Bocconea 29: 263-278
https://doi.org/10.7320/Bocc29.263
Version of Record published online on 5 August 2021

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Plant life on European volcanoes

Abstract

Poli Marchese, E.: Plant life on European volcanoes. — Bocconea 29: 263-278. 2021. — ISSN: 1120-4060 printed, 2280-3882 online.

The study regards the primary succession on active European volcanoes where the different habitats and substrata are mainly originated by the volcanic activity. Besides those originated by lava flows, there are also particular volcanic habitats as thermal springs, fumaroles, solfataras and cinder cones. The habitats are ecologically different, according to the age of the parent materials, soil and to the surface morphology.
Plants on volcanic areas adapt to different ecological conditions that often may represent the limits of the range of their life.
The available soil or substrata may be given by loose material, called "ejecta" or "pyroclastic material", and lavas set up by blocks, called "aa" lavas, or by slabs, called "pahoehoe" lavas.
On the lava flows the first colonizers are Blue-green Algae and Bacteria thanks to their ability to fix atmospheric nitrogen; this stage is followed by one of Mosses and Lichens that prepares the stage of small herbaceous annuals, while shrubs and trees are establishing only where there is a deeper accumulation of fine material and humus

Key words: plant colonization, European active volcanoes.

Introduction

This work deals with one of the most interesting and striking ecological processes: plant colonization on active volcanoes i.e. the volcanoes which have been active in historical ages (Tazieff 1970; Rittmann A. & Rittmann L. 1976). The study of the plant colonization of barren volcanic substrata is of particular interest considering its significance in the study of the primary successions (Beardsley & Cannon 1930; Smathers & Mueller-Dombois 1974; van der Maarel & al. 1985; Whittaker & al. 1989; Kitayama & Mueller-Dombois 1995).

The primary succession on active volcanoes involves many important biological and ecological phenomena since volcanoes may represent "extreme environments" for plant life. There are many active volcanoes in Europe (Rittmann A. & Rittmann L. 1976; Rosi & al. 2003). Most of them are localized in three large areas: the Mediterranean, the Atlantic and the Turkey region also including the mountains of the Caucasus.

The volcanos of Mediterranean area are located in Italy and in the Aegean sea (Greece). Italy is rich of volcanoes. They are in the area of Neaples (Vesuvius (1281 m), Campi

Flegrei and the island of Ischia); in Sicily (Etna (3330 m), the most active volcano in Europe) and in the sea around Sicily (Stromboli, Lipari, Vulcano and Vulcanello). In Greece they are located in the Aegean archipelago (Santorini (Théra), with its two volcanoes, Paleo-Kaimeni and Nea-Kaimeni, and the volcanic island Nisiros)

In the Atlantic area the active volcanoes are located in Iceland, in the Canary Islands (Spain), in the Azores and in the Cape Verdes Islands (Portugal). In Iceland there are numerous volcanic phenomena, various geysers and fumaroles, the volcano Hekla (1500 m a.s.l.) and the new Surtsey island. In the Canary Islands that constitute a volcanic archipelago, there are three active volcanoes (Pico de Teide, 3715 m) on the island of Tenerife, while the Azores islands include 12 active volcanoes. In Turkey and in the region of the Caucasus there are about 20 active volcanoes.

There are many studies on the vegetation of European volcanoes (Fridriksson 1966, 1975, 1992; Bjarnason 1991; Fridriksson & Magnùsson 1992). Raus (1986, 1988, 1991) studied the vegetation of Icelandic volcanoes, Dimopoulos & al. (2010) the vegetation of Santorini (Thera) while Poli (1979) and Gonzales & al. (1990) studied the vegetation of volcanoes of the Canary Islands. In Italy, studies have been conducted principally on Mt. Vesuvius (Agostini 1975; Mazzoleni & al. 1988; 1989; Mazzoleni & Ricciardi 1993), on Eolian Islands (Ferro & Furnari 1970) and on Mt. Etna (Poli 1965, 1970a, 1970b; Di Benedetto 1983; Poli & al. 1975, 1995; Poli & Grillo 1975, 2000; Del Moral & Poli Marchese 2010).

In this paper I present some aspects of primary succession in different European active volcanoes with the aim to give an outline of the subject.

