2015)**	Unzen	282100		
Asia and the Pacific	Japan	Oki Islands	2013 (2015)**	Oki Dogo shield	283003		
Asia and the Pacific	Japan	Toya Caldera and Usu Volcano	2009 (2015)**	Usu	285030		
Asia and the Pacific	Japan	Aso	2014 (2015)**	Nakadake	282110		
Asia and the Pacific	Japan	Izu Peninsula	2018	Izu-Toba	283010		
Asia and the Pacific	Republic of Korea	Jeju Island	2010 (2015)**	Mount Halla; more than 300 monogenetic vents	306040		
Asia and the Pacific	Republic of Korea	Cheongsong	2017	Cretaceous to Tertiary volcanism	N/A	36.43	129.05
Asia and the Pacific	Republic of Korea	Mudeungsan Area	2018	Cretaceous volcanism	N/A	35.13	126.95
Africa	Republic of Tanzania	Ngorongoro Lengai	2018	Oldonyo Lengai	222120		

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