Volcanoes of the Parícutin Region Mexico

By HOWEL WILLIAMS

GEOLOGIC INVESTIGATIONS IN THE PARICUTIN AREA, MEXICO

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VOLCANOES OF THE PARICUTIN REGION

By Howel Williams

ABSTRACT

The oldest bedded rocks in the Parícutin region comprise the Zumpinito formation, presumably of early Tertiary age. They consist of andesitic lavas, mudflow breccias, tuffs, and tuffaceous sediments, with subordinate sheets of welded rhyolite tuff, olivine basalt, and hornblende andesite that lie horizontally or almost so. Probably they underlie Parícutin volcano at a shallow depth.

Near Uruapan, the Zumpinito beds are closely associated with coarse-grained gabbros of uncertain age, which are probably coeval with the quartz monzonites found among the ejecta of the new volcano.

Following a long period of erosion, the huge volcanoes of Cerros de Tancítaro and Cerros de San Marcos were built to the southwest and northeast, respectively, of Parícutin by quiet effusions of pyroxene andesite. Shortly thereafter the andesitic volcanoes of Cerro del Aguila and Cerros de Angahuan were developed. The adjacent volcanoes forming Cerros de Los Hornos, which may have originated at the same time, continued to be active to a later date, building an overlapping group of cones of basalt and basaltic andesite. All these post-Zumpinito volcanoes are considerably eroded and, for that reason, are considered to be of late Pliocene or early Pleistocene age.

During the remainder of Pleistocene time, and subsequently, scores of large lava cones and hundreds of smaller cinder cones rose to dominate the landscape of Michoacán. Most of these erupted olivine basalt and olivine-bearing basaltic andesite, but many volcanoes and several isolated flows discharged during the last few thousand years consist of pyroxene andesite. No regular trend of differentiation has been detected.

The lavas now being emitted by Parícutin are olivine-bearing basaltic andesites essentially similar to the majority of the late Pleistocene and Recent flows of the region. Most of the young volcanoes are arranged without order; a few are alined northeast-southwest, parallel to the principal fissure zone at the new volcano.

INTRODUCTION

SCOPE OF WORK

On February 20, 1943, a new volcano burst into activity in the State of Michoacán, Mexico, approximately 65 miles northwest of Jorullo, the volcano born in 1759. The new volcano aroused widespread interest, and many geologists, both from Mexico and the United States, hastened to examine its activity. Particularly important has been the work of the late Ezequiel Ordóñez, dean of Mexican geologists, who first visited the volcano a few days after its birth and then returned at short intervals to observe its behavior. During the first 2 years the volcano was also studied closely by Jenaro González R., of the Instituto de Geología, and by W. F. Foshag, then a member of the United States Geological Survey.

In 1944 the National Research Council appointed a "United States Committee for the Study of Parícutin Volcano" under the chairmanship of R. E. Fuller to work in cooperation with a Mexican committee appointed by the Comisión Impulsora y Coordinadora de la Investigación Científica in order to stimulate, guide, and facilitate a program of research. In November of that year, through the financial support of the State Department's Interdepartmental Committee on Scientific and Cultural Cooperation, the writer was sent by the United States Geological Survey to prepare a reconnaissance map and report covering an area of about 600 square miles around the new volcano with the object of determining its relations to neighboring cones. The present paper embodies the chief results of that work. After laboratory examination of collections made between November 1944 and May 1945, the writer revisited the region during 5 weeks in July and August 1947, aided by grants from the Geological Society of America and the Board of Research of the University of California.

Geological boundaries were plotted on aerial photographs made in 1934 by the Compañía Mexicana Aerofoto. Unfortunately no topographic base has been compiled from these pictures; hence the geological map reproduced here as plate 8 is only approximately correct. Nevertheless, for the purpose in mind, the photographs sufficed. In May 1945, additional pictures were taken, by the same agency, of the area immediately adjacent to the new volcano after Kenneth Segerstrom of the United States Geological Survey had prepared a ground control.

By November 1944, when the present survey began, the region close to Parícutin was already so heavily blanketed by newly fallen ash that it proved impossible to make an accurate geological map. It can only be hoped that this critical area will be restudied when the cover of ash has been largely removed by erosion.

In the pages that follow, no attempt is made to present more than a brief summary of the history of the new volcano. Many published accounts are already available (see "References cited" at the end of this report), and shortly others by Foshag and González R. and by Wilcox may be expected to appear. Nor has any attempt been made to describe in detail the petrographic character of the Parícutin lavas and fragmental ejecta. Enough information is included, however, to indicate the principal features of the lavas and to show how they compare with earlier volcanic rocks in the vicinity.

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LOCATION AND TOPOGRAPHY OF AREA STUDIED

The region to be described lies near the southern edge of the Mexican Plateau, within the Neo-Volcanic Zone where it passes through the western part of the State of Michoacán. It is limited by parallels 19°21′ and 19°37′ N. and meridians 102°2′ and 102°22′ W., and covers approximately 600 square miles.

The new volcano lies near the center of the area, about 200 miles west of Mexico City and 15 miles west-northwest of Uruapan, the nearest town (fig. 74). By paved highway, the distance between Uruapan and Mexico City is 330 miles; by railroad the distance is even longer. About 12 miles north of Uruapan, a branch road leaves the paved highway to run westward through Angahuan to the edge of the Parícutin lava field near Cuezeño and the buried town of San Juan Parangaricutiro. Only during the dry season, and then only with difficulty, is it possible to continue westward by car from San Juan Parangaricutiro to Peribán and Los Reyes. From Angahuan another road runs northward to Corupo and thence via San Felipe to rejoin the main highway

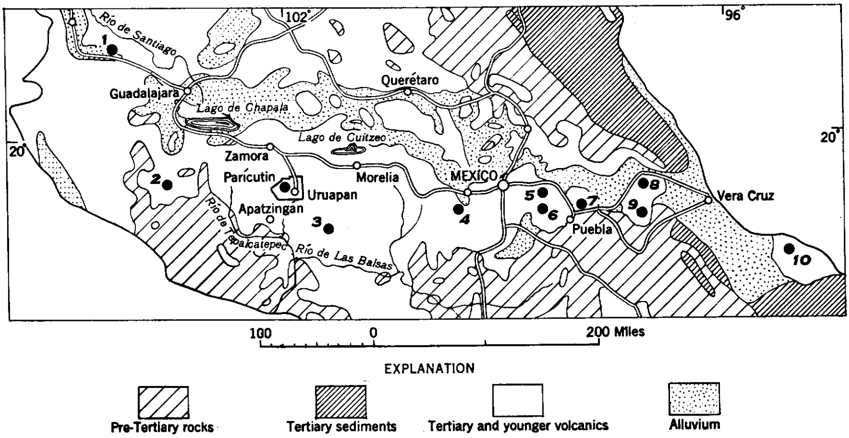

FIGURE 74.—Sketch map of central Mexico, showing location of area studied. Some of the important volcanoes, several of which have erupted in historic times, are indicated by numbers, as follows: (1) Ceboruco, (2) Colima, (3) Jorullo, (4) Nevado de Toluco, (5) Ixtaccíhuatl, (6) Popocatépetl, (7) Malinche, (8) Cofre de Perote, (9) Orizaba, (10) San Andrés Tuxtla. Main highways are shown by double lines. Geological boundaries taken from Geological Map of North America, by G. W. Stose, 1946.

above the village of Capacuaro. Pantzingo, close to the southeast margin of the new lava field, is accessible by a poor truck road that leaves the highway near Cheringerán. Another poor road links Peribán with the villages of Apo and Tancítaro, but it is not recommended for ordinary passenger cars even in the dry season. Buses connect Uruapan with Los Conejos, whence horse trails lead to Tancítaro either through Tejamanil or Las Barrancas.

Parícutin volcano stands in the heart of a country peopled by Tarascan Indians, in a landscape considered by many to be the most beautiful in Mexico. Most of the region is drained westward by the Río de Itzícuaro and its tributaries, which go to feed the Río de Tepalcatepec, itself a branch of the mighty Río de Las Balsas. The remainder of the region is drained southward by springs and streams that swell the Río de Cupatitzio, another feeder of the Río de Las Balsas.

Although satisfactory topographic maps are available only for the immediate vicinity of the new volcano, some idea of the general features of the region may be gained from the sketches and photographs accompanying the present report. In the southern part of the area the land forms are primarily products of erosion; elsewhere the landscape is dominated by volcanic cones. Even the oldest of these still retain slopes that coincide closely with the original surfaces; the youngest are so fresh that they have scarcely been modified by denudation. Within the limits of the geologic reconnaissance map reproduced as plate 8, more than 150 cinder cones and more than 20 large lava cones may be counted, and the mapped area is only part of a vastly larger volcanic field, 500 kilometers long and 100 kilometers wide, extending through the States of México, Michoacán, and Jalisco. As Graton (1945a) has remarked, "probably nowhere else in the world is there such a great concentration of conspicuous volcanic cones over so large an area * * * and nowhere are the basaltic cones more numerous than in the western half of Michoacán, nor in the immediate environs of Parícutin."

The town of Uruapan stands on the edge of the Tierra Caliente, approximately a mile above sea level. The adjacent plain is deeply incised by the gorge of the Río de Cupatitzio and is flanked on the south and east by hills that rise from a few hundred to more than a thousand feet above the general level. The town of Peribán, in the northwest corner of the area mapped, lies at about the same elevation. Farther west gentle slopes descend to the sugarcane country around Los Reyes at an elevation of approximately 4,200 feet.

By far the greater part of the region, however, stands at much higher levels than those just cited. Northward the region of coffee and banana plantations around Uruapan gives place rapidly to pine-clad hills and mountains. Within 12 miles the highway climbs 2,000 feet. Most of the cultivated valleys between the volcanoes lie above 6,500 feet and below 8,000 feet. Here one finds the principal settlements.

Among the volcanoes themselves, the largest and highest by far is the denuded cone forming Cerros de Tancítaro, the summit of which rises almost to 13,000 feet (3,845 meters), towering a mile above the encircling, younger cones (pl. 8; fig. 75). Next in prominence are the twin volcanoes that make up Cerros de Angahuan (figs. 78, 79), culminating in Cerro de La Purísima at an elevation of approximately 10,800 feet (3,292 meters). Then comes the arresting peak of Cerro del Aguila (fig. 77), which also exceeds 10,000 feet in height. Most of the host of cinder cones that crown the lava-built volcanoes and dot their flanks range from 100 to 1,000 feet in height. Late in 1947, the top of Parícutin itself stood at an elevation of 9,100 feet (2,775 meters); the elevation of the cornfield from which it started was approximately 1,400 feet lower.

Eighty percent of the region around the new volcano is forested, chiefly by pines and oaks. Above 10,000 feet, firs predominate. Prior to the present eruptions, half of the cultivated land was given over to corn; less important crops were wheat and beans. Apples, pears, and other fruit were plentiful. It was a countryside as pleasant as its people.