The data are partially from the literature and partially are personal unpublished data, collected over many years of research on the subject.

Primary succession on active volcanoes

On active volcanoes there are “a wide range of disturbances” and particularly the volcanic eruptions present very extreme disturbances on the earth.

Such disturbances, which vary “in the thickness and extent of deposits” (Walker & Del Moral 2003), are most important for providing surfaces on which primary succession can start.

“Damage severity reaches its highest values with lava, where the surface is completely transformed” (Walker & Del Moral 2003). The new barren volcanic surfaces often are very large, they present extreme habitats that lack of nitrogen and/or organic matter (Walker & Del Moral 2003), it follows that on active volcanoes there are the conditions in which primary successions are starting.

Soil development is more rapid where the surfaces are stable. Water retention is best in cracks and in impermeable lava surfaces.

Factors influencing primary succession

The plant colonization on volcanic barren surfaces is conditioned by both chemical-physical, that are called external factors and biological factors (that are considered internal factors):

1 - External factors

The volcanic activity can give rise to different volcanic substrates, and to different volcanic habitats.

Volcanic substrates – They are highly variable. The material originating from activity of the volcanoes produces substrata that are ecologically different, according to their degree of breakdown and to their surface morphology. These two factors condition each other.

The surface morphology of the volcanic substrates changes as follows:

-“Ejecta”, loose material, also called pyroclastic material or tephra, produced during explosive volcanic activities. This material is classified according to size, as: dust, cinders, ash, sand, lapilli or fragments (Cucuzza Silvestri 1966-67; Rittmann A. & Rittmann L. 1976). As far as plant colonization is concerned sand and lapilli are the most interesting as they are the most widespread.

During the explosive volcanic activity there are often pyroclastic flows particularly intense, combining intense heat with rapid air and soil movement. Primary succession is clearly influenced by all these factors.

-“Lavas”, originated by volcanic effusive activity. The lava flows can have different surface morphologies according to the viscosity, the speed and the regularity of the flows.

The lava surface morphology is uneven, therefore, as many scientists pointed out (cfr. Mazzoleni & al.1989; Bjarnason 1991; Mueller-Dombois 1992), there is a different deep of soil layers on the various surfaces of the rock and in cavities and crevices.

There are: a) lavas in scoriaceous blocks and fragments, called “aa lavas” in the now widely used Hawaian terminology; these appear as a masse of blocks and fragments of various forms and sizes and form very irregular microsurfaces; b) lavas in slabs and compact surfaces called “pahoehoe lavas”, in Hawaian terminology, if they have a continuous surface. They are often made up of smooth compact slabs, piled up together at random and interrupted by fissures of different depth.

The various types of lava flows give rise to different substrates and micro-habitats not only because they break down at different rates and in different ways, but also because a varying quantity of fine material is accumulated on the surface of the rock or in the cavities and crevices.

Surface characteristics determine the rates and trajectories for succession on a local scale. Soil development is more rapid where the surface is stable, fine textured and fertile. In contrast pahoehoe lava and rock outcrops are least fertile, but water retention is best in cracks in pahoehoe lava.

Characteristics of the substrate are also important.

In general, it can be said that the speed of plant colonization and the resulting soil formation largely depend on the looseness of the substrates; they are slowest on the most compact substrata.

Therefore. the plant colonization on “ejecta” is faster than on “aa lavas” and here is faster than on “pahoehoe lavas” (Poli 1970-1971).

The different dynamic stages of the primary succession on active volcanoes are therefore localized on various “microhabitats” according to two ecological gradients: looseness of substrata and deep of soil. They are consequently widespread like a great mosaic.

Age of the lava – Many Authors consider the age of the lava to be one of the most important factors in primary succession (the colonization process) as it imposes limit on the range of species that can colonize the volcanic substrates and also influences their number and development (Léonard 1958-1959). This factor is, however, less important than others, as irregularity of the microrelief, surface morphology, climate. Frequently some lava flows are colonized more quickly than others, that are older but more compact (then more hostile to plant establishment) or than lava flows that are of the same age but subjected to a dryer climate. This often makes it difficult, as Bjarnason (1991) pointed out, to identify the successional patterns.

