PLANT COMMUNITIES IN THE VICINITY OF THE VOLCANO EL PARÍCUTIN, MEXICO, AFTER TWO AND A HALF YEARS OF ERUPTION[1]

WILLIS A. EGGLER

Department of Biology, Newcomb College, Tulane University, New Orleans

INTRODUCTION

Volcanoes exert a great influence upon plant communities contiguous to them. While active they destroy the member plants. Their ejecta may so alter soil conditions that processes of plant succession requiring centuries to complete may be set in motion. There is now little specific information on these subjects. Krakatao has long been considered a classic example, but there is now some doubt if it is as valuable as presumed. Backer ('29) states that many false assumptions were made by the early workers and that actually little is known about the biological aspects of Krakatao. Katmai Volcano, Alaska, was studied from the time of its eruption and some phases of its revegetation have been reported by Smith and Griggs ('32), and Griggs ('33). Gadow ('30) reported his observations of the volcano Jorullo, Mexico (see fig. 1), and also summarized the literature. Lawrence ('39, '41) has studied the problem on Mount St. Helens, Washington. The present author has contributed to the subject in a study of extinct volcanoes in Craters of the Moon National Monument, Idaho (Eggler '41).

An opportunity to learn new details about the effects of volcanoes on vegetation presented itself when the Parícutin Volcano in the state of Michóacán, Mexico, began eruption on February 20, 1943. Two and a half years later the author and his assistant, Robert Hakala, visited the volcano for a three-month period, July through September, 1945. The work had three main objectives: 1. To learn the character of the plant communities about the volcano before the eruption began. 2. To find what effect volcanism had had upon the environment and upon vegetation, and, to learn how the vegetation was reacting under the changed conditions. 3. To lay groundwork for later studies of the process of revegetation. I hope to revisit the area at intervals over an extended period to add to the information presented in this paper.

DESCRIPTION OF THE REGION

Geography

Parícutin Volcano lies among masses of rugged volcanic mountains which form part of the southern end of the Central Mexican plateau (see fig. 1). Immediately to the south is the large Cerro (Mount) Tancítaro whose summit rises to nearly 13,000 feet (fig. 3). To the northeast is a smaller mountain mass, formed of several volcanoes, the nearest being Cerro Angáhuan (10,594 feet high),[2] which are much younger than Tancítaro. Hundreds of smaller volcanic cones, many about the size of Parícutin, lie about in all directions. Most of the plateau land between the cones varies from 7,000 to 7,800 feet in elevation.

The studies reported here were made in an area roughly rectangular, with Parícutin located about at the center. It lies east and north of the summit of Tancítaro which occupies one corner (fig. 2).

Geology

Williams ('45) has discussed the geologic setting of Parícutin rather fully. The

[1] This work was accomplished through the support of a grant from the American Philosophical Society. I am truly grateful for the aid.

[2] Altitudes given in this paper are unofficial and not verified. No others were available. Altitude at the summit of Cerro Angáhuan was determined by the present author with an aneroid barometer. The value for Tancítaro is that accepted by local residents but it is not verified.

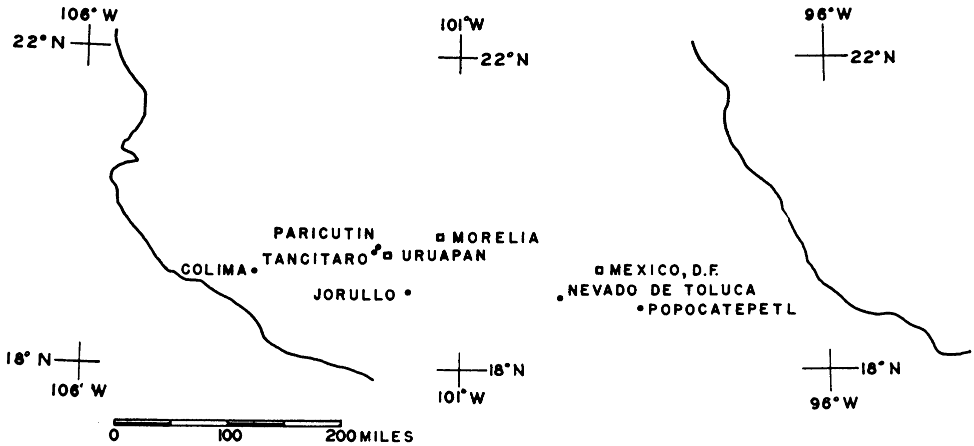

Fig. 1. Map of Central Mexico, showing location of Parícutin, some large volcanoes (dots), and important cities (squares).

eruption of Parícutin is the most recent incident in a long history of volcanism which extends back to Tertiary time. A wide belt of volcanoes, more than 500 miles long, crosses Mexico, approximately along the nineteenth parallel. In this belt are such giants as Popocatépetl, Nevado de Toluca, and Colima, as well as myriads of

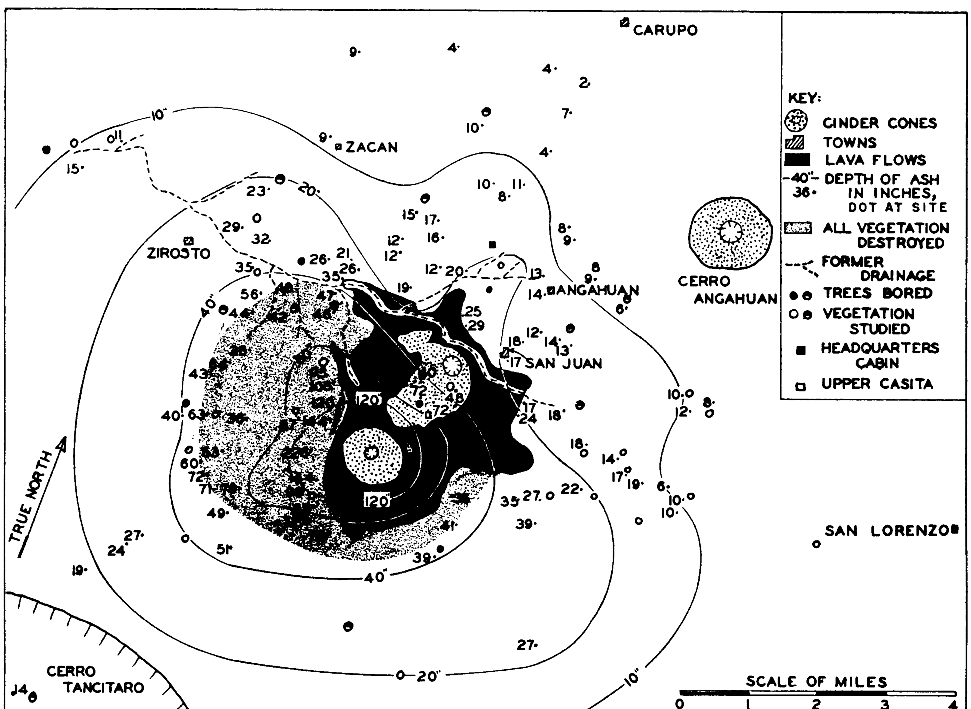

Fig. 2. Map of the study area, showing locations of villages, positions of cinder cones, extent of lava flows, depths of ash at the points where measured, sites where vegetation was studied, and extent of vegetation destruction as of September, 1945. Parícutin Volcano is the southernmost cinder cone.

smaller ones, most without published names. The two youngest are Jorullo, which began eruption in 1759, and Parícutin. These are about 50 miles apart (fig. 1).

Probably no single small, geologic incident has been honored with more writings that has Parícutin during the early years of its life. The most complete history is that by Ordoñez ('45), in which he relates the events from the beginning of activity to the end of December, 1944. Shorter periods, ranging from two days to fourteen weeks have been reported by others. A partial list includes Eggler ('45), Kennedy ('46), Krauskopf ('46, '46a), Krauskopf and Williams ('46), Lawrence ('44), Segerstrom and Gutierrez ('47), and Wilcox ('47, '47a).