PREVOLCANIC HISTORY

According to the paleogeographic maps prepared by Kellum (1944), almost all the Neo-Volcanic Zone of Mexico, including the State of

Michoacán, was dry land throughout Permian, Triassic, and Lower Jurassic time. According to Robles (1943), on the other hand, geosynclinal seas covered Michoacán intermittently from the Triassic to nearly the close of Cretaceous time. In Kellum's opinion, a seaway connected the Pacific Ocean via southern Jalisco and southern Michoacán with an enlarged Gulf of Mexico that covered the eastern end of the Neo-Volcanic Zone during Upper Jurassic and Lower Cretaceous time. "Broad warping of the continent in Upper Cretaceous time," says Kellum, "marked the beginning of the Laramide revolution which reached its maximum intensity after Maestrichtian time and continued with decreasing vigor in the early Tertiary." During the Upper Cretaceous epoch the seas that had covered the Parícutin region perhaps from Triassic time, certainly from Upper Jurassic time, were expelled by broad uplifts accompanied by igneous intrusions on a large scale.

No pre-Cretaceous rocks are exposed within or near the area to be described; hence there is an unfortunate lack of information concerning the nature and structure of the prevolcanic bedrock of this part of Michoacán.

THE NEO-VOLCANIC ZONE OF MEXICO

Precisely when volcanic activity began in the Neo-Volcanic Zone is still uncertain. Except in a few areas, there is doubt also concerning the succession of the various types of lava.

Robles (1943) states that the oldest lavas are generally andesites, dacites, and rhyolites of Eocene age, but among these he includes the lavas of Tancítaro, which, as noted below, are very much younger. Resting on the supposedly Eocene flows, according to Robles, are andesites and basalts of Pliocene age; then follow Pleistocene latites, andesites, and basalts and finally olivine basalts of Recent age. De la O. Carreño (1943) presents a slightly different succession, beginning with diabases in the early Cenozoic, followed by propylitized andesites in the Miocene, the andesites and rhyolites in the Pliocene, and lastly Pleistocene and Recent flows of basalt. Agreeing with Ordóñez, he assigns the great cones of Tancítaro, Orizaba, Nevado de Toluca, Nevado de Colima, and Ixtaccíhuatl to the Pliocene epoch.

Robles (1943) cites Ordóñez to the effect that the lavas of Eocene age are mainly hornblende andesites and that the ones of Pliocene age include both hornblende and pyroxene andesites and basalts, whereas the Recent lavas are latites, basaltic andesites, and basalts. In the State of Tlaxcala, according to Blásquez (1946), the first eruptions that followed the emergence of the area from the Cretaceous sea were andesitic, and no basalts were erupted until Pleistocene time.

From the foregoing summary it is apparent that much uncertainty remains concerning the age and sequence of the Tertiary lavas, and until the fossil floras and faunas of the interbedded tuffs are examined, the doubts will not be dispelled. The general impression among Mexican geologists is that the early Tertiary flows are dominantly andesitic and the later ones chiefly basaltic. This may prove to be correct for the Neo-Volcanic Zone as a whole, as it seems to be in Nicaragua, but it is true only in a broad sense of the region around Parícutin.

PREVIOUS WORK ON VOLCANISM IN MICHOACAN

Information relating to the volcanic history of that part of the Neo-Volcanic Zone which crosses Michoacán is particularly scarce. Publication of the results of work done in the southern part of the State by Jenaro González R. will do much to clarify the picture.

Flores (1946) reports that volcanism began in the northeast part of the State with discharge of andesite during the Miocene epoch. Then rhyolites were erupted, and, probably in Quaternary time, these were followed by outflows of basalt.

In eastern Michoacán, Ordóñez (1906) noted that near Lakes Cuitzeo and Pátzcuaro the oldest volcanic rocks are andesites and rhyolites. These include the widespread sheets of welded tuff adjacent to Morelia. Resting on these are young basaltic flows. Between Lake Pátzcuaro and Uruapan, andesites again underlie basalts, and, judging from the schematic profile drawn by Ordóñez, a long interval of erosion preceded the eruption of the younger flows.

Blásquez (1946b), writing of the geology of northern Michoacán, says that volcanism was initiated by the discharge of hornblende andesites during the Miocene epoch. Then followed eruptions of dacite and rhyolite. At the close of the Pliocene and during the Pleistocene epoch, these volcanic rocks were largely buried by copious outpourings of basaltic andesite and basalt.

Robles (1943), in discussing the area immediately south of Uruapan, states that two well-defined horizons are present in the gorge of the Río de Cupatitzio. These rest on a complex igneous basement composed of diorites, monzonites, dacites, latites, and andesites. One horizon is described as essentially "cineritic," deposited by eolian and fluvial action and composed of incoherent igneous materials charged with angular debris of fragmental latite. The other horizon is made up of chaotic deposits laid down by torrential waters and mixed with pyroclastic ejecta. These deposits were considered by Robles to be the products of "turbulent avalanches." No doubt both horizons belong to the Zumpinito formation described in the pages that follow.

Robles assigned them to the Pleistocene epoch despite the fact that he referred to Cerros de Tancítaro as Eocene in age. The present survey shows that Tancítaro was built on the eroded surface of the Zumpinito formation, and since part of its original conical form is still preserved, it cannot date farther back than late Pliocene if indeed it is older than early Pleistocene. Besides, if the Zumpinito formation were actually of Pleistocene age, cones of similar materials should still exist in the vicinity, but there is no trace of the volcanoes from which the bouldery deposits of the Zumpinito were derived. They must first have been leveled by erosion, and then their remnants must have been buried by the cones of Quaternary age that now dominate the Tarascan landscape.

ZUMPINITO FORMATION

GENERAL STATEMENT

Within the area covered by this report, the oldest volcanic rocks are referred to as the Zumpinito formation from their occurrence in magnificent sections near the Zumpinito hydroelectric plant, a few miles south of Uruapan. The formation underlies Uruapan itself and also the adjacent plain, where it is mantled by a veneer of basaltic ash blown from neighboring cinder cones. It is exposed in the gorges of the Río de Cupatitzio and its tributaries, and it forms the conspicuous Cerro de La Cruz on the outskirts of Uruapan, as well as Cerro Colorado and the Cerro de Las Ventanas to the east. The road connecting Uruapan and Apatzingán winds over a mountainous terrain carved in beds of the Zumpinito formation, and presumably the formation extends south at least as far as the valley of Apatzingán. It reappears from beneath the younger volcanoes to the west of Parícutin in the low country between San Francisco and Los Reyes.

Except on Cerro de Charanda, close to Uruapan, where the beds are tilted to a high angle, the Zumpinito formation lies either horizontally or has low initial dips. No original volcanic forms are preserved; hence the erosional topography carved in the rocks of the Zumpinito formation contrasts boldly with the constructional forms built by the later volcanoes. Nor is it possible to locate any of the vents from which the lavas and fragmental ejecta of the Zumpinito formation were expelled.

No fossil evidence has yet been found which indicates the age of the Zumpinito formation. Since, however, the formation includes at least one major disconformity and was already deeply dissected before the Tancítaro volcano began to develop, it must cover a long span of Tertiary time, and the topmost beds can hardly be younger than middle Pliocene.

Probably the Zumpinito formation is equivalent to the great mass of predominantly andesitic lavas that makes up the rugged country between Morelia and Zitácuaro, and presumably it is also to be correlated with the early volcanic rocks bordering the valley of Mexico.

To those familiar with the Cascade Range in the United States, the Zumpinito formation will call to mind the Eocene to Miocene volcanic rocks of the western Cascades, just as the younger volcanoes of the Parícutin region will call to mind the Pliocene, Pleistocene, and Recent cones of the high Cascades.

DETAILED DESCRIPTION

In composition the rocks of the Zumpinito formation within the area in question range from olivine-rich basalts to rhyolites. On Cerro de La Cruz and Cerro Colorado, as well as in the mountainous country crossed by the Uruapan-Apatzingán road, lavas predominate. Among the hills limiting the plain of Uruapan on the east and southeast, deeply weathered tuffaceous sediments are more abundant; in the gorge of the Río de Cupatitzio and the low country near Los Reyes, coarse, bouldery mudflow deposits are the principal units. Noteworthy is the marked lateral and vertical variation within the formation.

The oldest beds of the Zumpinito formation are those to be seen in the gorges of the Río de Cupatitzio and Río de Los Conejos near the Zumpinito hydroelectric plant and Cascada de Tzaráracua. These are deposits of volcanic mudflows or lahars. Their thickness approximates 450 feet. Typically they are chaotic, unstratified beds in which angular and subangular blocks up to 10 feet across lie in a pale-gray tuffaceous matrix. Most of the larger fragments are of hornblende andesite; with these are pieces of pyroxene andesite, dacite, and basalt. The fine matrix consists of andesitic crystalvitric tuff. Locally lenses of andesitic tuff and conglomerate separate the sheets of laharic debris, but they are quite subordinate. Except for a few thin layers of air-borne ejecta, all the deposits were laid down either by streams or by torrential volcanic mudflows.

Other laharic deposits accompanied by tuffs and tuffaceous clays crop out near Peribán and Los Reyes. Hereabouts they are partly covered by Recent flows of olivine basalt and by Pleistocene and Recent laharic beds deposited by torrents from the flanks of Cerros de Tancítaro. Indeed, beds of somewhat similar character are being laid down today by floods that wash the newly fallen ash from Parícutin into the canyons to mingle with water-worn boulders of andesite from the Tancítaro cone.

Near the type locality, the coarse laharic detritus grades upward into brownish and reddish tuffaceous clays, the transition zone forming benches along the rim of the Cupatitzio gorge. Close to the road that skirts the foot of Cerro de Jicalán the clays have been extensively quarried for the making of adobe bricks.

A short distance to the south, where the Apatzingán road crosses the Río de Los Conejos, the clays are covered in turn by spheroidally weathered flows of olivine basalt. These continue westward for about 2 miles. Farther west, an upper series of laharic deposits is exposed; then for 6 miles to the summit of the pass, the road crosses massive flows of porphyritic pyroxene andesite.

A similar assemblage of rocks forms the dissected country traversed by the trail leading from Los Conejos through Los Lobos and Las Barrancas. Here, and particularly in the canyons of the Río del Fresno and its tributaries, there is evidence that the Zumpinito formation was already deeply eroded before the first flows of the Tancítaro volcano were erupted. Near Tejamanil, the disconformable contacts lie at about the same elevation as the base of Parícutin, approximately 8 miles to the north.

Attention is directed next to the hills flanking the plain of Uruapan on the east. Where the Río de San Antonio is incised into the plain, the canyon walls reveal coarse laharic beds. Overlying these are varicolored and intensely weathered tuffaceous clays, between 600 and 700 feet in thickness. These form most of Cerro de Las Ventanas and the adjacent Cerro de Los Tecates. On the southernmost peak of Cerro de Las Ventanas, the clays are capped by a thick flow of coarsely porphyritic hornblende andesite; on the northern peaks and the neighboring parts of Cerros de Los Tecates, the capping rocks are flows of olivine-rich basalt.