Volcanic habitats – The effect of secondary volcanic activities give rise to particular habitats in which there are other factors that limit the range of plants that can become established. These potentially limiting factors are: Soil temperature and thermal gradient, at hot springs and fumaroles; Chemical composition of soil, in the solfataras; Exhalation of gases and ejection of material, at the active cones and craters with persistent activity. The plants colonize these different habitats according to ecological gradients.

Climate

Among the environmental factors the climate, and particularly temperature and rainfall have a very important role. They condition the speed of colonization and impose restrictions on the range of species that can colonize.

The climate, in his turn, is regulated by the altitude and latitude and, locally, by the relief, slope and exposition, factors influencing, above all, the microclimate.

Generally, the colonization process is shorter where the climate is more humid. The altitudinal climatic changes represent, for the primary succession, a very important ecological gradient.

b) Biotic factors

There are other important factors influencing plant colonization. They are linked both to the plants themselves and to external factors (Chevennement 1990).

They include:

- *Dispersal* – The species that colonize new lava substrates usually come from nearby. Spores, fruits and seeds are transported by specific agents (wind rain, see, animals, man), according to their characteristics (Poli & Giacomini 1970). Clearly dispersal depends on the action of these agents in each volcanic area (van Leeuwen 1936; Poli & Giacomini 1970).

- *Establishment and Development* – Germination and establishment depend on various genetic properties of the organisms and on ecological conditions and particularly: climate and edaphic factors in the new habitat, factors which also condition the development in the new habitat.

- *Competition and Allelopathy* – The plants that colonize the new volcanic substrata can be in competition with other plants which settle in the same habitat. They some time, due the poor life conditions, are forced to succumb.

Sometime the new colonizing plants are subject to have allelopathy relations with plants linked to the same habitat.

Primary succession

In considering the establishment and development of plant life on volcanic substrates and habitats, there are various aspects to take into account. This process involves a series of biological and ecological phenomena, all of which are remarkably important. Life, after all, has to begin from the beginning on the barren lava substrates, almost in the same extreme conditions as there where when the first living organisms began to populate the earth. Therefore, every volcano represents a new world for plant life to conquer but in this process a large scale destruction is the norm. The adaptation that must be made are often such that new endemic forms may arise; these range from simple ecotypes to genetically distinct entities. For example, the endemic species on the Pico de Teide on the island of Tenerife (Canarian Islands) represent 2/5 of all the flora of this volcano (Poli Marchese 1982).

Lavas – While the physical-chemical breakdown of the lava rocks is taking place and fine material is being deposited on the surface and in the cavities of rocks or in the cracks and crevices between them, the first organisms begin to become established. This promotes the conditions required for the beginning of soil formation.

We can synthetize the different stages of the primary successions as follows:
I stage: bleu green Algae and Bacteria
II stage: Mosses and Lichens
III stage: Nano-Therophytes
IV stage: Hemicryptophytes with some Therophytes
V stage: principally Chamaephytes and Hemicryptophytes
VI stage: Nano-Phanerophytes
VII stage: Phanerophytes

The primary succession begins by means of the more primitive organisms and gradually moves by means of the more evolved organisms up to the settlement from the Phanerophytes. Bjarnason (1991) points out that the different stages are characterized by the interaction of climatic, topographic and biotic factors.

I – Bleu green Algae and Bacteria. The first colonizers of barren lava are blue-green Algae (*Cyanophyta*) and Bacteria, which cover the rock in colonies, often forming a "patina". Their ability to fix atmospheric nitrogen makes them independent of the substrate. On the Etna volcano we observed *Cyanophyta* of the genus *Choroglaeopsis* (Grilli Caiola, Poli Marchese & Caruso 1995). Often the *Cyanophyta* may be accompanied by unicellular eukaryotic Algae; *Chlorophyta* (*Protococcaceae*) and Diatoms were observed by Comes (1887) to be growing on Vesuvius on a lava flow that was just a few years old.

II – Lichens and Mosses. The next stage is characterized by the establishment of other cryptogams: Lichens and Mosses which utilize the first organic substances accumulated on the soil after the decomposition of the first colonizers. Scoriae, fragments and rough edges of rocks are colonized by Lichens, which soon flourish and with the physical-chemical action of their hypotallus help to break down the substrate.