In the summer of 1945 the central figure of Parícutin was a symmetrical cinder cone whose summit stood about 1,500 feet above the field on which it began to deposit, and whose base was a mile across (fig. 3). A field of aa [3] lava, about five square miles in extent and varying from about fifty to a few hundreds of feet in thickness, had flowed from several vents near the base of the cinder cone. Extending for several miles in all directions from the main orifice was a mantle of ash (fig.

FIG. 3. Parícutin Volcano in eruption. Highest mass in background is Cerro Tancítaro. Village is Angáhuan. Photo from Cerro Angáhuan. August, 1945.

FIG. 4. Corn plants 7 to 8 feet tall growing in village of Angáhuan. August, 1945.

[3] Aa lava breaks into fragments as it moves and cools. Surfaces of these flows are jagged and broken.

2). All material which Parícutin has ejected is basaltic in character, and when unweathered is nearly black in color (figs. 6, 7, 8). Gratan ('45) has pointed out that Parícutin is a typical example of the volcanoes of the region. It is likely its history will be a repetition of that of the hundreds of its older fellows.

Soil

Soil derived from volcanic ash is usually fertile and all soil in this area was directly or indirectly of that origin. Where exposed through the new volcanic deposits it is generally fine in texture and very deep. A chief limitation to agriculture has been the scarcity of land level enough to cultivate. Occasionally one sees attempts to grow crops on the slopes of old volcanoes, but the erosion which results when such land is cleared and the soil cultivated indicates that it would be better left in native vegetation. No terracing is done in this particular part of Mexico.

Climate

The climate of the region is distinctly temperate in character, without frost at the altitude of the study area. Cool temperatures prevail throughout the year. A dry season, from November through May, is followed by a rainy, humid, summer and autumn. Temperature and precipitation records for a period of 15 years are available for the cities of Uruapan and Morelia (fig. 1).[4] Uruapan is 12 miles southeast, at an altitude of 5,285 feet, compared with about 7,400 at the volcano. In Uruapan January is the coldest month, with a mean of 61 degrees F. May is the warmest month, with a mean of 72.3 degrees. During the years of the record the maximum temperature recorded was 97.7 degrees, and the minimum 41. Average annual rainfall is 66.2 inches. September has the highest monthly rainfall, with 16 inches, and April the lowest, with 0.16. Morelia is about 80 miles east of the volcano at 6,309 feet elevation. Its temperatures generally run lower than those in Uruapan. May has a mean of 68.9 degrees, January a mean of 57. The maximum recorded during the 15 years is 87.9 degrees, and the minimum is 34.9. Average annual precipitation is 30.7 inches. July is high with 6.7 inches, and December is low with 0.2. Temperatures near the volcano are probably similar to those of Morelia while precipitation is apt to be not greatly different from that of Uruapan.

Contreras Arias ('42) has prepared a climatological map of Mexico, based upon the system of Thornthwaite, in which two factors, temperature and precipitation, are considered of prime importance in determining the distribution of vegetation. The area of this study is described on the map as moderate in temperature, without a well defined winter cold season, dry, with especially dry winters.

Rains are usually of the flash type. Topography is rough near the volcano, hence effectiveness of precipitation is less than the total rainfall might suggest, because of the large amount lost in runoff.

Some observers believe volcanic activity has caused precipitation to increase, locally. Pough ('48) states that vapor emitted from the volcano may condense and fall as rain. Munns ('48) has a somewhat different theory. He suggests that convectional currents, resulting from the sustained heat of the volcano, bear aloft great masses of air. As these masses cool clouds form and rain results.

If it be true that rainfall has increased then erosion has also been increased. Other factors have also tended to increase erosion near the volcano. The subject is discussed at more length in another section of this paper.

Population and industry

Residents of the region are almost all Tarascan Indians who generally live in villages. In the area studied there had been seven villages, indicating their closeness and the density of population (figs. 2, 3). Two, San Juan Parangáricutiro

[4] Climatic data were obtained from the Mexico City office of the Servicio Meteorologico Mexicano. The data were converted from metric and centigrade units to English and fahrenheit units by the present author.

(generally called San Juan), with a population of about 3,000 persons, and Parícutin, with about 800, had to be evacuated and were later destroyed by the volcano. The other villages all have populations of between 800 and 1,000 persons. Three of the five have suffered materially, Zacán and Zirósto most. In these two villages some buildings collapsed under the weight of ash, and nearly all the fields have been made useless. Angáhuan (figs. 3, 4) has had as much or more ashfall but it has been kept in a better state of repair. It too has lost the use of its fields in most instances, partly because of ash deposits and partly because of lava flows covering them. Carúpo village has been little affected by the volcano but some of its fields have been abandoned. San Lorenzo has been little influenced by the volcano. Fortunately there has been no loss of human life directly attributable to the volcano.

Agriculture has been the chief means of livelihood for the people. A family often worked several fields which may have been two or three miles apart. Maize is the main crop and yields are low, judging by the fields seen. After agriculture, turpentining was the chief source of income. Pine trees were tapped throughout the region at the lower altitudes about the site of the volcano. This industry has now been brought to a standstill by the volcano. Where trees were not killed the constant fall of ash into the collecting cups spoiled the sap. With loss of their fields and the turpentine industry many people have turned to the cutting of dead and dying timber for railroad ties and for saw-logs. It appears that they have been cutting too much living timber, along with the dead, for the future good of the forests and for stability of the human communities in general.

Plant Communities Before Volcanism Began

Prior to the eruption of Parícutin volcano about 75 per cent of the land of the region was forested (estimated from an aerial photo taken prior to February, 1943). This was generally the part too rough for agriculture. Conifers usually predominate in the forests, but hardwoods are also present, except at the highest altitudes.

There are three rather distinct vegetational zones. Occupying the plateau area between cones, and the sides of cones up to about 9,000 feet is a pine-oak forest. From 9,000 to about 10,000 feet fir is the dominant tree; and above 10,000 feet pines are dominant, continuing to the summit of even the highest mountain, Tancítaro. There is no timber line and trees do not appear to decrease in size with increased altitude.[5]

Pine-oak forest

This is the most important plant community from an economic standpoint as it covers the greatest area and furnishes forest products for local industry. It is variable in composition, ranging from mixed pine and hardwoods to nearly pure stands of pine or to almost pure hardwoods. Several sources of information were used in studying this community: general observations throughout the area, data on density and frequency from a mixed forest, and the ages and rates of growth of pine trees as obtained from increment cores.

General observations.—The most striking thing about this forest of lower altitudes, when first seen, is the predominance of pines over other tree species, particularly in the more level places. Two species, *Pinus leiophylla* Schl. & Cham.[6]

---

[5] On higher mountains there may be distinct timber lines. On Popocatépetl, for example, which the writer visited, timber line begins very abruptly at around 12,000 feet. Here also pine is the timber-line tree. There was no indication of krumholz and trees appeared erect and healthy.

[6] I am indebted to Dr. Paul Standley and Dr. J. A. Steyermark of the Chicago Museum of Natural History for the identification of most of the plant species. Many of the specimens collected were unavoidably poor because of the effects of volcanism. As a consequence positive identifications, particularly of the oaks which require the presence of good leaves, buds, and fruits, were often not possible.

and *P. pseudostrobus* Lindl., are about equal in importance and make up most of the pine population. A third, *P. teocote* Schl. & Cham., is of minor importance. When out-of-the-way spots, such as steep sides of cones some distance from a village or road, are examined it becomes evident that hardwoods, particularly oaks, are present and important. In many places they equal or exceed the pines in numbers. Continued observance reveals that even in areas where pines are dominant a few small hardwoods may be scattered among them and occasionally a large oak of great age is present. Eight oaks were identified from the area. These are *Quercus Fournieri* Trel., *Q. magnoliaefolia* Neé, *Q. mexicana* var. *angustifolia* H. & B., *Q. obtusata* H. & B., *Q. oligodontophylla* Trel., *Q. orbiculata* Trel. *Q. Radlkoferiana* Trel., and *Q. transmontana* Trel.

