13 Geomorphosites and volcanism

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Abstract

Geomorphological features or landforms due to volcanism have formed during all phases of the earth's history, and over time erosional processes have modified the original landforms. Volcanic features are in large part constructional but sit on earlier landscapes, which may influence cone-building, ash deposition, and lava flows; for example, existing valleys often control the path of lava flows. A system of classification of landforms due to volcanic processes provides a necessary starting point for any discussion of volcanic geomorphosites, and this needs to be followed by a further classification of the effects of erosional processes through time. As well as their scientific heritage, the values of geomorphosites include their relation to cultural heritage, which may include the history of the geological sciences, human history, and art and literature. Both sets of values, scientific and cultural, should be used when planning management of volcanic geomorphosites, and management must be based also on a good understanding of current erosional processes, and in some areas the possibility of further volcanic activity.

1 Introduction

Not all parts the earth show obvious volcanic regions today, although most have had at least some volcanism in their geological past. For volcanic landforms to survive and be recognisable as geomorphosites, the volcanic activity in most cases must be at least as recent as mid-Cenozoic, and perhaps no more than 30 Ma old. This means that volcanic geomorphosites can be recognised not only in modern volcanic regions, such as plate boundaries, mid-ocean ridges, continental rift valleys and hot spots, but also in areas not commonly recognised as areas of active volcanic activity. Intraplate volcanism, that is volcanic activity within plates and so often found on continents, can be recognised from the mid-Cenozoic through to late Quaternary or even into the Holocene, in areas that may not be thought of as active today (volcanoes are sometimes classified as active, dormant or extinct).

This chapter discusses the classification of volcanic geomorphosites, their assessment, as well as vulnerability and promotion issues related to volcanic landforms.

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2 Geomorphosites due to volcanism

2.1 Classification of volcanic landforms

Most textbooks on volcanoes and volcanism include detailed and often very similar classifications of volcanoes as landforms, based in part on their assumed processes of formation, and in part on their chemical and petrological composition (Table 1). Classifications for lava and ash flows, and ash fall deposits, are also generally similar in most textbooks (see for example Williams & McBirney 1979) (Table 2). Textbooks on volcanoes with a geomorphic approach (e.g. Ollier 1969) provide similar classifications, but also include useful classifications of post-eruption erosional landforms. Thouret (1999) gives a detailed account of the geomorphology of volcanoes, including a discussion of classification and erosional changes over time.

Volcanic landforms are mainly *constructional*, produced by processes, which have built up deposits on pre-existing landscapes. Some are *destructional*, e.g. maar craters formed by phreatomagmatic explosions often extend below the original ground surface, and may expose underlying rock in their inner walls. Calderas are generally destructional, collapsing over subsurface spaces formerly occupied by ascending magma. Erosional processes are responsible for post-eruption landform changes, and a sequence of changes over time (a chronosequence) in

Table 1. A classification of volcanic activity and landforms (based on Ollier 1969 and Gray 2004).

Type	Magma	Flows and explosivity	Landforms
Icelandic	Basic, low viscosity	Thick extensive flows from fissures, weak explosivity	Lava shields and lava plains, with cones along fissures
Hawaiian	Basic, low viscosity	Thin extensive flows from central vents, weak explosivity, but sometimes water-generated phreatic explosions	Broad lava domes and shields, and long lava flows, fed by internal lava tubes, sometimes scattered scoria cones, spatter cones, maar craters and tuff rings, built up by lava fountains i.e. areal volcanic activity
Strombolian	Moderate viscosity; mixed basic and acid	Flows often absent, weak to violent explosivity	Cinder (scoria) cones with shallow craters and short flows; sometimes more extensive lava flows, scattered scoria cones, spatter cones, maar craters and tuff rings, built up by lava fountains i.e. areal volcanic activity
Vulcanian	Acid, viscous	Flows often absent, moderate to violent explosivity	Ash cones, explosion craters
Vesuvian	Acid, viscous	Flows often absent, moderate to violent explosivity	Large cones built up of alternating ash and lava, i.e. stratovolcanoes, extensive ash fall, explosion craters and large collapse calderas
Plinian	Acid, viscous	Flows may be absent, very violent explosivity	Widespread pumice and ash deposits
Pelean	Acid, viscous	Domes and/or short very thick flows, nuées ardentes, moderate explosivity	Domes, spines, ash and pumice cones, ash flows forming ignimbrite plains and plateaus
Krakataun	Acid, viscous	No flows, cataclysmic explosivity	Large explosion caldera

Table 2. Four types of volcanic landforms.