- Lichens: the species with the most important role on "aa" lavas is *Stereocalulon vesuvianum* Pers, whose small, silver grey cushions cover vast areas of lava surfaces. Comes (1887) observed isolated individuals of *Stereocaulon vesuvianum* on lavas of Vesuvius immediately after cooling. This species is largely spread in the Etna (Poli 1970-71) and on many other volcanoes. *S. vesuvianum* is often accompanied by other lichens, including *Candelariella xanthostigma* (Pers) Lett. and *Parmelia conspersa* (Ehrht) Ach., on the 1906 and 1944 lava flows in the Vesuvius (Mazzoleni & al. 1989); seven other species of *Stereocaulon* in the volcano Hekla in Iceland (Bjarnason 1991); *Candelariella vitellina* (Hoffm.) Muell. Arg. on the 1909 lava flow in the volcano Chinyero in the island of Tenerife (Gonzales et al. 1990); the same *Candelariella* with species of the genus *Parmelia* and *Lecanora,* and many other species, on different lava flows in the Etna (Grillo & Caniglia 1988, 1989; Poli Marchese & al. 1995; Poli Marchese & Grillo 2000).

- Mosses: In small rock cavities, where a small amount of soil has accumulated, Mosses become established. They are represented by various genera, including *Bryum*, *Grimmia*, *Tortula*, *Rhacomitrium*. The species *Rhacomitrium lanuginosum* (Hedw.) Brid and *R. canescens* (Hedw.) Brid. cover the lava fields of the volcano Hekla in Iceland in vast carpets (Bjarnason 1991). These two species are also widespread on lavas of the Etna, particularly on the lavas of the northern slopes (Poli Marchese & al. 1995; Privitera & Puglisi 1996; Poli Marchese & Grillo 2000), and in other volcanoes.

Colonies of *Tortella nitida* (Lindb.) Broth. colonize the 1886-70 lava surfaces of the volcano Nea-Kaimeni of Santorini (Raus 1986). On some surfaces, Hepaticae settle among the Mosses.

III. <u>Vascular plants: Nano-Therophytes</u> – In the small amount of humus, made by the colonies of Cryptogams, and sometimes on a moss layer, small herbaceous Vascular plants become establish. There are particularly annual species (dwarf-Therophytes) colonizing the little surfaces between the rocks. This is the first stage of Phanerogamic vegetation which includes communities belonging to the class: *Tuberarietea guttatae* Br. Bl. (1940) 1952; communities, dominated by different species, have been described in areas of Etna (Poli 1970a), Vulcano, in the Aeolian archipelago (Ferro & Furnari 1970), Pantelleria (Brullo & al. 1977), Vesuvius (Mazzoleni & al. 1989) and other volcanoes.

IV. <u>Vascular plants: Hemichryptophytes with some Therophytes</u> – In deep fissures, where there is a greater accumulation of fine material and humus, woody plants, shrubs and trees, peculiar of each volcanic area become established (Poli 1970a).

These different dynamic stages occur on both "aa" and "pahoehoe" lavas, albeit in different ways and in different times (Poli 1970b), but not on "ejecta", where from the first stages, in colonization, higher plants play the most important role.

V. <u>Vascular plants: principally Chamaephytes and Hemichryptophytes</u> –The increase in breakdown and the accumulation of other fine material and humus allow the establishment of other Vascular plants; Phanerogams begin to spread.

Among the vegetation types of this dynamic stage, it is worth mentioning the different plant communities identified on Nea-Kaimeni (Santorini archipelago) by Raus (1986) and in various Italian volcanoes. On Etna there are different plants and, particularly, species of the genus *Rumex* as *Rumex scutatus* L. and, at the highest slopes, *R. aetnensis* C. Presl (Poli 1970-71). Most of these plants belong to the classes *Tuberarietea guttatae* Br. Bl. (1940) 1952 and *Thero-Brachipodietea* Br.-Bl. (1940) 1942. Ferns find place in little rocky crevices and between blocks of rocks. They have been described by Raus (1986) in little rocky crevices of Nea-Kaimeni.

VI and VII. Vascular plants: Nano-Phanerophytes and Phanerophytes – The last stadies of the primary succession are characterized by woody plants: trees and scrubs, of which some are also present on precedent dynamic stages. On Etna, *Genista aetnensis* DC. and *Pinus laricio* Poir. are often present in lava colonization processes (Poli & Grillo 2000).