Next in importance among the trees, after Pinus and Quercus, are alder (*Alnus jorullensis* HBK.) and madroña (*Arbutus xalapensis* HBK.). In protected ravines are basswood (*Tilia Houghi* Rose), and fir (*Abies religiosa* (HBK.) Schl. & Cham.), in very small numbers. A cherry (*Prunus Capuli* Cav.), hawthorn (*Crataegus pubescens* (HBK.) Steud.), and ash (*Fraxinus Uhdei* (Wenzig) Lingelsheim), are minor members of the community. They are more often along the margins of fields and in fence rows where they may have been planted.

Shrubs of importance in the pine-oak community are *Arctostaphylos rupestris* Rob. & Seat., *Ceanothus coeruleus* Lag., *Cestrum terminale* var. *latifolium* Francey, *Baccharis pteronoides* DC., *Buddleia parviflora* HBK., *Fuchsia Pringlei* Rob. & Seat., *Salix Hartwegii* Benth., and *Symphoricarpos microphyllus* HBK.

Statistical studies.—Forest in which Quercus is of major importance is relatively scarce and is generally confined to slopes of cones. This type of forest is dense, particularly in the shrub stratum. The south side of an old volcanic cone about 1,500 feet high and a mile in diameter at the base was chosen for detailed studies of this forest type. There were no evidence differences in the vegetation on different sides of this cone. The cone lay about two miles east of the village of San Lorenzo and ten from the volcano. It had been little affected by volcanism, beyond receiving a thin layer of ash on its surface, and seemed to be little disturbed by cutting and grazing. The angle of the slope was about 38 degrees where the study was made. Fourteen plots, 10 by 10 meters in size, were evenly spaced

TABLE I. *Density and frequency of tree species in plots on south side of cone near San Lorenzo. Angle of slope about 38 degrees. Area, 1,400 square meters*

	Diameter size classes in inches								
	Less than 1*		1–3		4–9		10 or more		Totals
	D.	F.	D.	F.	D.	F.	D.	F.	D.
Symplocos prionophylla	2060	50%	1	7%	0	0%	0	0%	2061
Quercus magnoliaefolia	630	36	23	50	20	57	9	43	682
Taonabo Pringliei	280	43	11	29	7	14	1	7	299
Arbutus xalapensis	140	43	6	29	2	7	0	0	148
Quercus orbiculata	120	21	17	14	3	7	2	7	142
Pinus pseudostrobus	130	29	3	21	2	14	6	43	141
Pinus leiophylla	80	14	0	0	0	0	1	7	81
Alnus jorullensis	60	7	5	21	2	14	0	0	67
Quercus obtusata	0	0	20	14	7	14	0	0	27
Clethra sp.	0	0	4	7	5	14	0	0	9
									3682

* Values have been multiplied by 10 to compensate for the smaller area sampled.

through the middle two-thirds of the side of the cone. Disturbace was less there than at the base and summit. In the plots all trees an inch or over in diameter (as measured four feet from the ground), were counted and grouped in several size classes. Trees under an inch, and shrubs, were tabulated in plots 2 by 5 meters; and herbs in plots one-half by 2 meters. The small plots were always located in the one next larger in size, in a predetermined corner. Results of these studies are given in tables I and II. An indication of the importance of a tree species in a community is its presence in many size classes, with a high density and frequency for each class. On that basis Quercus, four species collectively, occupies first place among trees; Pinus is second, and Arbutus third. *Symplocos prionophylla* Hemsl. and *Taonabo Pringlei* Rose, though they have high densities, are small trees and only subordinate members of the community. Pinus contributes the tallest and most conspicuous members of the forest. *P. pseudostrobus* is the more important of the two species in the plots; it has the greater density and is present in all size classes. Economically it is said to be superior to *P. leiophylla,* both as a lumber tree and as a turpentine source. Trees of other species are all small and are subordinate members of the community.

TABLE II. *Density and frequency of shrubs and herbs on the south side of a cinder cone near San Lorenzo. Angle of slope about 38 degrees. Values are based on an area of 140 square meters. Shrubs tabulated in fourteen 2 by 5 meter plots; herbs computed in fourteen plots one-half by 2 meters*

	Density*	Frequency
Shrubs		
Arctostaphylos rupestris	167	86%
Fuchsia michóacánensis	102	93
Coriaria thymifolia	92	36
Ceanothus coeruleus	68	50
Salvia longispicata	44	36
Russelia polyedra	41	36
Cologania biloba (Lindl.) Nichols	39	57
Xylosma flexuosum Hemsl.	8	7
Crotalaria pumila Ort.	6	21
Cestrum terminale var. *latifolium*	4	7
	571	
Herbs		
Bromus pendulinus Sessé	210	36
Stipa mucronata HBK.	190	43
Cystopteris fragilis (L.) Bernh.	150	7
Ranunculus sp.	120	21
Passiflora sp.	90	7
Trifolium amabile HBK.	70	14
Physalis subintegra Fern.	70	14
Adiantum Poiretii Wikstr.	60	7
Cynodon dactylon (L.) Pers.	50	7
Lupinus elegans HBK.	50	7
Pteridium aquilinum (L.) Kuhn	40	7
Onosmodium strigosum Don.	20	14
Cyperus flanus (Vahl.) Nees	10	7
Begonia balmsiana Ruiz	10	7
	1140	

* Multiplied by 10 in case of herbs to compensate for smaller area.

Ten species of shrubs were present, the two most important being Arctostaphylos and *Fuchsia michóacánensis* S. & M. *Coriaria thymifolia* H. & B., number three in terms of density, has a rather low frequency, 36 per cent, which indicates it is not widespread, but grows in colonies. *Salvia longispicata* M. & G. and *Russelia polyedra* Zucc. are as well distributed as Coriaria but each is only half as dense. It is worth noting that only three of the ten shrubs in the plots were included in the list of those considered to be important throughout the region. This may mean the other seven are confined to forests with considerable hardwood present, or it may mean that they have been killed out of other forests by the volcano. The first explanation seems more likely.

There was an unimpressive number of herb species in the plots, only 14 species, and those in small numbers. Frequency is also low in all cases. First two places are taken by grasses and third by a fern. A heavy canopy of trees and shrubs which overshadowed most of these plots probably inhibited the growth of more herbaceous ground-cover.

Rate of growth of pines.—Increment cores were taken from 65 pine trees, *Pinus pseudostrobus* and *P. leiophylla,* located in 18 different stations, as shown in figure 2. The trees selected were generally of moderate size, between about 5 and 12 inches in diameter. One station which furnished three trees was in the upper pine zone; all others were in the pine-oak zone.

The cores showed the annual diameter increment of the pine trees to be rather "moderate" in amount. The maximum diameter increase for any tree for a year was 24.4 mm. The minimum increase was 2.8 mm.; the average for all trees was 8.5 mm.