Types of landforms	Landforms and morphogenesis	Examples
Constructional volcanic landforms	(volcanic cones, shields, domes and spines (central, fissure or areal in extent (with or without craters and calderas (large to small in height, and in crater diameter and depth (single or multiple landforms; nested or parasitic (characterised by their shape and slope angle	Paricutín in Mexico, with several cones and craters, steep scoria (cinder) slopes, airfall ash deposits and extensive blocky to aa lava flows (Fig. 1, 2).
Original constructional volcanic landforms affected by subsequent erosion	(erosion by water, wind and ice (Fig. 3) (mass movement including landslides, and mudflows (lahars) (development of radial drainage, and perhaps parasol ribbing and planezes (wind erosion forming yardangs	Exposure of volcanic necks (Le Puy-en- Velay in France), dykes (Ship Rock, New Mexico), and dyke swarms (Iceland) sills (the Whin Sill of Northern England).
Lava flows	(original flow surfaces including pahoehoe and aa flow surfaces (Fig. 2; the names come from Hawaii) (flow ridges and tumuli due to flow pressure, as well as flow collapses (formation of lava channels and lava caves (lava tubes) (tree moulds (pillow lavas when flows enter water or travel over wet ground (flows channelled down valleys (burial of alluvial sediments – buried alluvium deposits containing gold, tin or other minerals are known as deep lead or placer deposits (littoral cones and lava deltas built where flows enter seas and lakes (plateau surfaces formed as streams lateral to flow edges erode valleys, causing inversion of relief (waterfalls at plateau edges, often showing exposures of columnar jointing (extensive and often thick piles of basaltic lava formed from flood basalts, apparently rapidly and catastrophically emplaced (flow landforms, like cones, can be degraded by later weathering and erosion (Fig. 4)	Lava flows of Hawaii, lava deltas of Taveuni Island in Fiji, flood basalts of the Deccan Traps of India. Plateaus, waterfalls, the columnar jointing of Newer Volcanic Province of South-eastern Australia.
Ash falls and ash flows	(airfall mantle bedding (phreatomagmatic base surge deposits (Fig. 3) (ash flows (nuée ardente) (ignimbrite plains and plateaus	Ignimbrite plateaus in the North Island of New Zealand with subsequent spectacular erosional landforms.

Fig. 1. Paricutín volcano in Mexico, part of the Michoacán-Guanajuto monogenetic field, formed by activity between 1943 and 1952, with several cones, a flat grassy ash plain (llano) in the foreground, and partly vegetated lava flows beyond. – Photo: B. Joyce, November 2003.

Fig. 2. Pahoehoe lava flows from Paricutín volcano broken into blocks and collapsing around the partly buried tower of the village church of San Juan Parangaricutiro. – Photo: B. Joyce, November 2003.

Fig. 3. Capelinhos volcano on the northwest coast of Faial, Azores, erupted in 1957 and 1958 and now over two-thirds eroded by the sea, exposing pale ash of the tuff ring formed by the initial Surtseyan submarine eruption, and also late stage lava flows, and nested subaerial scoria cones with a pit crater from the final Strombolian eruptions. Although classified as a Forest Reserve, Site of Communitarian Interest (SIC) and Zone of Special Protection (ZPE) the volcano has unrestricted access and no obligatory paths, and has been affected by "extraction of volcanic ash for construction, riding motor bikes on the flanks of the cone, writing names and phrases by displacing and painting volcanic bombs" (Madeira 2005). Wind and water erosion of the ash surface is visible near the signboard. – Photo: B. Joyce, September 2005.