Farther north, among the hills adjoining the Apatzingán railroad, the tuffaceous clays carry many concretions of opal and chalcedony and occasional geodes lined with drusy quartz. Close to Caltzontzin, in the narrow strip separating the railroad to Apatzingán from the one to Mexico City, the clays are covered by rhyolite tuffs up to 400 feet thick. In their lower part these tuffs are strongly welded, pinkish, streakily banded rocks that simulate lavas; upward they become less compact and finally grade into friable lump pumice. Hence they are regarded as the products of nuées ardentes. Before the overlying beds were laid down, a long period of erosion intervened. Discussion of the evidence is best deferred, however, until the Zumpinito rocks on Cerro de La Cruz and Cerro de Charanda are described.

Cerro de La Cruz, the high peak that rises from the edge of Uruapan, is composed chiefly of flows of pyroxene andesite that are almost horizontal. Hence the conical form of the mountain (fig. 82), though deceptively like that of many younger volcanoes in the region, is solely the result of erosion. Much of the lava on the higher parts of the mountain is thoroughly decomposed. Where the flows are thick and cut by vertical joints, the weathering is spheroidal; where they are marked by closely set, flattish joints, thin plates of fresh andesite are encased in bands of brownish clay up to several feet in thickness. Locally, indeed, alteration has gone so far that the lavas are difficult to distinguish from lapilli tuffs and agglomerates, sporadic kernels of unaltered rock lying in a tufflike matrix of clay. These alterations are ascribed, not to deuteric solutions, but to weathering in a climate warmer and more humid than that which now prevails.

The lower slopes of the mountain consist mainly of rotten tuffs and tuffaceous sediments similar to and probably of the same age as those seen on Cerro de Las Ventanas.

At the southwest foot of the mountain lies the small hill known, on account of the red, loose, crumbling earth of which it is largely composed, as Cerro de Charanda. Its steeper face has been widely stripped for clay used in the local adobe factory. Interbedded with the clay are thin layers of tuff breccia and flows of decomposed olivine basalt that dip to the southwest at angles of approximately 30°. On the summit and eastern slopes of the hill exposures are scarce and only tuffaceous clays are to be seen. It appears, therefore, that Cerro de Charanda is a tilted block and that the gully separating it from Cerro de La Cruz was developed by erosion along a fracture zone.

We may now return to the vicinity of Caltzontzin for evidence of a pronounced disconformity within the Zumpinito formation. Thereabouts the hummocky top of the rhyolite tuffs already described as products of nuées ardentes is patchily covered by well-rounded fluviatile sands and conglomerates largely composed of rhyolitic debris. Resting on these is a thick series of basaltic flows that makes up most of Cerro Colorado. Southeastward from their contact with the rhyolitic sediments, the basal flows of basalt are traceable for about 2 miles down a slope averaging 10° to 15°, so that they rest on successively lower units of the Zumpinito formation. In the opposite direction they lie on reddish-brown tuffaceous clays similar to those that underlie the rhyolitic tuffs and those that form the lower slopes of Cerro de La Cruz. Possibly the andesite flows forming the upper slopes of Cerro de La Cruz once covered the rhyolitic tuffs and were removed by erosion prior to the eruptions of basalt. Alternatively, the andesitic and basaltic flows are approximately coeval. Unfortunately the evidence on which to base a decision is buried by Recent flows that fill the valley between the two mountains. If the first suggestion is correct, the erosion surface cut before the discharge of the basalts had a relief of more than 2,500 feet; and even if the other suggestion is the proper one, the relief was more than 1,000 feet.

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The basalts of Cerro Colorado are highly vesicular, thoroughly decomposed flows abnormally rich in iddingsite. They are exposed in magnificent sections along the railroads that wind across the lower slopes (fig. 82). Nothing characterizes them more than their spheroidal weathering, with ovoid kernels of relatively fresh lava lying in a rotted, clayey matrix. On the higher flanks of the mountain these rounded kernels, from the size of peas to 6 feet across, are littered in profusion over the surface. Some of the alteration of the flows may well be the result of deuteric solutions, but, as in the case of the andesitic flows of Cerro de La Cruz and the tuffaceous clays in other parts of the Zumpinito formation, the prime cause is thought to be weathering under the warmer and wetter climate that prevailed at the time of deposition.

INTRUSIVE ROCKS OF UNDETERMINED AGE

At two localities in the Parícutin region, the Zumpinito formation is associated with coarse-grained intrusive rocks. The first of these is at Parícutin volcano itself. During the early stages of growth the new volcano blew out many large fragments of plutonic rock, chiefly quartz monzonite but perhaps also granite and diorite. The number and size of the fragments have since diminished until now those found in the lavas and bombs are extremely rare and small. They are described more fully on pages 258–259. Here it is enough to remark that there is no satisfactory evidence to show whether the fragments were torn from a plutonic basement beneath the Zumpinito formation or from a body intrusive into them. Quartz monzonites and diorites are widespread around Jorullo, and they also occur as inclusions in the lavas and fragmental ejecta of that volcano. Ordóñez (1906) held the view that similar plutonic rocks underlie the vast accumulation of lavas forming the plateaus of Ario de Rosales and Pátzcuaro. As to their age, the evidence is meager. Robles (1942) says that many plutonic rocks in the Neo-Volcanic Zone of Mexico date back to late Eocene or possibly to late Mesozoic time. De la O. Carreño (1943) and others assign them merely to the early Cenozoic. Probably many of them form stocks intrusive into the early Tertiary lavas, like the stocks intruded among coeval flows in the Cascade Range of the United States.

The other locality where intrusive rocks are found is a low ridge, called the Bolita or Cerrito de La Magdalena, that rises from the plains about a mile and a half south of Uruapan. Many shallow clay pits have been dug in the summit of the ridge, but none penetrates the mantle of decomposed ash to the underlying rocks. Only in the quarry at the western end of the ridge are these revealed. Here gabbroid rocks of extremely variable texture are cut by thin veinlets of pegmatite. Except for a few boulderlike kernels of fresh material, the rocks are thoroughly rotted to whitish and reddish-brown clay. Their microscopic features are described on pages 233–234. Here it suffices to note that both the field appearance and microscopic textures are so radically different from those of any of the volcanics in the Zumpinito formation that their intrusive character is hardly to be questioned even though no contacts are to be seen. Whether they form part of a basement of pre-Zumpinito age or, as seems more likely, represent a minor intrusion into the Zumpinito formation remains uncertain.

If the intrusive rocks just described do actually come from a plutonic floor, then that floor must have been deeply dissected prior to deposition of the Zumpinito formation; and even if they merely represent minor stocks intrusive into that formation, they serve to show that a long interval of erosion preceded the growth of Tancítaro and the younger volcanoes of the Parícutin region.

OLDER VOLCANOES OF POST-ZUMPINITO AGE

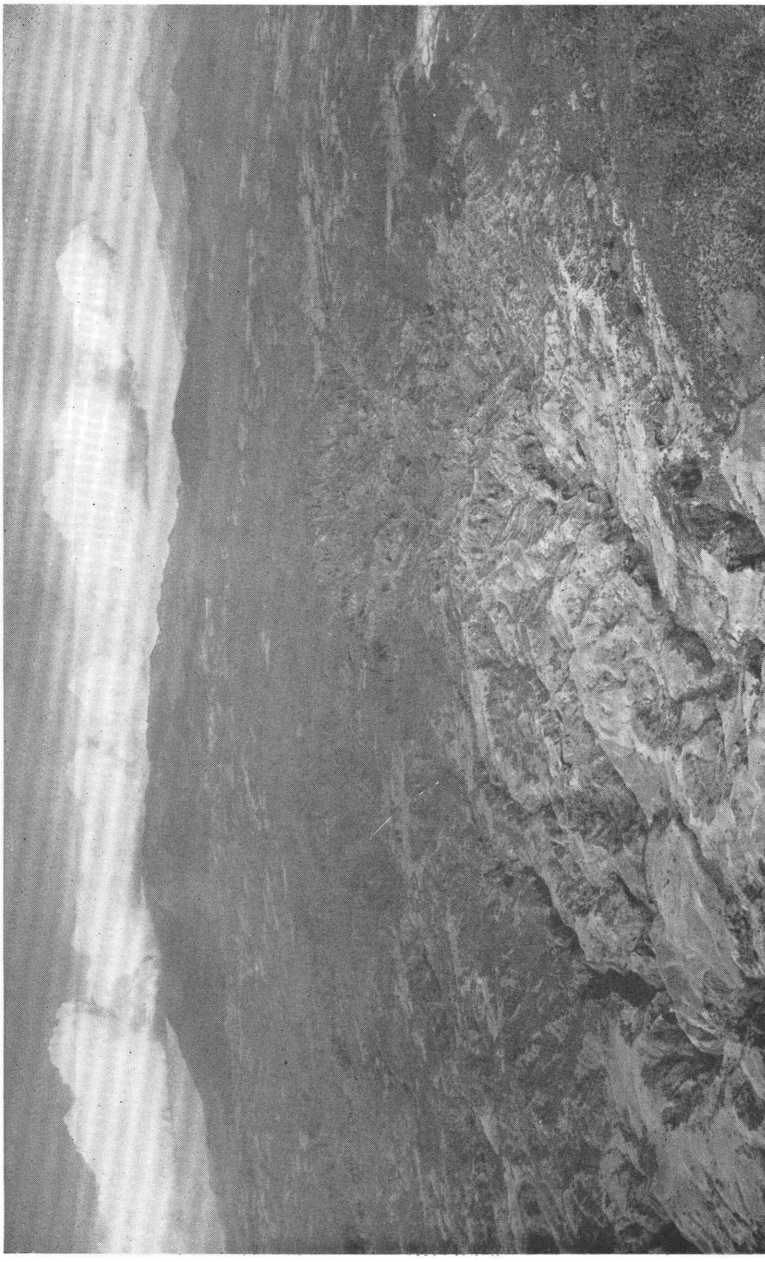
CERROS DE TANCITARO

The oldest volcano of post-Zumpinito age forms the towering mass of Cerros de Tancítaro, the highest peak in the State of Michoacán. Its summit rises to an elevation of almost 13,000 feet, providing an unparalleled view over an immense volcanic field dotted with hundreds of lesser cones.

Prior to dissection, the form of the Tancítaro volcano approximated that of a shield with slopes flattening toward the top (fig. 75). The visible diameter of the volcano is about 7 miles; its buried extent may be twice as much, for the lower flanks are covered by the flows and fragmental ejecta of younger, basaltic cones. Where the lavas of the Tancítaro volcano disappear beneath these younger rocks there is a distinct break in slope and the topography changes suddenly, narrow ridges giving place to flat-topped divides of gentler gradient.

Erosion of Tancítaro has advanced to full maturity, so that the original shield has been reduced to radiating, sharp-crested spurs separated by V-shaped canyons, some of which exceed 1,000 feet in depth. On all sides the ridge crests descend in approximate conformity with the dips of the constituent flows. None of the original constructional surfaces remain, but some of the sharp ridges close to the foot of the mountain merge into flat-topped, wedge-shaped interfluves that coincide fairly closely with the initial flanks. Such slightly modified planezes may be seen, for example, among the spurs that adjoin the village of Zirosto.