Succession and climax. — Indications are that the climax forest in the pine-oak zone is one in which deciduous trees make up a considerable part of the population, perhaps half of the large trees and even more of the small. In the lower strata such forests are dense but at crown height they are rather open. Areally this type of forest is much less extensive than one in which pines are the important and, sometimes, almost the only trees. This second type appears to be in a subclimax condition. Three evidences substantiate these opinions: 1. There are small areas, such as found in some of the plots of the statistical studies, or that illustrated in figure 5, in which a majority of the trees are hardwoods. Such areas are almost without exception on steep slopes of cones, or other places not easily accessible to woodcutters and grazing cattle and sheep. 2. Large oaks are found sparingly but widely distributed. 3. Pines are the pioneer trees in abandoned fields and pastures. The seedlings grow rather thickly and seem to succeed under conditions of disturbance. Figure 6 shows a stand of pines in a field which has apparently been abandoned for some reason. Some of these trees were ten to twelve feet high. In forests the pines are often even-sized and may have all started about the same time in an abandoned field or, following disturbance, in a forest.

FIG. 5. Mixed forest on southwest facing slope of small cinder cone a half mile west of village of Carúpo. Largest trees are oaks. Dense shrub stratum; upper strata are open. Note epiphytes.

FIG. 6. Pure stand of pines (*Pinus pseudostrobus*) in an abandoned field about a mile north of village of Angáhuan. Ash about 10 inches deep. Trees 10 to 12 feet tall. July, 1945.

Most of these areas are subject to considerable disturbance. Sheep, cattle, and burros are grazed wherever there is forage. Because of the uncertainty of land ownership which has prevailed, any area not actually in use seems to be considered open for grazing and timber cutting. Woodcutters travel miles for firewood which they haul on burros, or to hew railroad ties which are transported by trucks. Oak wood is used in many parts of Mexico for making of charcoal, and may have been used for that purpose here too in times past.

Fir and pine forests of upper elevations on Cerro Angáhuan and Cerro Tancítaro

Some comparisons between the vegetation of Cerro Tancítaro, which had been studied extensively by Leavenworth ('46) in the two years just before Parícutin began eruption, and the vegetation of Cerro Angáhuan, which I observed in 1945, are of interest. Cerro Tancítaro is much older than Angáhuan, covers several times the area and is over 2,000 feet higher. Because of its greater age, and possibly also because of its greater size and larger water shed, Tancítaro is much more eroded. Consequently physiographic differences play a much bigger part in determining distribution of vegetation on Tancítaro than on Angáhuan.

On Cerro Angáhuan there are three forest zones. The pine-oak zone of lower altitudes gives way to a fir zone at about 9,000 feet and the transition is completed at about 9,400 feet. Besides Abies, which is the dominant tree, Quercus is also important in this second zone. Some of the oaks are five feet in diameter. Pines persist but are few in number. At about 10,000 feet Abies is rather suddenly reduced in amount and, while a few trees were observed up to the summit of Angáhuan, 10,594 feet, pines almost completely take their place. The pines are the same species as at lower altitudes. (Leavenworth ('46) states that on Cerro Tancítaro *Pinus montezumae* Lam. var. *rudis Shaw,* is common above 9,500 feet.) Oaks are absent. This forest is generally open and park-like, with grasses forming the main undergrowth. In a few places a low shrub, *Pernettya mexicana* Camp., grows densely.

Forest zonation on Tancítaro is essentially similar to that on Angáhuan, the chief difference being in the position of Abies. On Angáhuan this species is rather general between 9,000 and 10,000 feet, but is not present in important amount elsewhere. On Tancítaro it is confined largely to valleys, where it descends to a lower altitude than on Angáhuan. On ridges it is scarce at any altitude.

It is evident that pine can, and does, grow from low altitudes up to the summits of these mountains. In some places they form only a minor part of the forest but that is because there oak and fir grow more luxuriantly. Both oaks and fir are more limited in their altitudinal ranges. Oaks grow to about 10,000 feet but no higher. Firs are nearly confined to a one thousand foot belt, between 9,000 and 10,000 feet, although in valleys they go lower. The upper limit of oak may be determined by temperature. There are no climatic records of any kind for these mountains but winters must be rather cold. Temperature may play a part in determining distribution of fir, although firs in general are quite cold resistant. The general distribution of fir here indicates that favorable water balance which results from reduced evaporation may be the critical factor in its success. Certainly its presence in valleys, but at the same time absence from ridges of the same altitude (Leavenworth '46), suggests the importance of water balance, or water balance and temperature differences due to air drainage. The fir belt is also the belt of most fog. My experience was that a fog blanket was the rule rather than the exception at this altitude, often being there when absent at lower and at higher altitudes. The importance of fog has evidently been appreciated by others, hence the name "cloud forest," which is applied to it.

Ecological Effects of Volcanism

The volcano is affecting vegetation now, while it is still active, directly, in the way of destruction. But it will continue to influence vegetation indirectly for many years, probably centuries, after it ceases activity because of the way it is changing the environment. The indirect effects will be considered first.

Effects upon the environment

A new "soil."—Over a considerable area lava flows have effectively buried the old soil. In 1945 this area was about 5 square miles (fig. 2), but as the lava continues to flow it is greatly increased. The lava is basaltic rock, bare and sterile and incapable of supporting plant life until processes of weathering begin its decomposition and pioneer plants can become established. Revegetation on the flows will be slower than elsewhere and it may require centuries to effect a return to subclimax or climax forest, even if it is left undisturbed and is not used for agricultural purposes. It is probable that parts of the flows, especially such as are adjacent to large cinder cones, will have ash and soil washed or blown down onto them. Revegetation would take place more rapidly under such conditions.

The main cinder cone of Parícutin covers about a square mile. Its cinders are sterile, inorganic matter, similar in composition to the lava of the flows, and vary in texture from dust to boulders, most being of the size of sand and gravel. Revegetation of the cone cannot commence until activity ceases or at least is very slight. It will need to start with plants which are capable of living in such sterile soil, possibly thallophytes or bryophytes.

Extending beyond the cinder cone are a few square miles of area where ash (material small enough to be wind blown, see fig. 7) is so deep that all influence of the old soil is lost, and here too revegetation, starting with pioneer plants, will be necessary.

Fig. 7. Ash surface devoid of vegetation. Ripple marks are result of wind. September, 1945.

Thickness of ash.—Many measurements of the thickness of the ash were made in most parts of the area. It was done by making a cut with a shovel to the old soil surface and then measuring vertically along the cut. These measurements in inches, recorded at the places where made, and also iso-lines of ash depth are given in figure 2. The area south and west of the volcano is poorly investigated because that runs up into Cerro Tancítaro where work of this type is difficult because of erosion; records there would be extremely unreliable. No measurements of ash depth were made on flows.

In general there was a decrease in depth of ash with increase of distance from the volcano, as would be expected. This decrease is much less rapid to the south and west than it is to the north and east. For example, at the summit of Tancítaro mountain, which is about 6 miles away, ash was 14 inches deep, and 6 miles in the opposite direction, 2 inches. The prevailing winds which blow from the northeast are undoubtedly responsible.

The variation in depth of ash is often not uniform and gradual, and there may be a considerable difference between that of two spots quite near each other. Such discrepancies may be partly the result of the way the material was deposited by the wind, but it is more likely that erosion by water, after deposition, is responsible. As is shown below, erosion goes on quite unchecked during the rainy season.

Krauskopf and Williams ('46) present a generalized figure in which are shown with closed iso-lines the 6 inch, 1, 2, 3, 4, 5, and 10 foot ash depths, as of May, 1945. There is general agreement between their figure and the more detailed measurements recorded here, and the two sets of data complement each other nicely.

Erosion.—Erosion by water would always be considerable in such a mountainous region, but since volcanism began it has been increased manyfold. Much vegetation has been destroyed and no longer exerts its binding effect. The character of the ash is such that it "invites" erosion. It is generally fine in texture and quite unconsolidated, and during a heavy rain the surface layer turns to a mud which flows away in sheet erosion. This mud coalesces into mud streams which flow down the gullies and into stream channels. Specific gravity of the flowing mud is nearly 2.0.