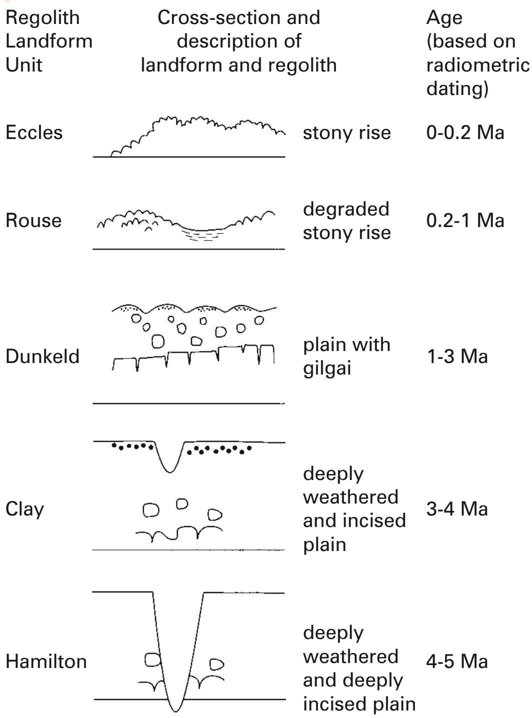

Fig. 4. A chronosequence of regolith landform units on lava flows of the Newer Volcanic Province of South-eastern Australia (Joyce 2005).

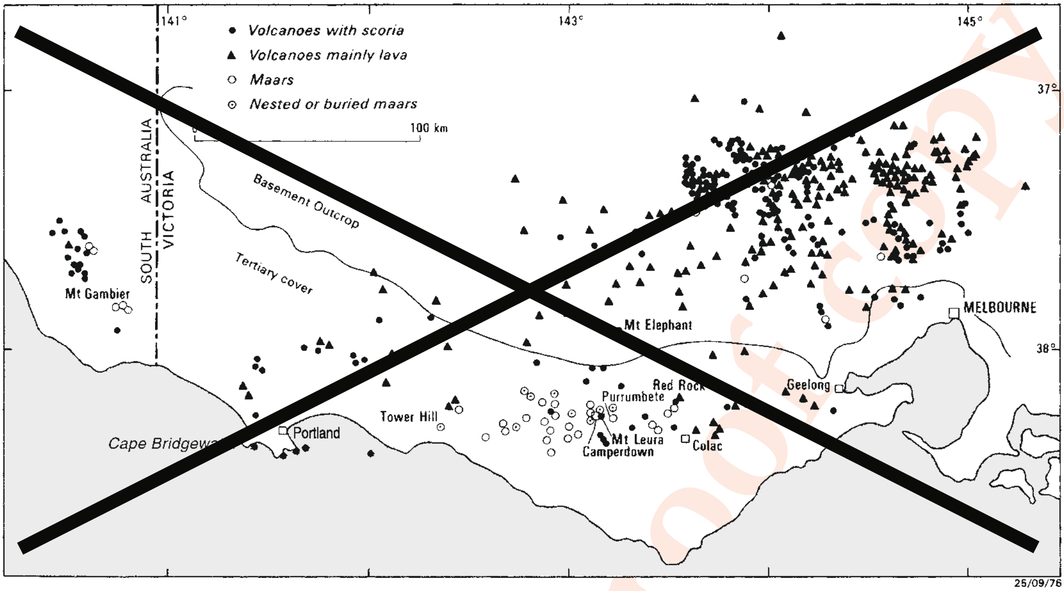

Fig. 5. Distribution by type of the monogenetic areal volcanoes of the Newer Volcanic Province of South-eastern Australia (Joyce 2005).

landforms, weathering, soils and drainage development can be used to estimate the time which has passed since volcanic activity occurred and so help in estimating the possibility of future eruption (Joyce 2005).

A further level of classification of volcanoes and their deposits is provided by the chemical composition of the ascending magma, which directly influences the violence of eruption, and thus the landforms constructed. Magma compositions may range from basalt (basic magma), giving mild eruptions with generally small volcanoes and extensive mobile flows, to rhyolite and andesite (acid magma), giving violent eruptions and over long periods of time constructing large volcanoes, with little lava flow but possibly extensive ash deposits including ignimbrite sheets, and at the eruption points perhaps large collapse calderas.

Two classifications of types of eruptions and related landforms, based on several textbooks, are given in Table 1 and 2.

2.2 A proposal for a classification of volcanic geomorphosites

It can be argued that detailed classifications such as these are not the best way to approach the study and description of volcanic geomorphosites, when the audience may include mostly non-geologists. A simple geological and geomorphological scheme of classification may be better, leaving more scope for discussions of non-geological cultural heritage, including historic, artistic, aesthetic and other values, which may be of equal or greater interest to many of the visitors to geomorphosites. A classification in three main groups of geomorphosites is proposed here.