Generally, on the different geographical areas, the primary succession on volcanoes occurs, how many scientists pointed out, in different ways and at different times.

On prehistoric lavas, where the processes of plant colonization and soil formation are advanced, the vegetation is characterized by a certain stability and maturity even though its physiognomy greatly varies according to the geographical region. In prehistoric soils of Etna, for example, located in the Mediterranean area, the soil is covered by forests up to their altitudinal limit; above there is an altitudinal belt characterized by the thorny chamaephyte endemic species *Astragalus siculus* Raf. (Poli 1965).

This is very different from the vegetation of the prehistoric lavas of other volcanoes, as for example the volcano Hekla in Iceland. On this volcano, located on a geographical area where the plant life is subject to extreme climatic conditions, the prehistoric lavas are extensively covered only by cryptogamic vegetation, where two communities can be distinguished: "*Andreaea-Stereocaulon* formation" on hummocks and "*Rhacomitrium* moss-heath", in depressions in the lava, distributed in such a way as to form a mosaic structure (Bernhardt 1986).

In general, it can be said that the primary successions above outlined takes place in different ways at different rates and involves different plant species according to the geographic area and the history of the local flora.

Other peculiar volcanic habitats

In addition to the different types of lava substrata, how before indicated, particular habitats are present in various volcanic areas; they were produced by secondary volcanic activities. In these habitats the plant colonization is conditioned by specific environmental factors.

They are habitats as: hot springs, fumaroles, solfataras, active craters, new volcanic Islands, as it is under indicated.

In such habitats here are other factors conditioning the plant establishment. Such factors are potentially limiting factors and particularly:

- soil temperature conditions the plant establishment in the hot springs;
- soil temperature and soil humidity condition the plant establishment in the fumaroles;
- soil temperature and soil chemical composition condition the plant establishment in the solfatares;
- soil temperatures, hot vapors and material emitted condition the plant establishmet in the area of active craters.

These different factors are present in the soil with different values, according to a gradient. The colonizing organisms are distributed in horizontal zoning, according to ecological gradients.

Hot springs – In the springs of thermal waters, which are widespread in many volcanic areas, there are thermophilous organisms which can live where the temperature is up to 80°C and above. These organisms are Procaryota. They include:

- Bacteria, which, in a vegetative state, can live at temperatures up to 88°C.
- Blue-green Algae (*Cyanophytes*) that can withstand the temperatures of up to 85.2°C.

Similar organisms live at the same habitat conditions as those which were present on the earth when life began to it colonize.

- Thermophilous *Cyanophytes*, among them the cosmopolitan species *Mastigocladus laminosus* (Ag.) Cohn, have been found in thermal springs of Iceland at temperatures of up to 63-64 °C, whereas the species *Phormidium laminosum* (Ag.) Cohn can only live at temperatures of up to 58-60°C. In all there are only 6-8 species of *Cyanophytes*, which , in Iceland, can live in thermal springs having temperatures over 45°C (Castenholz 1969). In the Mediterranean region, in Greece, more than 60 species of *Cyanophytes* are present in 20 hot springs; they can live where the temperature is above 45°C (Anagnostidis 1961).

-There are also some unicellular eucariotic Algae that can adapt to high temperatures. Algae belonging to the *Confervaceae* family, typical of the hot springs, can continue to flourish at temperatures of 69°C and 74°C; Diatoms can live at temperatures of 54-60°C and sometimes of 94°C (Schimper 1935).

Algae of the genus *Protococcus* have been observed (Pedicino 1873) in the hot springs of the island of Ischia (Italy), at temperatures between 54°C and 62°C and occasionally even at 67°C.

The above shows the remarkable ability of these simple photosynthetizing organisms to live at high temperatures. They were obliged to live at these temperatures when life began on earth where only similar habitats were available.

Fumaroles – In the habitat of fumaroles the soil is characterized by higher temperatures and humidity levels. Therefore, the plants living in such habitat have to be doubly able to adapt. Moreover, when other gases like hydrochloric acid, sulphur dioxide, carbon dioxide and ammonium chloride are emitted with the water vapour, at high temperatures, the organisms that are to become established have to be capable of further adaptations.