During the dry winter season ash is blown into dense dust clouds. The general result of several months of blowing is that the surfaces of ash fields are smoothed and evened. Early in July ash fields were somewhat eroded and dissected by water action but not nearly as much as by the middle of September after they had been subjected to two and a half months more of action by water. In September there was scarcely a square meter of surface left undissected on slopes (fig. 8). Lowdermilk ('47) estimated that about one-third of the ash which had fallen on slopes up to August, 1945, had already been moved into valleys.

The drainage pattern of a part of this area has been changed. Lava flows have cut across and filled some stream channels (fig. 2). Now, upon reaching the lava, streams are ponded and drop their sediments. There are numerous playas, formed in that way, east, south, and north of the lava flows. Debris has accumulated to a depth of many feet and consists of a great mixture of ash, old soil, leaves, branches of trees, logs, and disseminules of many plants. This should form a fertile spot for plant growth in the future. Streams whose upper courses have been blocked by lava flows have cut new channels along the west edge of the lava and then continue below in their former channels, where these have not been filled in.

Direct effects of the volcano upon vegetation

Up to the date of this study direct effects had been largely in the nature of destruction, varying from complete elimination of all plants in areas buried by the cinder cone, deepest ash fields, and lava flows, to partial destruction where ash was shallower, to less and less influence with increasing distance from the volcano.

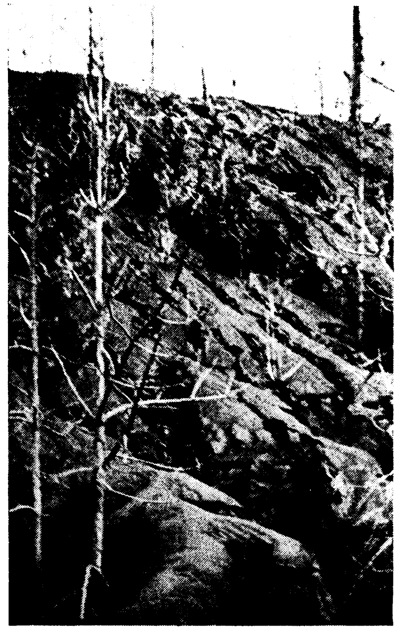

FIG. 8. Severely gullied ash deposits estimated to be 30 to 40 feet deep, with tops of large pines protruding. One-half mile west of volcano. August, 1945.

Lava flows.—After emerging from their orifices the aa lava flows moved quite rapidly, during the present study, in narrow streams for a short distance. One flow observed at intervals over a period of several days, about an eighth mile from from its origin, was moving on an average of 15 feet per minute. That speed was faster than the average but by no means the maximum. Farther away from the orifice the lava spread into wider streams and the front was often an eighth or quarter mile across. The speed was then much reduced, being only a few feet per hour, or even per day.

Attention was given to moving flows to learn how they damage plants: whether the living plants are burned outright, whether radiant heat from the front of the flow kills them, and whether mechanical breakage is important. Observations were made along the margin of active flows and also of flows which had been "dead" for a considerable time. An active flow which was moving into a forest was observed for about three hours. The flow was there about a mile north from its source and advanced, on an average, about six feet during the time. Over a hundred oaks and more than forty pines were overtaken by the flow during the three hours. In most instances the trees were bent away from the flow by the material pushing against the trunks and then they were buried. No instance of burning of such trees was seen. Rarely the tree fell toward the flow and then it usually burned because it came in contact with hot lava exposed when cooled pieces fell away from the front. We saw only one tree in actual process of burning. Quite often the tree was not moved from its position and the lava piled around it as it remained standing. No burning of such trees was seen.

At first thought it might seem impossible for an aa lava flow to move around and over trees without burning them but the explanation is comparatively simple. When flows move slowly there is ample time for surface material, both front and top, to cool. This cooled lava continually breaks from the upper front as the flow advances, it falls to the foot of the flow, and is then over-ridden. Hence there is an insulating layer of cold rock at the front and base of the flow, and only rarely does hot lava of the inside of the flow reach the extreme front. It is of course likely that when a flow has advanced a considerable distance over trees that they would be burned and that even the cooled rocks would be remelted.

The "dead" flow whose effects are described here had been active in 1944, (about a year before these observations). It was studied at a site about five miles from its source, considering the circuitous route it had taken, at a point adjacent to the Headquarters Cabin (fig. 2). The flow averaged about fifteen feet in thickness. The edge where observed varied from the vertical to a low angle of about 20 degrees. The ash blanket in this vicinity was about two feet thick. For about a mile along the edge of the flow observations were made on the condition of all plants and plant remains which were within six feet of the flow. Any plant farther away was assumed to be beyond the influence of the flow. Each plant was put into one of three categories, according to its condition: 1. Apparently unharmed by the flow. 2. Injured, but making a recovery (usually partly or entirely killed above ground but sending out new growth from stem or roots). 3. Apparently dead. The results are summarized in table III.

TABLE III. *Effects of proximity to a stationary lava flow edge on plants. All plants were within six feet of the flow which had cooled a year before observations were made*

	Apparently unharmed	Injured but recovering*	Apparently completely dead
Trees			
Alnus jorullensis	1	0	0
Arbutus xalapensis	1	4	0
Crataegus pubescens	12	7	12
Pinus leiophylla	4	1	0
Shrubs			
Bouvardia ternifolia (Cav.) Schlecht	2	1	0
Rosa sp.	1	0	0
Smilax moranensis M. & G.	0	2	0
Symphoricarpos microphyllus	2	1	0
Herbs			
Cynodon dactylon	2	0	0

* Usually partly or entirely killed above ground and sending out new growth from stem or roots.

The flow happened to pass through the edge of the village of San Juan and the vegetation was not all native forest. Most of the Crategus had probably been planted. The rose was certainly a cultivated plant. This latter was a large plant with a stem about two inches through at the base. Even though the lava was touching it the plant was healthy, showed no sign of damage and bore quantities of beautiful blossoms. Figure 9 shows the lava flow and the character of some of the vegetation that remained.

These observations indicate that the effects of aa lava flows upon plants, particularly trees, are largely in the nature of mechanical injury rather than burning or killing by radiant heat. Contact of a lava flow with a plant, or even partial burial, if the plant is not crushed, may not result in its death.

Ash Deposits.—Studies were made of the vegetation of the ash fields in relation to environment. These included: keeping a record through the season of plant species found in the areas; excavations of the root systems and buried stems of many plants; and the plotting of a map of the limits of plant survival, that is, points closest to the volcano where plants remained alive. All these studies were carried on at the 34 stations indicated in figure 2, and plants census records were kept at many more than the 34 sites. The following discussions are based upon these studies and the measurements of ash depths which are given in figure 2.

1. Vegetation in different directions from the volcano

Indications are that several factors may be responsible for the destruction of vegetation in ash fields. Sometimes it is rather evident which are effective, and again one cannot know. The first and most obvious cause is complete and continued burial. Others are partial burial which would reduce access of oxygen to the roots; breakage because of the weight of ash upon the plant; starvation and suffocation because of a coating of ash over the leaves or stems which would reduce light intensity and clog stomata thereby reducing photosynthesis, or starvation because of the prolonged absence of leaves. Possibly, when the volcano was younger poisonous gases may have been a factor, but by 1945 nothing survived near enough to the main vents to be much affected by that.

It very early became evident that there was rather poor correlation between survival of vegetation and distance from the volcano. Plants have been harmed much less north and east than at equal distances south and west. This suggests a relation between vegetation and depth of ash since it has been shown that ash is deeper to the south and west. But here again the records do not show more than a general relationship. Vegetation is generally in better condition east and northeast than west and southwest at comparable depths of ash. This suggests that accumulation of ash about the base of a plant is not the only factor at work here. Effects of continued presence of a layer of ash on the

FIG. 9. Edge of a "dead" lava flow which had stopped advancing in this direction about a year before. Photo taken about a half mile southwest of headquarters cabin. This flow was studied to learn its effect upon marginal vegetation.

plant leaves seem to be even more important. Prevailing winds for much of the year are from the east or northeast, hence vegetation to the west is subjected to an almost constant shower of ash and has little chance to recuperate. Ash is blown east and northeast but not for long periods and plants can recover between times.