The classification given earlier of eight types of eruptions (Table 1) is simplified into just two main groupings of *small* and *large* volcanoes, i.e. based on the size of the landform constructed at the eruption point. Small and large volcanoes often have other differences, which can be characterised by the amounts and types of lava and ash produced, which are in turn related to their chemical composition. A third group of *other volcanic landforms* is needed to complete the coverage of volcanic geomorphosites.

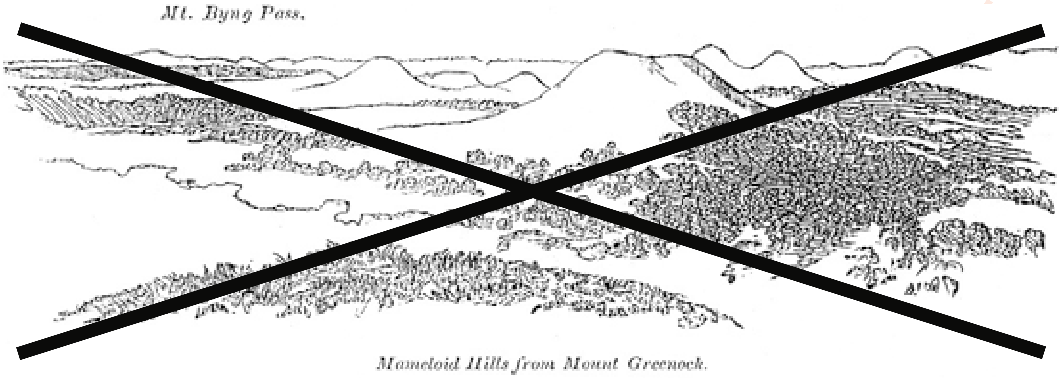

Fig. 6. Scoria cones of the Newer Volcanic Province of South-eastern Australia, sketched by the explorer Mitchell in 1836 (from Mitchell 1838, author's collection).

Small (monogenetic) volcanoes

Numerous small scoria (cinder) cones, characterised by Strombolian/Hawaiian activity, broad but low elevation lava shields, explosive maar craters, and associated and often long basaltic flows, 65 km or longer, following pre-existing slopes and river valleys, are characteristic of monogenetic (single episode of activity) volcanoes. A single magma type, generally basalt, predominates in the activity, which may continue over millions of years, with many short-lived individual volcanoes scattered with a high density across a broad area; the volcanism is often termed "areal" or "polyorifice" to describe the regional distribution (Fig. 5).

Such monogenetic, areal basaltic fields are widely distributed across the World, largely as intraplate volcanism (i.e. volcanism away from plate boundaries). Well-studied examples include the Auckland region of New Zealand, the Eifel area in Germany, the Newer Volcanic Province of South-eastern Australia (Fig. 5), the Auvergne region of South-eastern France, and the Rift Valleys of East Africa and Ethiopia. Other areas include China, Korea, Mexico (Fig. 1), South-west United States, North-eastern Spain, Armenia, Western Hungary and Southern Slovakia. Similar examples of monogenetic volcanic activity can often be found superimposed on areas of current large-scale volcanism, such as Hawaii and Iceland.

An example of a monogenetic, areal basaltic field is the young volcanic region of South-eastern Australia, known as the Newer Volcanic Province. Beginning about 6-7 Ma ago, but mainly since 5 Ma, nearly 400 small, monogenetic scoria cones, maars and lava shields have been built up by Strombolian/Hawaiian eruptions (Nicholls & Joyce 1989, and Fig. 5). Fluid basalt flows have spread laterally around vents, and often for many tens of kilometres down river valleys. Where the lava flows blocked drainage, lakes and swamps have been formed. Phreatic eruptions deposited ash and left deep maar craters, often now with lakes. The youngest dated eruption is that of Mt Gambier in South-eastern South Australia, at 4000-4300 BP. First identified as a volcanic region nearly 170 years ago by the British surveyor, scientist and explorer Major T. L. Mitchell (Morello 1998, and Fig. 6), the Newer Volcanic Province of South-eastern Australia is now one of the best studied of the world's many young basaltic monogenetic areal volcanic fields (Joyce 2005).