The organisms that can adapt to fumarole habitats are therefore very specialized; they are distributed in horizontal zoning: from the least evolved to the most evolved taxonomic groups, according to the temperature and humidity values. In various volcanic areas it has been observed that the least evolved taxonomic groups occupy the areas with the highest temperature and humidity values and vice-versa.

On Etna, at the 1991-93 cones (2300 m a.s.l.), where there was fumarolic activity, we have observed, at temperatures of 55-60°C, colonies of the Cyanophyte *Chlorogloeopsis fritschii* (A. K. Mitra) A. K. Mitra & D. C. Pandey (Grilli Caiola & al. 1995). This Alga, where the substratum conditions are difficult, might act as nitrogen fixing species. With this species there were also colonies of *Nostoc*, a genus known for its nitrogen fixing ability. At lower temperatures (26-33°C), at the same cones, but further from theirs rims there were colonies of the moss *Pohlia* cfr. *drummondii* (Muell. Hal.) Andrews. On areas more distant of the cones the new lava substrates ware still barren, because they were still very young.

Around the Vesuvius fumaroles, inside the central crater, various *Cyanophytes* have been found (Maini 1963) in crevices down to a depth of 15-20 cm and at temperature of 40°C. A Chlorophyte of the genus *Cosmarium* was also found. Not far away, still on hot soil, the first pioneer Bryophyte communities were found; Pteridophytes were also observed.

A more complete ecological arrangement in zones has been observed in the fumaroles of Pantelleria and of other volcanoes, with *Cyanophytes*, unicellular eucariotic Algae, Bryophytes and finally vascular plants following on from each other.

Of particular ecological and phytogeographical significance is the presence in the fumaroles of tropical species, which are sometimes very isolated from their place of origin. This has been pointed out as regards some fumaroles in Campania, in the Phlegrean fields and in the island of Ischia (Pedicino 1873; Merola 1957a, 1957b, 1957c; Giacomini 1958). In these areas there are species of tropical origin like the moss *Trematodon longicollis* Mx. Rottb., the fern *Pteris longifolia* L., and the phanerogams *Cyperus polystachyus* in whose rhizosphere temperatures of 40°C and 47°C respectively have been recorded.

Merola (1957b, 1957c) has observed shrubs of *Erica arborea* L. and *Myrtus communis* L. adapt in a particular way to survive. The roots of both species show signs of thermotropism. They reach a depth of up to approximately 5 cm where the soil temperature is 24°C. Having reached this heat threshold the roots deviate and continue to grow horizontally. Those that grow beyond the heat threshold die.

Solfataras – In this habitat both the chemical composition of soil and the high temperatures can impose limits on the plant life.

The soil is characterized by its high acidity (pH values of down to 1,0), poor mineral salt and nitrate content and richness in alum and silicic acid. Few plants can adjust to these conditions and those that are able have also to withstand the vapours emitted from the subsoil. These are rich in sulphur dioxide, sulphydric acid and carbon dioxide.

Various groups of organisms have been observed in solfataras: *Sulphobacteria*, *Ferrobacteria*, thermophylous Algae, Lichens, Bryophytes and vascular plants. Most solfatara plants are clearly pioneer plants. According to Schimper (1898) they are mainly alophytes and xerophytes, while Faber (1927) considers the mesophytes with remarkable hygromorphic characteristics to be the most representative. There would seem to be oligotrophic species present, able of tolerating high percentages of aluminium, which some plants, so called "aluminophiles", would seem to be capable of storing (Faber 1987). To survive other plants grow in symbiosis: mycotrophic and bacteriotrophic species.

Some *Ericaceae* seem to be able to adapt in particular ways. Faber (1927) pointed out that they protect their roots with a thick layer of soil which covers them completely. Other plants manage to adapt to very acid soils, with a pH of less than 3.0, which generally is considered the limit of plant life. The lowest pH values (from 2.9 to 1.6) were measured in the rhizospheres of some plants living in Japanese solfataras (Poli 1970-71, Yoshioka & al. 1964) of others on the volcano Tecapa in El Salvador (Loetschert 1959), and yet others in Italian solfataras like the solfatara of Pozzuoli and "la Caldara" in Lazio. In this solfatara we found pH values of 2,9 in the rhizospheres of *Agrostis* cfr. *canina* L. and *Thypha angustifolia* L., and of 2,8 in the rhizosphere of *Schoenoplectus tabernemontanae* (Gmelin) Palla.