The approximate limit of living vegetation is indicated in figure 2. At the outer limit of this area ash varied between approximately 4 and 6 feet in depth. It is not possible to indicate an exact line, beyond which there was no living vegetation. There were many small areas outside the line where all was dead, and there were scattered living plants inside. For example there were a few pines inside sufficiently alive to warrant the taking of increment cores.

2. Species present in different depths of ash

The most interesting studies of the ash fields were in the large area outside that of total destruction. It has already been stated that there was not a close relation between vegetation and depth of ash; nevertheless it seems worth while to present this comparison for what it is worth as a matter of record. Most of the observations on vegetation upon which it is based were made north, east, and south of the volcano. There is closer correlation between vegetation and depth of ash in these directions than west of the volcano where starvation and suffocation played a bigger part in killing of plants. The information is summarized in table IV.

(*a*) *Trees*

(*1*) *Pines*

No attempt is made here to differentiate between pine species as they reacted rather similarly. For convenience of record the pines have been considered in five size classes. First to succumb in ash were small ones, those under an inch in diameter. They were generally dead where ash was about a foot or more deep. In some places however this size was all killed in 8 inches of ash. Next to be killed were those an inch or over, but under three inches; then those 3 to 5 inches. Almost as easily killed as those in group three were the big trees, those over a foot in diameter. They suffer exceedingly from breakage; their branches are brittle and cannot withstand a heavy load of ash. Generally about 24 inches of ash was needed to kill the big trees but many were dead in 10 inches. The last pines to succumb were those having diameters between 5 inches and a foot. They are large enough for the main stem to resist strong bending and burial, yet the branches are flexible enough to yield and not break (fig. 10). The maximum depth of ash in which a pine survived was about seven feet.

Often in ash between 8 and 20 inches deep small pines were bent over and their tops buried. Some of them subsequently died, but a good many continued to grow. Upper branches of the latter group grew rapidly if the tree was healthy, and altered their polarity and symmetry to produce vertical tree-like growth, but, inasmuch as there were never adventitious roots from main stem or branches to furnish extra nourishment, aeration, and support, it is unlikely that many of the branches can grow to tree size. No branch or tree top which was buried to its tip end remains alive. (It may be mentioned here that adventitious roots were found on no trees buried in ash and in only one shrub species were there individuals with adventitious roots).

There is no evidence that among those pines which remained alive there has been more than a modest decrease in rate of growth during the two and a half years of volcanic activity as compared with the years just preceding. Numerous trees in the vicinity of the Headquarters Cabin, where ash was about 20 inches deep, grew more in height during each of the years of volcanism than in the year just before. It may be that killing of most of the under-

TABLE IV. *Average maximum depths of volcanic ash in which plants were able to survive. Includes plants north, east, and south of Parícutin Volcano*

Depths of ash in inches	Trees	Shrubs	Herbs
70	*Quercus*		
60	*Alnus*		
50	*Pinus* (5″–12″ diam.)	*Cestrum, Smilax*	
40	*Crataegus*		
	Arbutus		
	Pinus (Over 12″ diam.) *Pinus* (3″–5″ diam.),		
30		*Symphoricarpos*	*Argemone platyceras* Link & Otto *Mimosa*
		Bouvardia	
	Pinus (1″–3″ diam.) *Fraxinus, Prunus*		*Mirabilis longiflora* L., *Pteridium aquilinum*
		Baccharis, Fuchsia Pringlei *Coriaria, Senecio platanifolius*	*Stipa*
20	*Abies*	*Amelanchier, Salix*	*Cynodon, Digitaria, Asclepias neglecta* Hemsl. *Geranium Seemannii* Poyr., *Senecio affine* Stutz. *Erythrina leptorhiza* DC., *Solanum michoacanum* (Bitter) Rydb. *Passiflora exsudans* Zucc., *Bromus pendulinus* *Valeriana procera* HBK., *Erigeron scaposus* DC. *Desmodium millicum* (HBK.) DC., *Ipomoea* sp. *Salvia prunelloides* HBK., *Sporobolus indicus* (L.) Br. *Fuchsia fulgens* DC.
	Pinus (Under 1″ diam.), *Tilia*	*Arctostaphylos*	
10			*Galium mexicanum* HBK., *Galium trifidum* L.
	Clethra obovata Hook. & Arn., *Symplocos*		

FIG. 10. Pine forest about two miles northwest of volcano, showing effects of 46-inch ash deposit. Most trees have broken branches; some have tops broken also. A few medium sized trees (most resistant size class) remain alive. August, 1945.

growth actually improved growing conditions. The average annual diameter increase, during the period of volcanism, of the 65 pines bored (fig. 2) was 4.2 mm. The average for each of the ten years preceding was 6.74 mm. This is not a great difference considering that many of the trees occupy positions close to the volcano and are constantly subjected to conditions that may eventually lead to their deaths. Some of the decrease in growth rate is normal slow-down that comes with greater age and diameter.

(2) Oaks

Oaks are among the most resistant to volcanism of all plants found here. Because of their small numbers at the lower altitudes and their scattered occurrence it was not possible to correlate their condition with depth of ash as completely as was possible for the pines. There were oaks with at least vestiges of life in ash as deep as was possible to measure—226 inches. Such a "vestige" might be only a green branch on a tree which otherwise seemed quite lifeless. Probably many with such bits of life in evidence never recovered enough to retain it for long. As in the pines, a branch or tree top buried to its tip never lives. Also like the pines, the medium sized trees, those between 5 inches and a foot in diameter survived best. An indication of the hardiness of the oaks is seen in the fact that in one-fifth of the ash field sites where living oaks were studied the ash was over 6 feet deep. (See fig. 11.) Usually, however, there were few alive if ash was two or three feet deep, and large trees generally failed to survive in 20 inches.

(3) Other Trees

Madroña, a small tree and minor member of the community, withstood burial rather well. Usually it was dead in two or three feet of ash, but several living specimens were seen in 78 inches, one in 95 inches, and another in 118.

Crataegus is usually low and quite branching from the base, and so not well adapted to withstand deep accumulations of ash but it did well for its size. It was often alive in ash up to 40 inches. It is a common habitant of fence rows were it may be the only plant left alive. Again, any branches completely covered die. Here, breakage of branches does not necessarily result in death of the tree, as in pines, because branches continue to function when partly broken off.

Alnus is small but has wonderful capacity for recovering from deep burial. After all its branches and leaves are gone, buds may come directly from the old trunk and the plant starts to grow again. It is not known if such recovery is more than temporary.

(*b*) *Shrubs*

Probably the most abundant shrub in ash-covered areas is Baccharis. It is most characteristic of fields but is also present in pine woods. Several plants which were

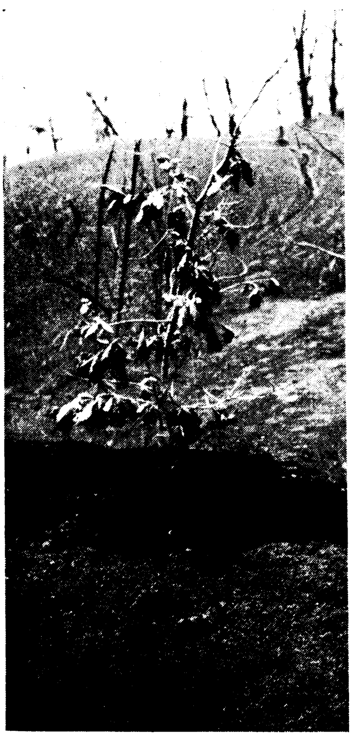

FIG. 11. A living oak tree with 6 feet of its body buried by ash and 7 feet above, unburied. July, 1945.