Large (strato)volcanoes

Best-known to the general public are the large stratovolcanoes of Vesuvius and Etna in Italy. These high elevation cones are the volcanoes of popular stories and films, and were among the first to be recognised in the 18th Century by early workers such as Sir William Hamilton in 1776. They, thus, have high cultural significance to historians of science, as well as to the general public. Other large stratovolcanoes include Mt St Helens in North America (best known for its activity on the 18th May 1980), Fuji in Japan, Teide on the Canary Island of Tenerife (Fig. 7), Pico in the

Fig. 7. Stratovolcano of Teide-Pico Viejo, island of Tenerife, Canary Islands, rising 3718 m above sea level, with its small summit cone El Pitón, black lava flows on the slopes, exposed dykes (Roques de Garcia) to the right, and the foreground arid ash plain. Writings by von Humboldt in 1814, von Buch in 1836, and Lyell in his major textbook of 1830 have made Tenerife a major part of the history of volcanology. The Teide National Park was inscribed on the World Heritage List in 2007. – Photo: B. Joyce, September 2005.

Azores, and Mt Taranaki (Mt Egmont) in New Zealand. These are large and polygenetic (many episodes of activity) volcanoes, producing successive local flows and ejecta to build stratovolcanic cones of great size over many thousands of years. They are often acidic (rhyolitic and andesitic) in rock composition, but some, such as Etna, Fuji and Pico, are largely basaltic.

Later stage development of a large caldera by subsidence is common in large stratovolcanoes, e.g. Faial in the Azores is 400 m deep but less than 2 km across (Fig. 8), and Aso in Japan is 23 by 16 km (Ollier 1969). Collapse calderas can be associated with major ore deposits including gold. Historic caldera-forming eruptions such as Tambora in 1815, Krakatau in 1883, and Pinatubo in 1991, have had significant but temporary impacts on global climate, with dramatic atmospheric effects such as strange colours and halos around the sun and moon, vivid sunsets and sunrises, and unusually cold weather.

Associated and potentially devastating ash falls and flows from large volcanoes, with the formation of thick and widespread ignimbrite plateaus, are features of the Taupo-Rotorua area of the central North Island of New Zealand (Ollier 1969). Lahars are a major hazard and landform builder in large Indonesian volcanoes. Major geothermal energy resources are associated with such large volcanoes, such as in New Zealand, Italy and Iceland, with major deep faults appearing to have some control over the locations of eruptive centres and other features.

Fig. 8. Stratovolcano of Faial, Azores, rising 1043 m above sea level, with a 1200 year old summit caldera 2 km in diameter, and a younger cone nested on the 400 m deep caldera floor. – Photo: B. Joyce, September 2005.

An example of a large stratovolcano is Teide, on the island of Tenerife, which has recently been added to the World Heritage List (Fig. 7). The Teide National Park includes the major Las Canadas depression and the Teide-Pico Viejo Complex, with lava flows, domes, small cinder cones, necks, dykes and erosional features including extensive debris slopes. Extensive pyroclastic fall, flow and surge deposits occur on the southern side of the island. Small cinder cones and long flows are superimposed on the main structure, which is of mixed composition including trachytic and phonolitic flows.

Shield volcanoes such as those of Hawaii and Iceland are also generally large volcanoes, built up over a long period, but while high in elevation, they have low angle slopes, reflecting their construction by successive basalt flows, rather than the successive flows and ash which build the steeper stratovolcanoes.

Other volcanic landforms

A third group of landforms is needed to complete this simplified classification of volcanic geomorphosites. This group includes modern and recently active submarine mid-ocean ridge volcanoes and seamounts (geomorphosites inaccessible to all but a few exploratory divers). Former mid-ocean ridge landforms can be found well-exposed above sea level on Cyprus, and especially on the World Heritage site of Macquarie Island (Australia). There are also the rare carbonatite flows of Africa and other unusual flows of sulphur. Mud volcanoes occur in Italy, India, Iran, Borneo, and the Lusi mud volcano of East Java is an extensive area, which is currently active.

Mud volcanoes, fumaroles, geysers and hot springs, as in the Rotorua area of New Zealand and in Iceland and Italy, may be sources of geothermal power, and together with moffettes (carbon dioxide vents), for example in the Eifel region of Germany, are often characteristic of the quiescent or dying stages of volcanism, and also can be major hazards to visitors. Hydrothermal ore deposits, including gold, silver, copper and sulphur are particularly associated with the Pacific margin volcanoes of North and South America.