The attitudes of the flows on the upper part of the mountain indicate that the main vent or vents lay between the present summit and the



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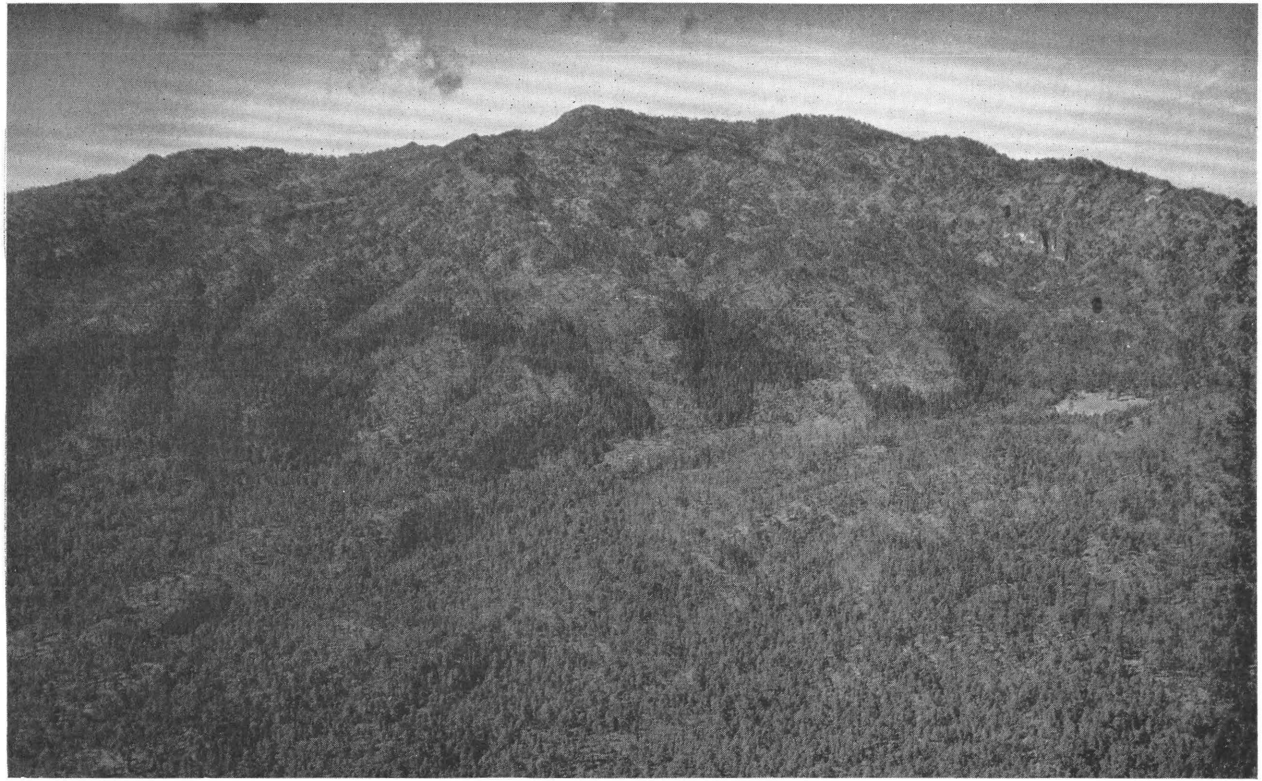


B

FIGURE 75.—Views of Cerros de Tancítaro. *A*, Looking north to Cerros de Tancítaro across terrain occupied by the eroded Zumpinito formation. To the right of Tancítaro, in shadow, the young volcano of Cerro Prieto. *B*, East-northeast slope of Cerros de Tancítaro, showing the eroded shield form of the volcano. Photographs by the Compañía Mexicana Aerofoto, 1934.

conspicuous peak known as Peña del Horno, about a mile to the north. Probably subsidiary vents served as feeders to parasitic cones close to the summit; if not, it is difficult to account for the numerous peaks that cluster around the highest point. All signs of the main and subsidiary craters have long since disappeared (fig. 76).

The eruptions that built Cerros de Tancítaro were almost all of the quiet, effusive type. Some interbeds of breccia and agglomerate were observed by Ordóñez (1910), but compared with the lavas they are very minor in amount. Dominantly the volcano consists of massive sheets of porphyritic andesite, some of which exceed 200 feet in thickness. Apparently the flows were extremely viscous, and many, in the later stages of advance, moved by shearing rather than by laminar flow, so that highly inclined and vertical joints were developed at steep angles to the fluidal banding. True obsidians were not observed, but most of the flows are rich in interstitial glass. Some show columnar structure; others exhibit reddened, scoriaceous crusts.

A few flows of hornblende-rich andesite are present, but most of the lavas are hypersthene-augite andesites plentifully studded with large phenocrysts of feldspar. According to Ordóñez, they resemble the principal flows of Cofre de Perote, Ajusco, and Ixtaccíhuatl, and they are identical with the andesites forming the coeval volcanoes of Cerros de San Marcos. They also call to mind the andesites that compose such volcanoes of the Cascade Range as Mounts Shasta, Rainier, and Hood.

Reference has already been made to the fact that previous workers considered the Tancítaro volcano to be of Pliocene or Eocene age. The latter estimate may be dismissed from consideration with the remark that no volcano of such antiquity would preserve any semblance of its original shape. However, in attempting to assign a more precise age to the volcano, there is little evidence upon which to rely. The volcano grew upon the deeply eroded surface of the Zumpinito formation, but the age of those bedrocks is still unknown. In using the degree of dissection as a criterion, it must be borne in mind that erosion has been tremendously accelerated in this region as a consequence of the explosive activity of the younger volcanoes. Every explosion of these younger cones blanketed the flanks of Tancítaro with fine ash, and during every rainy season the ejecta must have been swept into the canyons, converting the streams into muddy torrents of exceptional abrasive power. This acceleration of erosion is vividly seen today as the new cover of ash from Parícutin is stripped from the steep hillsides during the wet summers and devastating mudflows rush down the canyons to spread their bouldery loads in huge fans far beyond the base of Cerros de Tancítaro. Coarse deposits of older lahars have built great fans around the foot of the mountain. All are

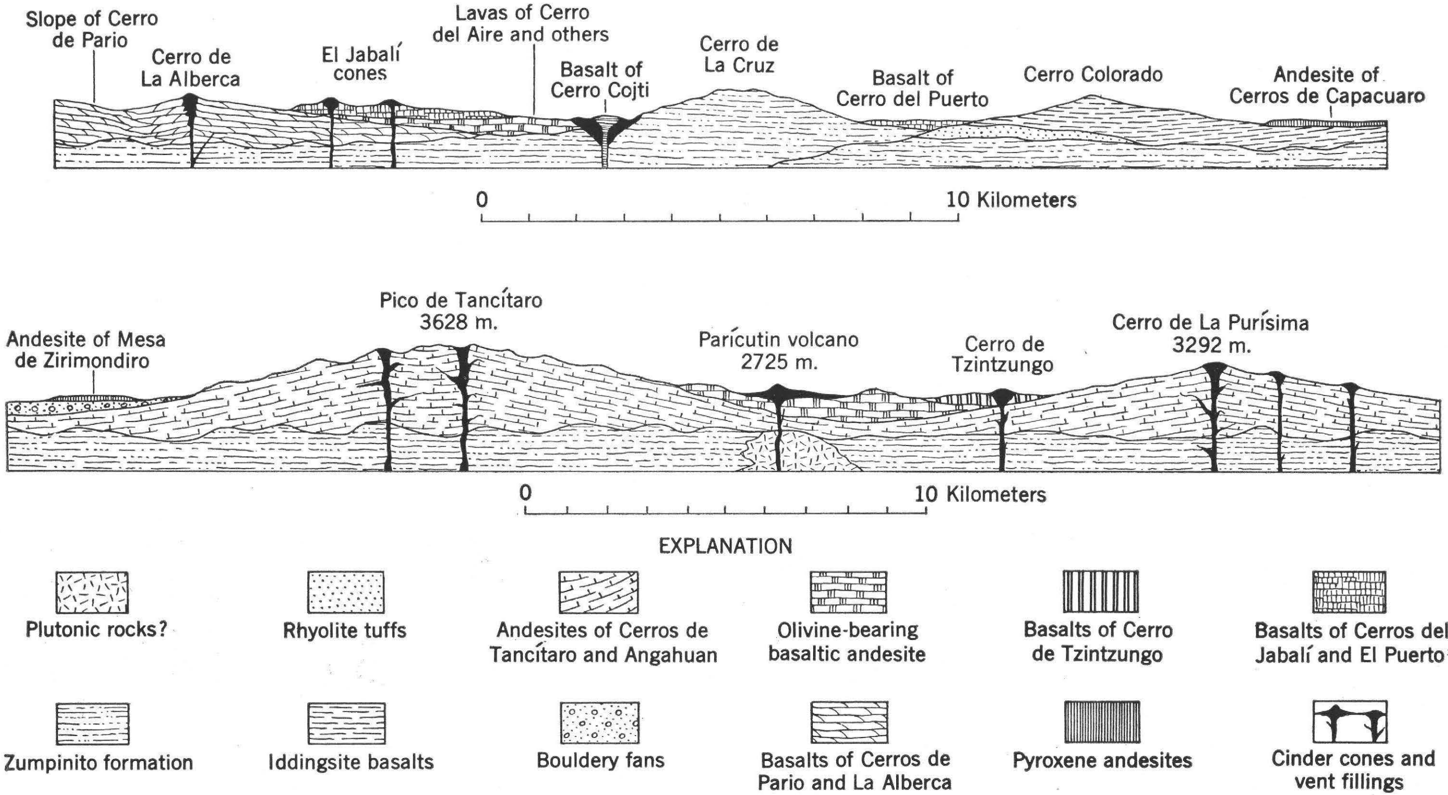


FIGURE 76.—Generalized geologic sections across the Parícutin region.

mantled by deeply weathered basaltic ash, locally as much as 50 feet in thickness, and in places beds of ash and flows of olivine basalt are interstratified with the bouldery debris. From this it follows that unusually rapid erosion of Tancítaro persisted throughout the growth of the encircling cones of basalt. Bearing in mind also that some of the present ridge tops almost coincide with the original slopes of the volcano and that dissection, although mature, has not proceeded far enough to expose the central feeding pipes, it can hardly be doubted that the last eruptions of Tancítaro took place either in late Pliocene or Pleistocene time.

Finally, it should be noted that no signs of glaciation have been detected on Tancítaro despite its great height. Their absence is significant in connection with the view advocated by some Mexican geologists that glaciers formerly spread far down the flanks of the valley of Mexico to elevations several thousands of feet lower than the summit peaks of Cerros de Tancítaro.