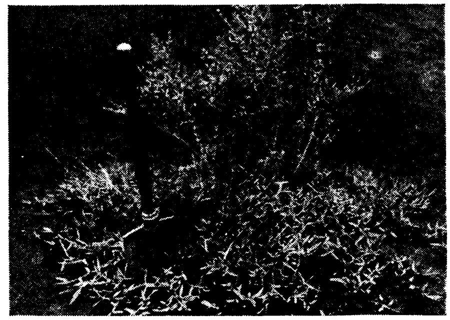

FIG. 12. Baccharis shrub with Bermuda grass (*Cynodon dactylon*) around it. Ash about ten inches deep. September, 1945.

partially buried were excavated (fig 12). All of them which were excavated had adventitious roots growing from the buried parts of the stems. This species was growing successfully in ash up to a depth of 22 inches and was one of the few plants which were spreading.

After Baccharis are two other shrubs, about equal in importance. In both fields and woods Cestrum is common although it never grows in closed stands. At times it is the only shrub. It has a capacity for continuing growth when only a small part extends above the ash. One plant was seen in 50 inches and two others in 46 inches of ash. The plants were healthy looking and bore quantities of fruits and flowers. *Fuchsia Pringlei* is a shrub in pine woods where it sometimes forms almost a continuous ground cover. This species is said to grow to a height of several feet but here it was usually not over two feet. It grew in ash to 22 inches. Excavations of several indicated that the parent plant was killed back, in all cases, to the old soil level and that it then resprouted.

A plant which is striking in appearance because of its red flowers which stand out against the background of ash is Bouvardia. All that were excavated had been killed back to the old soil and then sprouted from the old stem base. It generally survived successfully in ash which had accumulated to a depth of 20 inches,

Fig. 13. Small field near base of Cerro Angáhuan. Parícutin erupting in distance. Ash about 8 inches deep. Bermuda grass covers about a third of ash surface and has continued to grow all during period of eruption. August, 1945.

and one was found where the ash was 29 inches deep.

(*c*) *Herbs*

Herbs most important in the ash fields, from the standpoint of surface coverage, were grasses. Chief of these was Bermuda grass, *Cynodon dactylon*. In fields with not over 10 inches of ash this grass covered as much as half of the surface area (fig. 13). In a field with 15 inches of ash this grass covered about 10 per cent of the surface. Where ash was deeper, up to 20 inches, it persisted but only around stumps, bushes, and trees (fig. 14). It is not evident why grass would grow there and not elsewhere, but perhaps it obtained a degree of protection against wind and water erosion, or possibly received some special nutrition from dead fragments of bark. Several clumps of the grass were excavated and rhizomes were traced all through the ash down to the old soil surface. It is quite evident that the plants grew throughout the whole eruption. Where established the grass was spreading vegetatively. In a few places it had started to grow in old soil in the bottoms of small gullies in ash. In such cases it helped to control erosion. *Digitaria velutina* (Dc) Hitch., crab grass, has growth habits quite similar to those of Bermuda grass. It occupied habitats similar to those supporting Bermuda grass but there was less of it.

Fig. 14. Bermuda grass grown up through nearly two feet of ash at base of a dead pine tree. September, 1945.

Stipa mucronata was widely distributed in areas where ash was not over 22 inches deep. The plants were scattered in the usual bunch grass manner. It is believed that Stipa propagated vegetatively from old plants also.

Several dicotyledonous herbs were found in the ash fields. These either grew throughout the period of volcanism or else they sprouted from parent plants which were killed back to the old soil level.

First members of these dicotyledons are *Argemone platyceras* (fig. 15) and *Mirabilis longiflora* (fig. 16). They are large herbs and the most conspicuous plants in the fields. They produce large white flowers which stand out against the dark ash background. The deepest ash in which they were found was 29 inches for Argemone and 24 for Mirabilis. Other important herbs of the fields are *Asclepias neglecta* and *Erigeron scaposus,* in ash to 20 inches, and bracken fern (*Pteridium aquilinum*), in ash to 24 inches.

Century plant (*Agave,* sp.) a monocot which was probably originally planted in every situation where seen, deserves special mention because of its ability to retain life, even if completely buried for a long time. Plants may be buried under ash for a year or more and then, if uncovered through water erosion, appear quite alive and ready to continue to grow.

Propagation by Seeds

Consideration has been given thus far largely to plants which were present when volcanism began and then continued to grow without interruption, or were killed back and grew again from sprouts. Reproduction by seeds is just as necessary in these plant communities as vegetative propagation, for it will be only by means of seeds that many species which have been completely killed out can come back and it is only by seeds that some species can increase in numbers when established.

Fig. 15. Prickly poppy (*Argemone platyceras*) grown up through about 20 inches of ash. September, 1945.

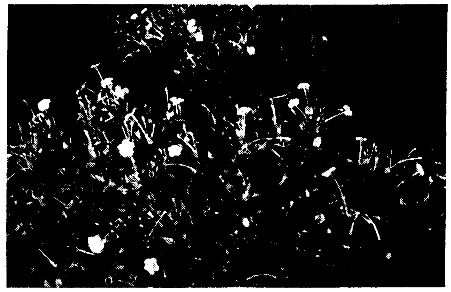

Fig. 16. *Mirabilis longiflora* grown up through about 16 inches of ash. September, 1945.

There are two potential sources of seeds for the ash covered areas: seeds buried under the ash in the old soil, and those whch had been dispersed after volcanism started and were therefore deposited at various levels in the ash. The problem of seed germination is associated with kinds and amounts of nutrients and possibly inhibitors which may be present in the raw ash. At the present time these problems remain largely unsolved.

Seeds in old soil

Undoubtedly many seeds were buried when volcanic ash started to fall over the area in 1943. Some of these seeds might be expected to germinate when moisture conditions are favorable, and, if the ash layer is not too thick, one would expect seeds to be able to germinate and seedlings to push through and reach light and hence become established. But apparently lack of aeration or some other influence prevents that, for seedlings do not occur. Constant watch was kept for seedlings which had germinated in the old buried soil, but none was found, not even in ash as little as two inches thick. (See the barren condition in fig. 7, taken in an old field where ash was about 3 inches deep.) Presence of carbon dioxide in inhibiting concentration or lack of oxygen supply are suspected, but it is not known what prevents germination and growth of seedlings through ash. Where erosion removed the ash a good crop of weeds usually soon appeared, indicating that viable seeds were present.

Seeds in new ash

Two instances were observed in the field of germination of seeds which were disseminated during the period of volcanism. About a dozen pine seedlings, probably *Pinus pseudostrobus,* were found five miles east of the volcano where ash was between 6 inches and a foot deep. The seeds had germinated at a depth of about four inches below the surface. When seen the seedlings were well established, parts above ground were six to eight inches tall, and roots had penetrated down into the old soil. Baccharis seedlings were also found. A large clump with hundreds of seedlings had started in about 22 inches of ash. When seen the tops were about five inches tall. Seeds had germinated about a half inch below the surface of the ash. Roots of these seedings had not yet reached the old soil surface and ultimate success was uncertain. Some of the ash in which they were growing appeared to have been brought by water and so may have been leached of toxic substances, and also under the circumstances, one could not be sure there was not some organic matter mixed with it.

Growing of Maize in Ash Fields

Erosion of fields by water and killing of plants by ash which settled as a film on the leaves apparently discouraged the Tarascan Indians so much that in 1945 almost no corn was grown in the area of this study. In most places it would have been impossible as well as impractical to plant. But small plantings in and near the village of Angáhuan indicated that possibly not all fields were as unfit for use as their owners may have believed. Ash in Angáhuan averaged about 14 inches deep. A few optimists planted corn and were obtaining an average crop (fig. 4). Grains were planted very deep so roots of the plants could soon reach the old soil.