3 The assessment of volcanic geomorphosites

In heritage studies the term *volcanic* includes not only cones, craters and calderas, lava flows, ash flows and ash falls, and the landforms produced by later erosion, but also “crater and caldera lakes, fluvial and lake features due to drainage modification by volcanic activity, (and) dykes, sills and necks exposed by post-volcanic erosion” (Joyce 1995). It includes modern landforms and active processes, but also recognisable ancient or palaeolandforms and evidence of palaeoprocesses. As well as individual geomorphosites, heritage features may include *view points* (lookouts, belvederes) and *landscape* areas, both large and small (Joyce 1995).

Geomorphosites can be assessed in various ways (see discussion in Chapters 5 and 6). In assessing volcanic geomorphosites, a decision must be made about whether a “representative approach” or an “outstanding approach” should be used. When several hundred small cones can be present in a monogenetic lava field, selecting the larger, or more complex volcanoes is a common initial approach (outstanding approach), and then later, after a full inventory has been carried out, a representative approach selecting a number of features is generally used.

Sites are often selected in relation to one or more uses: education, research, reference (as in a type example, e.g. Stromboli, as an eruption type) and recreation/aesthetic (see Joyce 1995). Sites may also have value for their relationship to the history of geology, or as *Classic sites*, such as those first used to study a particular phenomena e.g. the 79 AD eruption of Vesuvius, from which the term “Plinian eruption” has been derived. At Salisbury Crags in Edinburgh, Scotland, James Hutton in the 18th century recognised the rock dolerite as originally molten by its effect on the underlying sedimentary rock (Gray 2004: 28).

In preparing inventories, use should be made of geomorphological mapping (see Chapter 7). Regolith-landform mapping has been used to group eruption points and flows into age groups based on their geomorphology and weathering (Joyce 2005 and Fig. 4). It is generally easy to define the limits of a volcanic region, as volcanic deposits are normally superimposed on a pre-existing landscape and can be readily distinguished on maps and imagery. The boundaries of individual volcanoes and their deposits can also usually be easily mapped.

Finally, both the scientific and cultural heritage of a volcanic geomorphosite must be considered.

An example, which illustrates some of these values is the Giant’s Causeway in Ireland. This is a World Heritage area with excellent exposures of the internal features of basaltic lava flows due to coastal erosion. It is also a classic site for the early historical study of volcanic activity (e.g. Hamilton’s work in 1786), but also has associated myths and legends, and aesthetic values including historic and modern artistic depictions of its volcanic features. There are current problems of degradation due to visitors, and possible hazards to visitors by mass movement, due to the steep cliffs and unstable pathways, which may be used by those visiting the area (See further discussion of the management of the Giant’s Causeway in Chapter 11).

4 Threats to and vulnerability of volcanic geomorphosites

Threats may arise from natural processes – flooding, erosion, burial by mass movement and vegetation growth – or from human activity – destruction of volcanic features by continuing quarrying, road and rail works, degradation (for example of useful quarry exposures by reclamation or closure), burial by tipping, revegetation (i.e. cover by planting), building-over, as towns and cities grow outwards (Joyce 1995).

Problems of quarrying in volcanic landscapes of Ireland, New Zealand and Australia are discussed in Gray (2004: 139), and in the Newer Volcanic Province of South-eastern Australia in Rosengren (1994). A new threat in this area is the rock crushing, rolling and stone raking of flow surfaces by heavy machinery to increase the productivity of farming.

5 Protection and promotion of volcanic geomorphosites

5.1 World Heritage volcanic areas

Some thirteen or more volcanic places are now listed for World Heritage, and most are large stratovolcanoes. Recent additions to the World Heritage List of volcanic areas are Jeju Volcanic Island and Lava Tubes (Republic of Korea), an area of small monogenetic volcanoes, and Teide National Park, Canary Islands (Spain), with a large stratovolcano and caldera (Fig. 7). In 2007, UNESCO noted that "volcanic systems are relatively well represented on the World Heritage List and that there is increasingly limited potential for further inscriptions of volcanic sites on the World Heritage List".