CERROS DE SAN MARCOS AND CERRO DEL AGUILA

The paved highway connecting Capacuaro, Paracho, Aranza, and Cherán skirts the base of a long ridge trending northeast (pl. 8). This ridge is formed by a line of coalescing volcanoes, the oldest of which are andesitic cones that rise as conspicuous peaks—those of Cerros de San Marcos at the northern end of the ridge and Cerro del Aguila at the opposite end. In the intervening saddle lies Cerros de Paracho, composed of younger flows of basalt and basaltic andesite. Only narrow ravines cut the broad, gently rounded slopes of Cerros de Paracho; on the other hand, the older andesitic cones are scored by profound, V-shaped canyons between narrow-crested ridges. Judging by these criteria—and no other are available—the San Marcos volcanoes are slightly older than Cerro del Aguila and of approximately the same age as Tancítaro.

Circumstances prevented a close study of the San Marcos peaks, but reconnaissance of the lower slopes, coupled with examination of aerial photographs, indicates that they represent two overlapping volcanoes on a northwest-southeast line. The northwestern one, overlooking the village of Cherán, is capped by a monolith of lava approximately 300 feet high. A distant view is enough to suggest that this marks the filling of the central conduit. On the cliffed walls of the canyons below the summit pinnacle, several thick flows are exposed. Specimens collected by Krauskopf from some of the canyons and by the writer from the fans at the mouths of others show that the volcano is composed of pyroxene andesites identical with those of Tancítaro. If pyroclastic interbeds are present, they must be in quite subordinate amount. Similar andesites make up the southeastern volcano. This seems to be younger than its neighbor, for erosion has still to reveal the central conduit. In place of a summit pinnacle, the top is marked by a shallow basin almost surrounded by jagged peaks of lava.

Cerro del Aguila rises to a height of more than 10,000 feet. No landmark in the Parícutin region is more distinctive (fig. 77). Most of the younger volcanoes are surmounted by a symmetrical cinder cone, but Cerro del Aguila is capped by a huge, towerlike mass with precipitous walls and flattish top. Below the summit tower the flanks of the principal cone slope at angles of about 13° and consist of dark-gray and black, vesicular pyroxene andesite flows rich in porphyritic feldspar. Owing to the heavy blanket of ash blown from adjacent cones, exposures are scarce, and none reveals the presence of fragmental layers between the flows of andesite.

A discontinuous moat separates the principal lava cone from the summit tower. On its northern and western sides, the tower rises almost vertically to heights of 300 to 400 feet; on other sides the walls are lower. The constituent materials are yellowish tuff breccias and lapilli tuffs. Few of the larger fragments exceed a yard in diameter, and most measure less than a foot across. The majority are composed of dense, glassy andesite; these were erupted in a solid state. With them are scoriaceous lumps that were partly molten when discharged. Rounded, spindle- and almond-shaped bombs are lacking. The inference is that most of the culminating explosions of Cerro del Aguila were of the low-temperature Vulcanian or Ultra-Vulcanian type.

Throughout most of the summit tower the fragmental ejecta show no stratification. Where bedding can be seen, it dips outward more or less radially. On the southwest face the dips increase locally to as much as 50°, an inclination far steeper than the normal angle of repose for such ejecta. Presumably a concealed intrusion within the tower is responsible for this upward deflection. Similar upturning of tuff breccias by plugs of lava has been observed on many summit cones of the volcanoes of the Cascade Range in Oregon (Williams, 1933). At least in its upper part the tower of Cerro del Aguila represents a deeply denuded cone rather than the filling of the feeding conduit. If so, the fragmental cone was built within a deep, steep-sided crater about two-thirds of a mile wide, and it continued to grow until it overlapped the crater rim and spread onto the gentle outer slopes of the principal lava cone beyond.

Low on the western flank of Cerro del Aguila there are three cinder cones, one of which, known as Cerro de Capatacutiro, erupted a flood of pahoehoe basalt in recent times (pp. 252–253). These cones are so much younger than Cerro del Aguila itself that they cannot be regarded as parasitic structures; on the contrary, they developed long after Cerro del Aguila had become extinct, and they were probably fed from independent fissures.

FIGURE 77.—Cerro del Aguila from the south side. The main cone of andesitic lavas is capped by an eroded cone of tuff breccias. Low on the left (west) slope of the mountain rises the small basaltic cone of Cerro de Capatacutiro, from which a recent flow of pahoehoe lava was erupted. Beyond, in the flats, are two of the basaltic cones near the village of Paracho. Photograph by the Compañía Mexicana Aerofoto, 1934.

CERROS DE ANGAHUAN

After the formation of the andesitic cones of Tancítaro and San Marcos, and approximately at the same time that Cerro del Aguila was active, two other andesitic volcanoes developed near the village of Angahuan. These form the conspicuous Cerros de Angahuan (fig. 78), culminating in Cerro de La Purísima at an elevation of 10,864 feet.

Like Cerros de San Marcos, Cerros de Angahuan consists of two coalescing cones, the craters of which have been obliterated and the flanks of which are deeply trenched by radial ravines. Their lower slopes are buried by wide alluvial fans. Southward the lavas of these volcanoes pass under the basaltic flows of Nureto, Tzintzungo, and Cutzato; westward and northward they pass under basaltic flows and ashes erupted from cones near Corupo and San Felipe. Eastward they are partly overlain by olivine-bearing basaltic andesites discharged by Apupan, Matáncero, and adjacent cones and partly by still younger flows of olivine-bearing andesite that poured from the Surúndaro volcano.

Judging by the degree of dissection and the thickness of the ash cover, the two Angahuan volcanoes are of approximately the same age. The top of the northern one is an irregular, hummocky plateau that drops off precipitously in cliffs of massive andesite. The top of the other is marked by two sharp pinnacles that may be the fillings of the feeding pipes.

Except in texture the lavas composing both volcanoes show little variation. Most of them are black, olivine-free pyroxene andesites liberally sprinkled with porphyritic feldspar in a matrix of glass. Other flows are virtually devoid of phenocrysts and approximate obsidians in character. On the higher slopes of the northern cone, many flows are so markedly vesicular as to appear scoriaceous.

The activity of both volcanoes came to a close long before such cinder cones as Apupan, Matáncero, Cumbundicato, and Terutsjuata began to erupt on their flanks and around their feet. Consequently these minor cones are not regarded as products of lateral or eccentric eruptions but as independent forms built over separate feeding chambers.

CERROS DE LOS HORNOS

A large, multiple volcano rises about 1,500 feet above the village of San Lorenzo. It measures 4 miles across the base, and it was built on a floor sloping downward steeply to the south. Its last eruptions followed those of the Angahuan volcanoes and Cerro del Aguila.

A heavy cover of ash and vegetation masks all but a few poor exposures of the rocks forming these hills, but the topographic forms

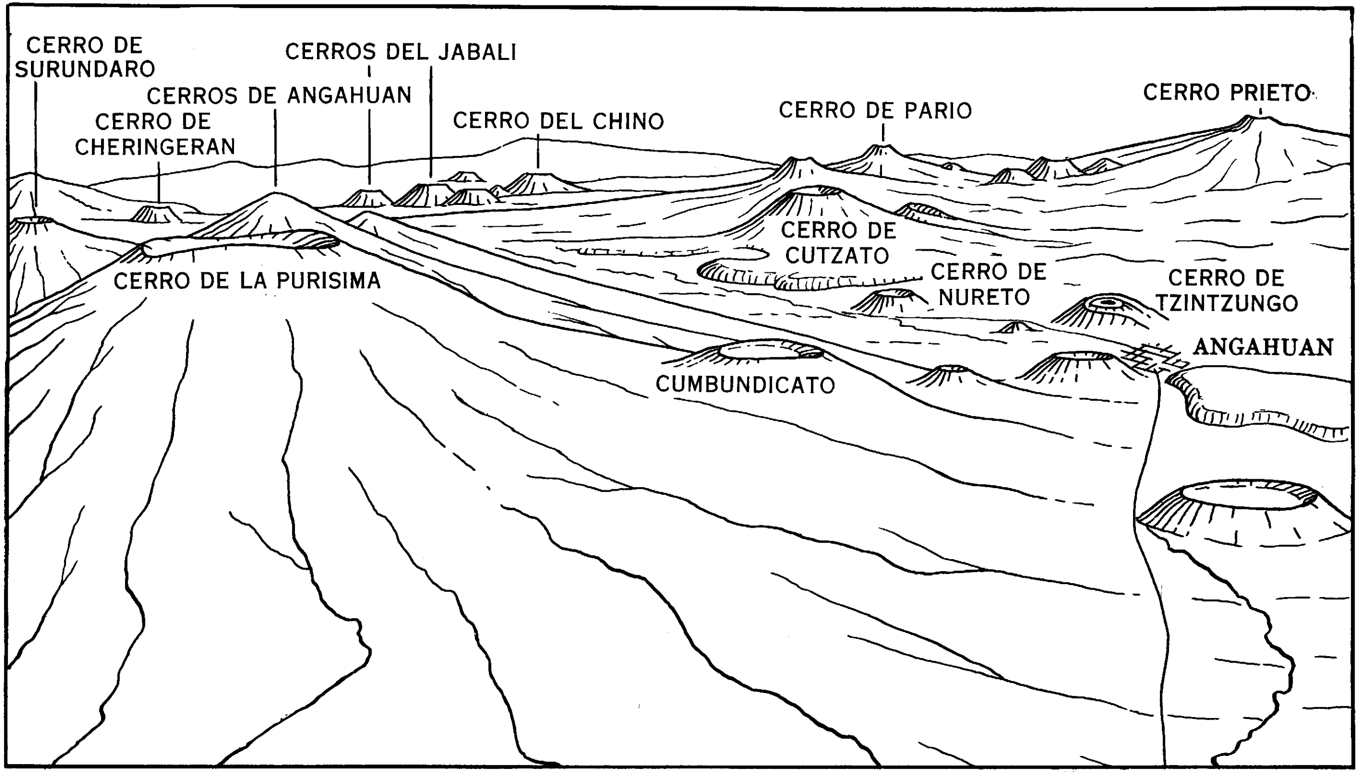


FIGURE 78.—Cerros de Angahuan from the northwest, showing the relation of these large eroded andesitic cones to the younger volcanoes in the vicinity. Photograph above (p. 186) by the Compañía Mexicana Aerofoto, 1934.

denote a group of overlapping cones and the available outcrops indicate that the cones consist partly of basalt and partly of basaltic andesite. Specimens found near the foot of the hills on the east, north, and southwest sides are dense, glass-rich hypersthene andesites like the principal lavas of the Angahuan volcanoes. Other specimens, chiefly from the southeast slopes, are olivine-bearing basalts or basaltic andesites. Unfortunately their sequence could not be determined.

The summit peaks, from which the hills take their name, are denuded, craterless cones of basaltic scoria. These had become extinct before three youthful cones were formed on the eastern flank of the Cerros de Los Hornos and a small volcano made up of olivine basalt developed close to the village of Capacuaro.