As in fumaroles, because of the various ways they are forced to adapt, plants in solfatares are distributed in horizontal zones corresponding to variations in the temperature, the soil acidity and the harmful gases present in the air. We have dealt with this more fully in other work (Poli 1970b).

Craters of active volcanoes – On the craters of active volcanoes colonization proceeds according to both the amount of time that has elapsed since the last eruption and the climate and type of the substrate. For example, on the crater of the volcano Nea Kaimeni (Santorini), 34 years after the last eruption, in 1950, a pioneer herbaceous vegetation dominated by *Corynephorus articulatus* (Desf.) Beauv. was found (Raus 1986).

In the same geographic and climatic regime (Aegean see) on the volcanic island of Nisyros (Burton 1991) the vegetation in the crater, a hundred years after the last eruption in 1871, was more advanced, consisting of low shrub communities (Papatsou 1975).

On the craters of the volcanoes in persistent activity, like Etna and Stromboli, the intense volcanic activity prevents plant life from becoming established. Indeed, life stops generally 200-300 m from the edge of the crater. Therefore, all around the crater there is a barren zone, a "volcanic desert" (Poli 1970b, 1970-71), whose existence depends only on the volcanic activity. There are, therefore, important ecological modification in the altitudinal zonation of the vegetation. The belts of vegetation belonging to each region at a certain extent stop to give way to a barren zone: the volcanic desert. In the zone between this and the last vegetation belt, there is also a new belt, which is ecologically very important. We called it (Poli 1982) "area of competition between plant life and destructive forces of the volcano". In this belt plant life is highly specialized and obliged to fight against the destructive activity of the volcano, sometimes yielding to it and sometimes surviving.

Table 1. Plant communities on the Greek volcanic islands of Nea-Kaimeni (Santorini) and Nisiros.

YEARS after last eruption	Plant COMMUNITIES	VOLCANOES
34 years (1950)	- pioneer herbaceuous *Coryneforus articulatus* (Desf.) P.Beauv -Gras-communities	NEA KAIMENI - Santorini – Grece (*Raus 1986*)
100 years (1871)	- low shrub-communities	NISIROS - Grece (*Papatsou 1975*)

New volcanic islands – The emergence of new volcfanic islands is of a great ecological interest and gives biologists a unique opportunity to study where does the colonizing organisms come from and how they live in completely barren and isolated areas. Events

of this type have occurred in various areas of the world including Europe. Here the volcanic island of Surtsey was formed by a series of eruptions during 1963-68 (Henriksson & Rodgers 1978). It emerged, rising from the oceanic floor in Vestmann archipelagus, south of Iceland.

It has been reported that on this new island, in 1964, a considerable number of microorganisms was found. It was clear, from the first investigation, that nitrogen fixers organisms like blue-green Algae and Bacteria were the first colonizers of the new volcanic substrates (Schwabe 1970, Fridriksson 1975). The first vascular plant was found in 1965. It was *Cakile edentula* (Bigelow) Hooker, which managed to survive just two years after (Fridriksson 1966). In 1977 there were 12 vascular species, of which *Cochlearia officinalis* L. and *Honckenya peploides* (L.) Ehrh. were represented by many specimens. In 1988, 25 years after the establishment of the first vascular plant, there were 25 species. Fridriksson (1992) pointed out that 27 years after the birth of the island, a total of 28 species of vascular plants had become established, but some of these were not represented at end of this period.

Bryophytes and Lichens seem to have only begun to colonize the island after establishment of vascular plants. The *Bryophytes* appeared in 1967 and already, after 6 years, they were represented by 72 species (Fridriksson & Magnùsson 1992). Schwabe & Behre (1972) pointed out that 6 years after the emergence of the island all the sites with *Bryophytes* were populated by nitrogen fixers Blue-green Algae (Brock 1973; Henriksson L. E. & Henriksson E. 1974) and particularly by the species *Anabena variabilis* Kützing ex Bornet & Flahault. Brock (1973) also observed the presence of *Oscillatoria* and

Table 2. The plant colonization on the Surtsey Island since its emergence.