There are obvious difficulties in assessing any new proposal for World Heritage listing if a comparison with similar or related sites has to be made. In the past, UNESCO has relied on the advice of expert assessors, but even these may not have the complete world-wide knowledge required. The use of an indicative list of volcanic areas to assist in future nominations is being considered by World Heritage/UNESCO, and the need for specific indicative lists of volcanic features such as lava caves, which occur across the world (Joyce & Webb 1993), was highlighted in discussions on the recent assessment of the World Heritage nomination of Jeju Volcanic Island and Lava Tubes, Republic of Korea. (See further discussion of the World Heritage List of UNESCO in Chapter 9).

5.2 Geoparks and volcanic regions

Some 48 Geoparks are currently listed by UNESCO, and of these so far only four are volcanic, and mostly small monogenetic volcanoes. The numbers of nominations for geopark status is growing rapidly, and given UNESCO's indication of "increasingly limited potential for further inscriptions of volcanic sites on the World Heritage List" volcanic sites will probably be important in any future Geopark nominations.

Six new volcanic Geoparks have been listed in China, including Wudalianchi, last active in 1721 (Dowling & Newsome 2006: 150). Other recently listed or proposed Global Geoparks with volcanic values include the Giant's Causeway (Ireland), and the Vulcan-Eifel in Germany (Frey et al. 2006.) (see also the general discussion of geoparks in Chapter 11.)

In Australia, the new *Kanawinka Global Geopark* is part of the extensive Newer Volcanic Province of SE Australia. Significant geological features and sites have been documented over many years in the Newer Volcanic Province, including the internationally significant lava caves (Joyce & Webb 1993), and a review of the main eruption points has been documented (Rosengren 1994), sponsored jointly by the Geological Society of Australia and the National Trust (Victoria). The indigenous heritage of the Plains includes a complex of Aboriginal fish and eel traps, and remains of stone houses, constructed in the stony rise flow landscapes of the Mount Eccles volcano. Historic "bluestone" (basalt) houses, bridges, churches and other town buildings, and the many striking stonewalls, help record European post-contact settlement. These cultural features, supported by a detailed geological and geomorphological story, help make the area an ideal candidate for nomination as a Geopark.

The *Llancanelo and Payun Matrú Volcanic Fields* "together with about 800 small mafic volcanoes near Malargüe, Mendoza (Argentina) is one of the volcanic fields on Earth that has the highest density of volcanoes. This field is suggested as a potential candidate for a UNESCO Geopark, one of the first in South America" (Risso et al. 2006).

Geoparks, with their allowable large extent, and associated human and cultural values, fit well with the features of small (monogenetic) volcanic fields. In contrast large (strato) volcanoes are often more localised, and often sparsely settled, and may already be part of a park or reserve, and so fit best with World Heritage requirements. Any analysis of possible World Heritage volcanoes, and possible Global Geopark volcanoes, would probably suggest that this division between large and small volcanoes is a good approach in planning future volcanic heritage reserves.

5.3 Examples of management of volcanic geomorphosites

As with any reserve or site, materials for both visitors and staff are needed, such as books, leaflets, signboards, trails and trail guides, lookouts, museums and displays, and control of visitors to help preserve sites and features (Fig. 3). Continuing research is needed to improve the information available to both staff and visitors. The volcanoes and islands of Hawaii are often described as a natural laboratory, with research strongly supported by government and applied for the benefit of tourists.

Geological and geomorphological mapping of cones, flow surface features and caves (lava tubes), as well as cataloguing and assessment of individual geomorphosites, is a necessary basis for interpretation for geotourism, and evaluation of risk and hazard may also be necessary in potentially active volcanic region. (see Chapters 10 and 12 for a discussion of management and risk/impact/natural hazards.)

Modern volcanic interpretation has benefited greatly from the use of photographs, filming (e.g. the recording of the Paricutín eruptions from their beginning in 1943), video recording, and modern imagery including the Landsat satellite, SIR, and most recently the use of Google World imagery. The pioneering work of Tazieff in the 1940s and 1950s in colour filming allowed the study of eruptions and lava flows in great detail, leading to new theories and greater scientific understanding of volcanic processes, and through television by the general public.

Geremia & Massoli-Novelli (2003) studied the volcanic geomorphosites along the coast of Lipari, an island totally composed of volcanic rock. They related coastal processes to the way the erosion of the volcanic rock has produced striking landforms, including a castle-crowned lava dome, black sand beaches, pumice beaches, open-cast pumice mine sites, obsidian lava flows with well-exposed flow structures, late-Quaternary raised shorelines, and striking cliffs, rock stacks and sea caves. A geological itinerary by boat to study the Island of Lipari is used to demonstrate the coastal geomorphology of volcanic origin. Castaldini et al. (2003) used geomorphological mapping and a DTM to study geomorphological processes in the active mud volcanoes of the "Salse de Nirano" in the Modena Appennines of Italy, and also to provide tourists with interpretive information.