YOUNGER VOLCANOES

GENERAL STATEMENT

After the growth of the large andesitic volcanoes of Tancítaro, San Marcos, Angahuan, and Cerro del Aguila and the mixed eruptions of Cerros de Los Hornos, the centers of activity in the Parícutin region became more numerous and widespread, and the dominant lavas changed to olivine basalts and olivine-bearing basaltic andesites. Eruptions of pyroxene andesite did not come to an end; on the contrary, some of the most copious flows of andesite were discharged within the last few thousand years.

These younger volcanoes, whose symmetrical forms typify the Tarascan landscape, are so little modified by erosion that all can be assigned without hesitation to recent time. While they were active, other eruptions continued throughout the length of the Neo-Volcanic Zone of Mexico from San Andrés Tuxtla, bordering the Gulf of Mexico, to the vicinity of Tepic, close to the Pacific coast. It was then that most of the volcanoes of the Pátzcuaro region and the basaltic cones around the valley of Mexico and Apatzingán were formed, and it was then that the highest volcanoes of Mexico—Popocatépetl, Orizaba, Nevado de Colima, and Nevado de Toluca—which began to grow during Pleistocene or late Pliocene time, passed through maturity to their present stage of decline.

STRUCTURAL TRENDS

Most of the Neo-Volcanic Zone from Colima to Orizaba trends approximately east, but at the extremities the trend changes. Thus the volcanoes of the Tuxtla group and those between Guadalajara and Tepic are alined in a northwest to north-northwest direction. Hobbs (1944) has suggested the possibility that the recent volcanism of Mexico and Central America is related to a rising anticline parallel to the foredeeps off the Pacific coast. Certainly in Central America the active cones are alined parallel to the adjacent deeps, but in Mexico the trends diverge widely. During the last few centuries eruptions have occurred in Mexico at the following places: Tres Virgenes (Baja California), Ceboruco, Colima, Parícutin, Jabalí, Jorullo, Popocatépetl, and San Martín Tuxtla. In other words, the latest eruptions have taken place at points scattered along the full length of the Neo-Volcanic Zone. Their distribution bears no apparent relation to the structural features referred to by Hobbs (1944).

Within the main east-west zone in Mexico, the individual volcanoes show little alinement. Locally they are disposed at right angles to the belt itself. Thus Cofre de Perote lies north of Orizaba, and Ixtaccíhuatl lies north of Popocatépetl. Several volcanoes in Java, though grouped in a broad east-west belt, are likewise alined perpendicular to the dominant trend.

Within the Parícutin region, most of the cones appear to be scattered haphazardly. Locally, however, a northeast alinement may be detected. Thus the old andesitic cones of Cerros de San Marcos and Cerro del Aguila, together with the younger cones of Cerros de Paracho and Cerros de Los Hornos, exhibit this alinement. More striking is the parallel series of youthful cinder cones including Pelón, Cumbuén, and Paracho Viejo (pl. 8). Indeed, if the line joining these three cones is prolonged, it passes through Parícutin volcano, through its parasite, Sapichu, and through the fissure-and-tremor zone on the opposite side of the new volcano. Other examples of the same alinement include Cutzato and its parasite, Pantzingo. The principal vent of Cerro Cojti lies northeast of the minor cone on its crater rim; the vents of Cerro de Curitzerán, Cerro del Anillo, and Cerro de Sicuín are on a parallel line; the central vent of Cerro de Pario lies northeast of the main vent of Cerro Prieto, just as the triple cone of Cerro del Aire lies northeast of the summit vent of Cerro de La Alberca. Moreover, it may not be fortuitous that the Jabalí and Capacuaro volcanoes, which are among the youngest in the region, are also on a northeast-southwest line.

However, the general rule deserves emphasis: lack of regular orientation characterizes most of the volcanoes of the region. Cinder cones cap many of the larger lava volcanoes, but they are most numerous in the depressions separating the major structures. A few cinder cones are disposed more or less radially on the flanks of the principal volcanoes; these may be considered as parasites. Most of them, however, are either products of eccentric eruptions of the main volcanoes or, more likely, were fed through independent fissures.

In the part of Michoacán lying to the north and east of Parícutin, Blásquez (1946b) has observed that the principal mountain ranges, basins, and hot springs follow a rectilinear pattern. One set of faults trends between N. 10° W. and N. 30° W.; the second trends at right angles to the other. The former accounts for the alinement of the Sierras de Venustiano Carranza, Cerro Azul, and Cerro Purépero not far to the north and northwest of Parícutin; the latter accounts for the orientation of the Sierras de Patamban, Ozumatlán, and Santa Clara, which lie to the north and east of Parícutin. The main depressions between these and parallel ranges trend approximately east. Especially striking are those that hold the great lakes of Cuitzeo and Chapala; less conspicuous and more irregular are the basins of Zamora, Zacapu, and Pátzcuaro. Presumably all are graben. Most of the faulting responsible for them probably took place during the first stages of volcanism in the Parícutin region. Yet within that region there is no hint of any alinement of cones parallel to the dominant trends of northern Michoacán and Jalisco. As noted already, the only distinct alinement of cones near Parícutin is one that trends northeast, approximately bisecting the major structural trends just enumerated.

Not a single fault scarp is to be seen in the Parícutin region. If any are present, they must be buried by accumulations of younger lava.

Too little is known of the geology of Michoacán, particularly of the prevolcanic history, to warrant further discussion of the influence of structure on the distribution of cones. The general disorder of the younger volcanoes of Michoacán bespeaks an absence of large, thoroughgoing fractures; it suggests discontinuous, short gashes such as might be produced by horizontal movements of small extent. Graton (1945a) has likewise cast doubt on the conception of master east-west fractures in the Neo-Volcanic Zone of Mexico, pointing to the absence of chains of minor cones linking the great volcanoes. Also, he has properly doubted that the smaller, short-lived volcanoes are fed from shallower depths than the longer-lived and larger cones. Their extremely wide distribution and lack of any doming of the adjacent rocks make it seem unlikely that the smaller volcanoes are connected with near-surface laccolithic reservoirs. Moreover, the present study shows that in the Parícutin region there is as much petrographic variation among the lavas of adjacent, short-lived volcanoes as there is among the lavas erupted by most of the long-lived, major volcanoes of Mexico. Possibly more seismic data will throw light on the depths from which the feeding magmas rise.

In the pages that follow, most of the younger volcanoes of the Parícutin region are described in the order of their formation, beginning with the oldest. It should be stressed, however, that the precise succession is often unknown, for the only criteria in many instances are the degree of erosion and the thickness and amount of weathering of the ash cover, all of which are rather unsatisfactory. Besides, the difference in age between many of the cones is at most a few hundreds or a few thousands of years, and probably some cones were active simultaneously. None dates back as far as the Pleistocene epoch.

Close to Parícutin itself the heavy cover of new ash has almost completely obscured the record; for that reason, and because of their proximity to the new volcano, the neighboring cones are discussed under a separate caption.

DESCRIPTION OF INDIVIDUAL VOLCANOES

CERROS DE PARACHO

Reference has already been made (p. 182) to the broad ridge forming the saddle between the andesitic cones of Cerros de San Marcos and Cerro del Aguila. These volcanoes were extinct long before the intervening depression began to be filled by lavas discharged from vents on a northeast-southwest line, the positions of which are now marked by four summit cinder cones. Two smaller and younger cones on the northwest flank of Cerro del Aguila contributed to the filling of the depression, and from one of them a fairly recent flow descended to the Mexico City highway.

The lavas of the four Paracho volcanoes, although heavily mantled by ejecta blown from Paracho Viejo, Pelón, and Cumbuén, are only slightly modified by erosion. Unfortunately only the lower slopes of the Paracho ridge were examined. Study of lavas in place and of debris brought down by streams from the higher slopes suggests that most of the flows on the northern side are either olivine basalts or basaltic andesites, whereas those on the opposite side are olivine-poor or olivine-free pyroxene andesites like those of the Angahuan and Capacuaro volcanoes. Nothing is known of their sequence.

MESA DE ZIRIMONDIRO AND MESA DE HUANARUCUA

At two localities, thick sheets of andesitic lava were extruded without attendant explosions of fragmental ejecta. One of these andesitic flows lies immediately north of the village of Tancítaro, forming the Mesa de Zirimóndiro, approximately 2 miles long and up to a mile in width. Its hummocky, cultivated top is thickly covered with yellowish basaltic ash blown from nearby cinder cones; its steep sides rise 200 to 250 feet above the surrounding alluvial flats. Except in gullies cutting the flanks, natural outcrops of lava are scarce; fortunately a large quarry on the outskirts of Tancítaro village provides excellent exposures. Where fresh, the andesite is pale gray and lightly stippled with large crystals of oxyhornblende and augite; where it has been affected by oxidizing vapors, the color changes to pink, the oxyhornblende is almost wholly altered to iron ores, and the dense groundmass is charged with minute flakes of hematite. The entire mesa appears to be the result of a single flow of unusual viscosity; indeed, the final effusion, being unable to spread laterally, piled over the vent to form a domical mound near the northern end of the mesa.

The other mesa is that of Huanárucua (figs. 79, 80), extending from near the village of Angahuan to the foot of the Curitzerán volcano. The road linking Angahuan with San Juan Parangaricutiro and Corupo skirts its edges. Toward the south the mesa falls off abruptly in cliffs and talus slopes 250 to 400 feet in height; toward the north it merges indefinitely into the basaltic flats of Llano de Paquichu.

Huanárucua covers an area measuring 1⅔ by 1¼ miles. The source of the flow lies close to the southeast edge, where a low, elongate mound marks the accumulation of the last-erupted material. The lava closely resembles that of Zirimóndiro. It is likewise devoid of porphyritic feldspar, and its dense microvesicular matrix also varies in color from gray to pink according to the degree of oxidation by fumarolic vapors. The only phenocrysts are a few prisms of augite and brownish-black oxyhornblende.

The gently undulating top of the mesa is blanketed with deeply weathered basaltic ash more than 10 feet thick, some of which was blown from the adjacent cone of Terutsjuata. Judging by the nature and thickness of this ash, the Huanárucua andesite is older than the flows erupted by the cones of Cutzato and Tzintzungo.

CERRO DE JICALAN AND THE TZARARACUA FLOW

The eroded cone adjoining the village of Jicalán is among the largest of its kind. Across the base it measures 1 mile, and it rises 800 feet above a pedestal of the Zumpinito formation clays. The sides are cut by deep barrancas, one of which leads into a breached crater. The cone consists of well-bedded basaltic tuffs and lapilli tuffs carrying sporadic bombs and blocks of basalt up to 6 feet across. Few of the larger lumps show rounding caused by rotation in flight; like the ejecta of Parícutin, most of them are irregular in outline, and their texture varies from dense and glassy to scoriaceous.