YEARS	Years after emergence	SURTSEY Island New emerged Island	
1963			
1964		- many nitrogen fixer *Microorganisms:* *Blu Algae* and *Bacteria*	Schwabe 1970 Eridriksson 1975
1965 1967 1970 1972 1973	 4 years 7 years 9 years 10 years	- first vascular plant: *Cakile edentula* *Mosses* appared *Lichens* become established up to 11 species of *Lichens* 72 species of *Mosses*	Fridriksson 1966 Fridriksson & Magnùsson 1992 Kristnksson 1974 Kristinksson 1974 Fridriksson & Magnùsson 1992
1977 1988 1990	14 years 25 years 27 years	12 *Vascular species* 25 *Vascular species* 28 *Vascular species*	Fridriksson 1992

Henriksson (1974) observed the presence of *Nostoc muscorum*. The Lichens and above all *Stereocaulon vesuvianum* Pers., *Placopsis gelida* (L.) Lind., *Trapelia coarctata* (Sm. & Sow) Choisy (Kristinsson 1974) seem to have become established in 1970, seven years after the emergence of the island. After nine years the number of Lichen species had gone up to eleven (Kristinsson 1974). Besides numerous blue-green Algae and many green Algae have been found. However, it seems that (Magnusson 1992) neither blue-green Algae and Bacteria nor Lichens and Bryophytes have had an ecologically important role in the island colonization, role which is clearly to be ascribed to vascular plants.

Conclusions

It is clear from the above that the plant life and its organization in communities on different surfaces and habitats on active volcanoes are greatly conditioned by factors depending on the volcanic activity. On volcanoes there is a great variety of habitats and microhabitats for plant life and in some of these the life conditions are extreme.

What characterizes plant life on active volcanoes is its dynamic successions which are closely connected with the continuous changing in the substrates and reliefs. Plant communities in volcanic areas are characterized by perennial poverty and immaturity and they frequently show simple dynamic stages. Very few plant communities are recognizable as authentic "associations" and even these are a long way from resembling well-defined units

Table 3. The distribution of vegetation on volcanic areas is connected to ecological volcanic factors.

DISTRIBUTION of VEGETATION (landscape)	DETERMINING VOLCANIC FACTORS	HABITATS (or REGIONS)
small-scale mosaic structure in vegetation complexes	**surface morphology** of Lava flow	scoriaceous lava flows slab lava flows
large-scale vegetation complexes (formation complexes)	different **age** of Lavas	not very recent volcanic regions climatically the same
horizontal ecological vegetation zoning	**heat** and **humidity** of soil	Hot springs and Fumaroles
horizontal ecological vegetation zoning	**heat** and **chemical composition** of soil	Solfataras
vertical edaphic vegetation zoning	frequent **issues of vapouros** and **materials**	active Craters and Cones

like those located in non-volcanic areas. It is usually only possible to identify communities whose phytosociological definition is often limited to syntaxa of superior rank.

This is not only because of the immaturity and instability of the vegetation, which is subjected to frequent changes, but also because of the lack of the flora which characterizes all the volcanic areas in the world. According to Bjarnason (1991) it can be said that even the most developed plant communities are still phytosociologically few definite.

This reflects the great ecological significance of the volcanic habitats; they provide an opportunity to study primary succession on the dynamic process.

Although the plant communities on active volcanoes are not clearly defined from a floristic-sociological point of view, they play however an important role in characterizing the habitats they colonize. Their distribution in these habitats is the result of the action of the volcanic factors operating in the area, as it is summarized in the following table (Table 3) which has been drawn up from the data discussed above.

From this table it emerges that the distribution of the vegetation and of the vegetal landscape, on volcanic areas, is closely connected to the ecological factors, depending by volcanic activities. The different vegetal landscapes, produced by the varying of the surface morphology of lava flows, are for example different from the landscapes caused by the age of the lavas.

Moreover, the zonation of the vegetation is horizontal on the habitats of the fumaroles and solfataras, where there are ecological gradients; whereas it is vertical on the highest slopes of the active craters where the ecological gradient is conditioned by the distance from such cones.

On the active volcanoes if the factors connected with volcanic activity are added to those that influence plant life and its distribution on each geographical area, it is clear how much complex is the problem and its ecological implications.

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