5.4 History and culture in volcanic geomorphosite management

One of the earliest written descriptions was by Pliny who survived the 79 AD eruption of Vesuvius, which destroyed Pompeii, and the earliest known human record of volcanic activity is that of Catel Huyuk where a wall painting of a nearby volcano in eruption has been dated at greater than 8000 years.

The modern science of volcanism can be said to have begun with the detailed descriptive and illustrated work on the current eruptions of Vesuvius published by Sir William Hamilton in 1776. The large active Italian volcanoes, and the small extinct volcanoes of France and Germany, were to pay a significant role in the development of volcanology, including the 18th century controversy between the German Werner and his Neptunists, and the Scot Hutton and his Plutonists. Guettard identified the volcanoes of central France, near Clermont-Ferrand (the Auvergne) in 1752, and in 1765 Desmarest confirmed their volcanic nature, while Humboldt described the Eifel craters in Germany in 1794.

A second geological controversy was over von Buch's theory of 'Craters of Elevation', based initially on his work in the Canary Islands in 1815. Humboldt and many others agreed with this theory, but the Englishman Scrope in 1825 disagreed, as did the Scot Lyell in his important textbook of geology in 1830, a book which influenced many geologists of the time, including Charles Darwin on his South American travels and volcanic studies. Geology as a new science developed in part through volcanic studies, of both active volcanoes such as Vesuvius and Etna by Goethe, Humboldt, von Buch and others, and the numerous extinct but young monogenetic volcanoes, in France by Guettard, Desmarest and Scrope, and Germany by Humboldt. Humboldt also worked in South America, studying active volcanoes in Mexico and the Andes, as later did Darwin in the Galapagos and Pacific, and Dutton in Hawaii, and in 1836 the British explorer Mitchell, drawing on Lyell's 1830 text, was the first to identify recent volcanoes in Australia (see Morello 1998 and Fig. 5). A major reference on the study of the history of volcanology is Sigurdsson (2000).

Cultural aspects of volcanoes and volcanic materials include the use of basalt volcanic rock as building stone in Roman cities such as Basra in Southern Syria, with its large amphitheatre, to the 19th century homesteads and town buildings in Western Victoria, Australia. Pozzolana of the Naples area is a pyroclastic (volcanic ash) deposit which Roman engineers mixed with lime to form a hydraulic cement (i.e. able to set under water) and used for building aqueducts and other structures and buildings. Volcanic ash deposits have provided human shelter in cave and troglodite dwellings such as in Cappadocia, Turkey, and in the less-known villages of Kandovan in Iran (Dowling & Newsome 2006: 83-84). Cultural features, which can be related to volcanic geomorphosites, include towns, castles and churches.

Beyond the Earth, volcanism on other planets can provide a link, which can be used to interest the public in volcanism on the earth. Volcanism has now been identified on the Moon, Mars, Venus, Mercury and moons such as Io and Titan. Studies of the Earth and other planets can lead to discussions of the different tectonic plate histories of the planets, and so their different volcanic histories. The Moon and some planets show basaltic and often small-scale monogenetic volcanoes, and some of the outer moons are believed to have lava flows and ash of sodium and sulphur-rich materials.

Geomorphosites on active volcanoes, and in areas with the risk of future volcanic activity can highlight the strikingly active processes of volcanism, and can in turn be used to highlight the renewable nature of some volcanic deposits!

6 Conclusions

Volcanic geomorphosites have been constructed throughout the earth's history, and modified over time by erosion. Classifying volcanic landforms by their origin, both by volcanic and erosional processes, is a necessary starting point for any discussion of geomorphosites. As well as their scientific heritage, the values of geomorphosites include their relation to cultural heritage, which may include the history of the geological sciences, human history, and art and literature. Scientific values are constantly being reassessed as current volcanic research goes on. So also the cultural heritage of sites may change over time, as new heritage values are recognised. Both scientific and cultural values should influence management of volcanic geomorphosites, and management must also be based on a good understanding of current landscape processes, and also the possibility of renewed volcanic activity.

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