From the foot of Cerro de Jicalán an undulating surface slopes gently to the confluence of the Río de Cupatitzio and Río de Los Conejos. Most of this surface is thickly covered with basaltic ash, but locally there are exposures of the underlying vesicular lava. On the precipitous east wall of Los Conejos gorge and the west wall of the Río de Cupatitzio, the same lava is revealed in high cliffs, and it may be traced continuously down the gorges to Cascada de Tzaráracua. Indeed, the falls themselves tumble over the lava, and ribbons of water spout from joints within it. Here the flow occupies a steep-sided valley cut in the coarse tuff breccias of the Zumpinito formation, the diverging columns in the lower part lying normal to the old valley walls. At this point the central part of the flow approximates 180 feet in thickness. The basal part shows closely spaced columns; upward the columns become coarser and cruder, until in the uppermost part of the flow the jointing becomes slabby and platy and almost horizontal. Examination of thin sections under the microscope indicates that this slabby and platy jointing resulted from shearing during the final stages of advance (see pp. 245–246).

The Tzaráracua flow is a basaltic andesite liberally studded with porphyritic olivine. Since the original snout lay not more than 200 or 250 yards downstream from the falls and headward erosion has been facilitated both by the strong jointing of the lava and by the nature of the surrounding tuff breccias, the flow is probably only a few thousand years old. Presumably it issued from fissures at the foot of Cerro de Jicalán.

CERRO DE PARIO AND CERRO DE LA ALBERCA

The summit cinder cone of Cerro de Pario, which rises to an elevation of about 9,000 feet, surmounts the highest of a group of overlapping cones composed of glass-rich, olivine-bearing basalts and basaltic andesites. The cinder cone is well preserved and contains a circular crater approximately 150 feet deep. Crags of scoriaceous lava are exposed below its western rim, but outcrops of the flows that make up the main lava cone are extremely scarce. Five other cinder cones rise from the flanks of the Pario volcano; some of these cap independent lava cones, and from others long flows spread southeastward to Los Conejos. Eight other cinder cones are scattered along the south and west base of the Pario volcano. The order of their formation was not ascertained, but probably all were active at about the same time as the Pario volcano. Immediately south of Los Conejos extrusions of basaltic andesite occurred without accompanying explosions of ash, forming a mesa measuring a mile or so across.

The breached and denuded cone of Cerro de La Alberca, to the east of the Cerro de Pario cluster, caps another large lava cone formed of olivine-bearing basalts and basaltic andesites. Flows from this source spread northward across the old road linking Uruapan with San Juan Parangaricutiro, where they are overlain by tongues of lava related to the cone cluster near San Lorenzo. Southeastward the Alberca flows pass under recent lavas discharged by the Jabalí cones. How far they moved in this direction is uncertain, but possibly they extended as far as the feeding springs of the Río de Cupatitzio.

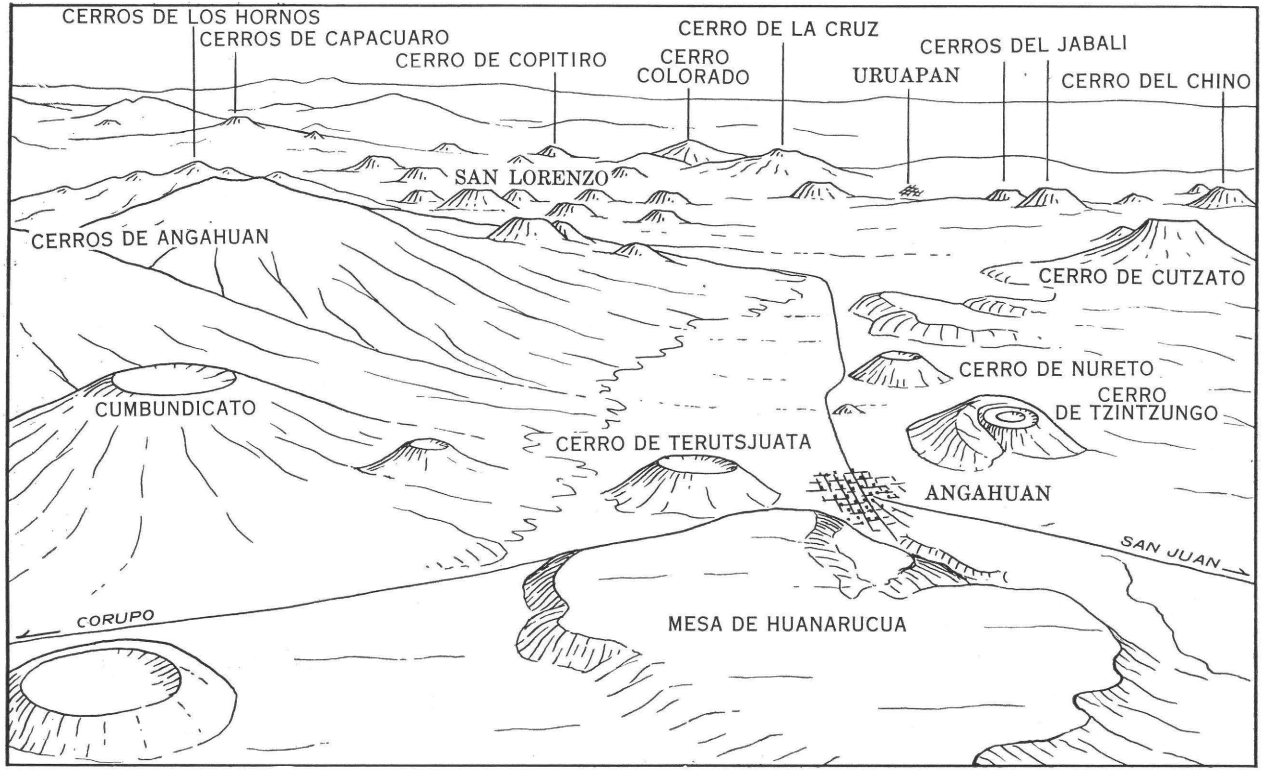


FIGURE 79.—Volcanoes near Angahuan, looking southeast. In the foreground, on the right, the andesitic flow of Mesa de Huanárucua. Older andesitic cones of olivine basalt and basaltic andesite. In the distance the Zumpinito formation forms Cerro Colorado and Cerro de La Cruz. Photograph above (p. 194) by the Compañía Mexicana Aerofoto, 1934.

CERRO DEL AIRE, CERRO DE COPITIRO, AND CERRO DEL PUERTO

Close to the junction of the Mexico City highway and the branch road leading to San Lorenzo is an unusually large group of coalescing cones having a basal diameter of more than a mile and a height of 600 feet. On the summit are three contiguous funnel-shaped craters that range in depth from 20 to 250 feet. These coalescing cones, known as Cerro del Aire, consist of well-stratified cindery lapilli and ash with sporadic bombs. No exotic lithic fragments appear to be present. A short distance to the east is another large cone composed of similar materials, and near its southern base is a mound of lava, approximately 150 feet high, which appears to represent the last viscous extrusion from a separate vent.

The flows from these cones and the adjacent lava mound were unable to move northward on account of the opposing slopes of Cerro del Aguila and Cerros de Los Hornos. How far they spread to the east cannot be ascertained; in that direction they are buried by younger andesites from the Capacuaro volcano. To the south, however, they traveled long distances, reaching at least as far as Cheringerán and possibly as far as Uruapan. The long grade followed by the main highway ascends across their surface, permitting views of the steep fronts of successive tongues. All are scoriaceous and blocky basaltic andesites plentifully charged with phenocrysts of olivine, augite, and feldspar. The yellowish basaltic ash which covers them does not increase in thickness toward the parent cones; on the contrary, its distribution indicates an origin among the younger cinder cones of the vicinity. Hence the explosive activity of Cerro del Aire had either ended or diminished greatly before the main effusions of lava took place. Such has also been the history of Parícutin and of many other volcanoes in the region.

Far down the southern flank of the Cerro del Aire lava pile is the younger cinder cone of Cópitiro, from which a stumpy tongue of coarse-grained, intergranular olivine-augite basalt was erupted. Farther south, in the valley separating Cerro de La Cruz from Cerro Colorado, there are still younger flows of olivine basalt that spread beyond Caltzontzin onto the plain of Uruapan. These issued from the twin cones of Cerro del Puerto and a third cone to the east.

CERRO DE CURITZERAN, CERRO DEL ANILLO, AND CERRO DE SICUIN

The villages of San Juan Parangaricutiro and Zacán are separated by a group of wooded hills crowned by two coalescing cones known as Cerro de Curitzerán, the topmost point of which stands at an elevation of 8,362 feet. These summit cones are only slightly modified by erosion and have well-preserved craters that lie on a line trending west-southwest. Nearby are two smaller cones: Cerro del Anillo, at an elevation of 7,755 feet, and Cerro de Sicuín, at 7,500 feet. Cerro del Anillo is breached on its southwest side. Taken together, the four cones are alined approximately parallel to the main fissure zone at Parícutin.

The visible parts of the two Curitzerán cones are about 500 feet high, but probably these are simply the exposed tops of much larger structures that are mainly buried by encircling lavas, for the flows from these vents form a broad pedestal up to 400 feet in thickness. The longest flows spread to the southwest, descending to the gorge of the Río de Itzícuaro. They are dark, vesicular and scoriaceous, glass-rich, olivine-bearing basaltic andesites that contrast with the pale-gray holocrystalline olivine basalts on the south side of the Río de Itzícuaro.

CERRO DE CHERINGERAN, CERRO COJTI, AND CERRO DEL CHINO

These three cones lie close to Uruapan. Cerro de Cheringerán is one of the largest pyroclastic cones of the entire region, rising to a height of 800 feet. In its summit is a nested crater, an inner depression being separated from an outer by a discontinuous bench. The cone consists of clinkery lapilli and ash and a few irregular bombs up to 6 feet across. Well-rounded fragments and accidental ejecta appear to be absent. Lava escaped from a fissure low on the southwest flank to build a low mound over the orifice.

Cerro del Chino is slightly smaller (fig. 84). It has a saucer-shaped crater, and its outer flanks are about as deeply dissected by radial ravines as those of Cheringerán. Short flows spread from the foot of the cone, chiefly toward the south; judging by the extremely heavy cover of ash, they were discharged before the main explosive activity of the cone had begun. According to Marian Storm (1945), "people still alive remember when ashes showered over Uruapan from the Chino Hill," but this seems doubtful. More probably the ashes were discharged by the neighboring younger cones of the Jabalí cluster, as described on page 210. Nevertheless, it is unlikely that either Cerro del Chino or Cerro Cheringerán dates back more than a few thousand years.

Not far from Cheringerán, at the foot of Cerro de La Cruz, lies Cerro Cojti, a cone that differs from all others in the region by reason of the great width of its crater in relation to the low encircling rim of ejecta (fig. 84). In the terminology of German volcanologists, it would be termed a "Ringwall." It is distinguished further by being the only crater into which lava was extruded after the main explosive activity ended. The rim is a narrow ridge rising no more than 100 to 150 feet above the crater floor except on the east, where the ejecta piled against the slopes of Cerro de La Cruz to a height of 500 feet. On the inner side the rim falls steeply; on the outer side the slopes are more gentle. The rim itself consists of weathered basaltic ash with sporadic lapilli and bombs. On the southwest side it is surmounted by a miniature cone.