The success in Angáhuan indicates that hundreds of acres of fields lying idle were capable of producing corn. Observations indicated that a field with not over a foot of ash, which lies to the windward side of the volcano so it is not subjected to constant ash fall, and which is in a position to avoid erosion and silting by water, could profitably be planted to corn. The grains should be planted 6 or 8 inches deep. It is likely that after a year or two of cropping, yields would be as good or better than formerly because of the availability of new nutrients released from the ash.

Summary

The new volcano, Parícutin, which was born on February 20, 1943, in the state of Michóacán, Mexico, began at once to change the character of vegetation in a variety of ways: by complete destruction, by selective killing, by changing the growth rates of plants that remained, and by providing a new mineral stratum which would affect germination and seedling establishment. Field studies for this report were carried on in the summer of 1945. They consisted of a reconstruction, through studies of unaffected forests nearby, of the ecologic character and floristic composition of the vegetation as it had been before volcanism started, and comparable studies of the affected vegetation after two and a half years of volcanic activity.

At the time of this study the summit of the main cinder cone stood about 1,500 feet above the original land surface (altitude 7,400 feet), the cone was a mile in diameter at the base, lava flows covered about five square miles, and hundreds of square miles of forest and fields were

mantled by wind-borne ash. Practically all the study was done in an area about 10 by 12 miles in extent, with the volcano near the center.

There are three main forest types in the region. Below about 9,000 feet altitude is a pine-oak forest. In the climax condition this forest contains a mixture of oak and pine, with oak probably in the majority. There is very little of the climax. There are three species of pine, the two main ones being *Pinus pseudostrobus* and *P. leiophylla*. There are eight oaks, two being most abundant, *Quercus orbiculata* and *Q. magnoliaefolia*. Pine reproduces more successfully in open woods and pastures and abandoned fields. Since disturbance is so common in this country where land is scarce, pine has come to be the main tree in most parts of this zone. Between 9,000 and 10,000 feet, *Abies religiosa* is dominant. Above 10,000 feet pines are again present and in almost pure stands.

Measurements of the thickness of the ash were made in many places in the study area and these are recorded on a map. The greatest depth it was possible to measure was 226 inches. Close to the main cinder cone ash was even deeper than could be measured.

The damage done by aa lava flows as they move toward and then overwhelm trees is not so much the result of excessive heat as of mechanical breakage. Even contact with a flow may not kill a plant, provided it is not injured mechanically. This is because surface lava cools quickly and serves as an insulation against the hot lava within the flow.

Several square miles of vegetation has been completely destroyed. The old soil had been buried so deeply by lava flows, cinders, and ash that its influence has been lost and revegetation will have to start upon the new volcanic materials.

Outside of the area of total destruction there had been selective elimination of plant species or of certain size classes of a species. Several factors, individually or collectively, caused this destruction: burial, partial or complete; breakage because of the weight of ash upon the plant; starvation because of a coating of ash upon the plant or because of repeated destruction of leaves. Destruction of vegetation is correlated to a degree with depth of ash. However there is more destruction south and west of the volcano than north and east at the same depths of ash because prevailing winds keep plants to the south and west coated with ash.

Pines are sufficiently abundant through the region to permit a correlation between their survival and depth of ash. First to be killed are trees under an inch in diameter; next, in deeper ash, those from 1 to 3 inches, then those 3 to 5 inches, then those over a foot in diameter, and last those between 5 inches and a foot. Among those pines which have survived there has been little decrease in rate of growth during the years of volcanism as compared with the years just before, even among trees in deep ash.

Shrubs which have survived near the volcano have generally continued to grow all during the period of eruption. An exception was Bouvardia, which died back to the old soil surface and then grew up again from the stump. Herbs which have survived have generally been killed back first to the old soil surface but two grasses, *Cynodon dactylon* and *Digitaria velutina*, were able in many cases to keep ahead of the ash and grew all during the eruption.

In the summer of 1945 essentially the only plants in the area were the survivors from pre-volcanic times. There was scarcely any reproduction by seeds, a necessary process before bare areas can be repopulated.

Literature Cited

Backer, C. A. 1929. The problem of Krakatao as seen by a botanist. The Hague. (For sale by Martinus Nijhoff.)

Contreras Arias, Alfonso. 1942. Mapa de las provincias climatologicas de la Republica Mexicana. Secretaría de la agricultura y fomento. Dirección de Geografía, Meteorología e Hidrología. Instituto Geografico.

Eggler, Willis A. 1941. Primary succession on volcanic deposits in southern Idaho. Ecological Monog. **11**: 277–298.

——. 1945. Parícutin, 1945. Mazama **28** (12): 80–84.

Gadow, Hans. 1930. Jorullo. Cambridge Univ. Press.

Gratan, L. C. 1945. The genetic significance of Parícutin. Trans. Amer. Geophys. Union **26**: 249–254.

Griggs, Robert F. 1933. The colonization of the Katmai ash, a new and inorganic "soil." Amer. Jour. Bot. **20**: 92–113.

Kennedy, George C. 1946. Activity of Parícutin Volcano from April 12 to May 3, 1946. Trans. Amer. Geophys. Union **27**: 410–411.

Krauskopf, Konrad. 1946. Notes on activity of Parícutin Volcano during December, 1945. Trans. Amer. Geophys. Union **27**: 119.

——. 1946a. Notes on activity of Parícutin Volcano during January, 1946. Trans. Amer. Geophys. Union **27**: 218.

—— **and Howel Williams.** 1946. The activity of Parícutin Volcano during its third year. Trans. Amer. Geophys. Union **27**: 406–410.

Lawrence, Donald B. 1939. Continuing research on the flora of Mt. St. Helens. Mazama **21** (12): 49–54.

——. 1941. The "floating island" lava flow of Mt. St. Helens. Mazama **23** (12): 56–60.

——. 1944. Parícutin, the world's newest mountain. Mazama **26** (12): 15–34.

Leavenworth, William C. 1946. A preliminary study of the vegetation of the region between Cerro Tancítaro and the Rio Tepalcatepec, Michóacán, Mexico. Amer. Midl. Nat. **36**: 137–206.

Lowdermilk, W. C. 1947. Erosional phenomena associated with volcanic eruption of Parícutin, Mexico. Trans. Amer. Geophys. Union **28**: 269–270.

Munns, E. N. 1948. Discussion of "Erosional phenomena associated with volcanic eruption of Parícutin, Mexico" by W. C. Lowdermilk. Trans. Amer. Geophys. Union **29**: 414–415.

Ordoñez, Ezequiel. 1945. El Volcan De-Parícutin. Comision Impulsora y Coordinadora de la Investigacion Cientifica.

Pough, Frederick H. 1948. The fifth anniversary of Parícutin. Science **107**: 635–637.

Segerstrom, Kenneth, and Celedonio Gutierrez. 1947. Activity of Parícutin Volcano from May 4 to September 18, 1946. Trans. Amer. Geophys. Union **28**: 559–566.

Smith, Nathan R., and Robert F. Griggs. 1932. The microflora of the ash of Katmai Volcano with especial reference to nitrogen fixing bacteria. Soil Science **34**: 365–373.

Wilcox, Ray E. 1947. Activity of Parícutin Volcano from September 18 to November 30, 1946. Trans. Amer. Geophys. Union **28**: 567–572.

——. 1947a. Activity of Parícutin Volcano from December 1, 1946, to March 31, 1947. Trans. Amer. Geophys. Union **28**: 725–731.

Williams, Howel. 1945. Geologic setting of Parícutin Volcano. Trans. Amer. Geophys. Union **26**: 255–256.