The main crater of Cerro Cojti is approximately half a mile wide; the circular biscuit-shaped mound of scoriaceous basaltic lava lying on the floor is about half as wide. Resting on the lava is a thick mantle of ash presumably deposited during the eruptions of the miniature parasitic cone.

A narrow flat-bottomed moat formed by inwash of sediment from the slopes of Cerro de La Cruz separates the central lava cake from the crater rim; hence the original crater may have been much deeper than at present. Even so, its width is remarkable. Possibly the explosion focus lay at a shallow depth, for there is no hint that the crater was enlarged by peripheral collapse of the walls.

CONE CLUSTER NEAR SAN LORENZO

Seven closely spaced cinder cones adjoin the village of San Lorenzo. The smallest is about 250 feet high; the largest is three times that height. All are composed of well-bedded, cindery ash and lapilli, excellent exposures of which may be seen in the quarry excavated into the westernmost cone. Fragments more than 3 inches across are exceptional, and none exhibit rounded or ropy forms indicative of fluidity at the time of discharge. All consist of dense, glass-rich olivine basalt or basaltic andesite. In the aforementioned quarry a few lapilli contain xenocrysts of quartz, but no accidental lithic ejecta were observed.

On all but one of the seven cones, the craters are breached. Particularly striking is the southernmost cone. This is a doublet breached on the south side by two barrancas that have extended headward to enlarge the moat separating the inner from the outer cone. The adjacent Cerro de Cuatzione also is breached on the south side, a deep gorge leading up to a precipitous wall of lava beneath the crater floor. Probably this breach resulted from collapse of the cone when a flow broke from a fissure low on the flank, just as part of the cone of Parícutin was undermined and carried away in June 1943 when lava burst from vents close to the base.

Gullies cut through the flats between the seven cones reveal deposits of weathered ash more than 50 feet in thickness. Beneath this mantle are sporadic outcrops of vesicular olivine basalt.

Judged by the degree to which they have been eroded, the San Lorenzo cones appear to be of about the same age as Cerro de Cheringerán and Cerro del Chino and younger than Cerro del Aire. The two westernmost cones are obviously younger than the lavas of Cerro de Surúndaro, for they deflected the lavas' advance.

CERRO DE CUTZATO

Approximately 4 miles east of Parícutin lies the high cone of Cutzato (figs. 78, 80). Its summit reaches an elevation of 9,240 feet, or about 900 feet above the surrounding flows, and its basal diameter is not much less than a mile. Hence it must be counted among the largest cinder cones of the Parícutin region. Indeed, it may well be that, as in the case of Parícutin volcano itself, much of the lower part of the cone is buried by the encircling lavas.

On the summit is a bowl-shaped crater with walls up to 300 feet in height. The flanks of the cone are deeply scarred by ravines, the size of which has greatly increased since the birth of Parícutin in February 1943. Segerstrom (1950) calculated that, if the present rate of erosion had obtained since Cutzato was built, the cone might not be much more than a century old; but clearly, as he adds, erosion has been much accelerated by accumulation and downwash of ash from Parícutin. Nevertheless, his estimate gives reason to suppose that the final eruptions of Cutzato may have taken place within the present or preceding millennium.

At the southwest base is a parasitic cone, Pantzingo, which is breached on the same side. The fissure connecting the parent and parasitic cones is thus parallel to that linking Parícutin with its parasite, Sapichu. Within the breach of Pantzingo, as within the breaches of Cerro de Terutsjuata, Cerro del Pueblo Viejo, and Cerro de Zacán, is to be found one of the large springs of the region.

Before the explosive activity of Cutzato and Pantzingo came to an end, flows of exceptional thickness and viscosity were discharged, chiefly to the northwest and east. The margins of these flows are steep and in some places almost precipitous, ranging in height from 200 to 300 feet. No flows of this magnitude have yet been erupted by Parícutin. They consist for the most part of gray and pink, microvesicular basaltic andesite devoid of porphyritic feldspar but liberally stippled with large crystals of olivine.

The tops of the Cutzato flows are thickly covered with ash, but the margins do not appear to have been modified much by erosion. Although the lavas are older than those of Cerro de Tzintzungo, they are much younger than those of the Pario volcano.

CERRO DE TZINTZUNGO AND CERRO DE NURETO

The large double cone of Tzintzungo rises from the outskirts of the village of Angahuan to an elevation of approximately 8,350 feet, or about 650 feet above the lavas at the base. A small inner cone partly fills the breach on the western side of the main cone (figs. 78, 79).

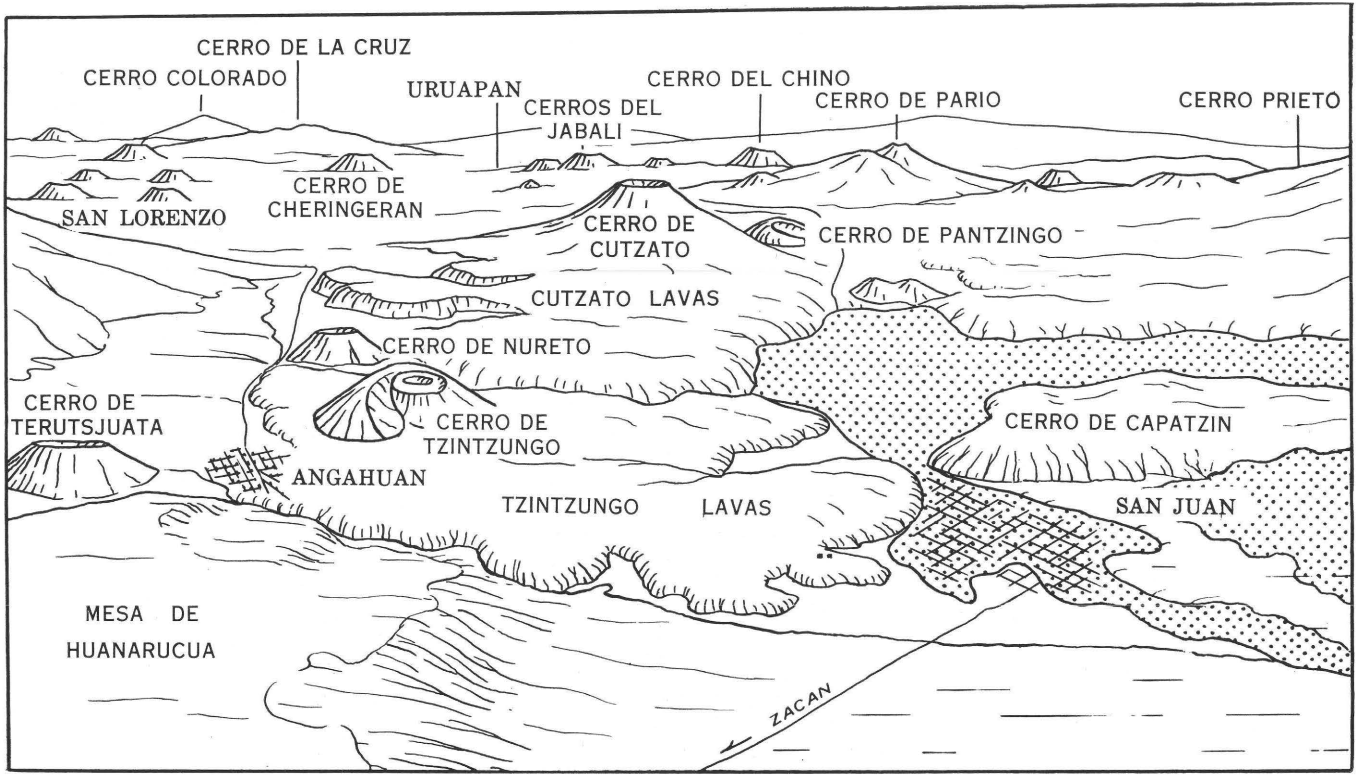


FIGURE 80.—Cerro de Tzintzungo, Cerro de Cutzato, and adjacent cones. View looking approximately eastward. The stippled area is covered by lava from Parícutin volcano (to August 1947). In left foreground, the andesitic lava of Huanárucua. Photograph above (p. 200) by the Compañía Mexicana Aerofoto, 1934.

During the closing stages of the growth of these cones, thick flows of scoriaceous and blocky, autobrecciated lavas issued from fissures around the base. The road cuts between Angahuan and San Juan Parangaricutiro expose some of these in section, showing a jumble of angular blocks in a matrix of rubbly and sandlike debris formed by decrepitation of the lava as it advanced. The flows underlie Angahuan and extend westward to form the bluffs overlooking San Juan Parangaricutiro and that on which Casa Cuezeño stands. The first flows moved to the east and south, but only for a short distance; the longest and last flow moved westward from the aforementioned breach on the flank of the cone.

Many small hillocks and ridges diversify the surfaces of the flows, especially near Angahuan. Some of these may be miniature scoria cones or large, dilapidated hornitos; others may represent parts of older flows rafted downstream by younger flows injected beneath them.

Although the lavas vary in texture, most of them are characterized by abundant phenocrysts, not only of augite and olivine but also of plagioclase. In fact, no other olivine-bearing basaltic andesites in the entire region are as plentifully charged with porphyritic feldspar.

A short distance to the east lies the smaller cone of Nureto. Its slopes are much more modified by erosion, and its crater has been replaced by a flattish top. The flows erupted from this source are of limited extent and poorly exposed. In the valley separating the Nureto from the Tzintzungo cone, ash has accumulated to depths of more than 100 feet, and it is from this valley fill that the large spring that formerly supplied San Juan Parangaricutiro issues.

Examination of ash profiles shows that the flows of the Tzintzungo cone are much younger than the andesite of Huanárucua and were erupted after the lavas of Nureto and Cutzato. They are, however, slightly older than the adjacent cinder cone of Terutsjuata.

CERROS DE CAPACUARO

By far the most voluminous outpourings of lava within recent times are those from the vent that lies between 4 and 5 miles east of the village of Capacuaro (fig. 81). A large conical mound rises over the vent, but whether this is a protrusion of viscous lava or consists of fragmental ejecta is not known.

The area inundated by flows from this source approximates 60 square miles, and the average thickness of the lavas is not less than 200 feet. Accordingly, more than 2 cubic miles of lava were discharged. By comparison, Parícutin erupted only about a sixteenth of a cubic mile of lava during the first 5 years of its history. Of special note is the fact that the lavas from Capacuaro do not consist of basalt or basaltic andesite like most of the recent lavas of the region but of glass-rich hypersthene andesite having a composition not markedly different from that of the andesite of Tancítaro.

Among the numerous flows of the Capacuaro volcano the largest deserves particular mention. This spread southward from the vent for about 12 miles. In places its width is almost 2 miles, and for most of its course it measures a mile across. Not only is it exceptionally long, but the steep margins rise to heights of 250 feet. Figure 82 gives an impression of the morainelike levees that confine the medial portions of the flow. Other massive flows spread westward to the village of Capacuaro and northward to the vicinity of Arantepacua; these also terminate in impressive blocky fronts up to 200 feet in height.

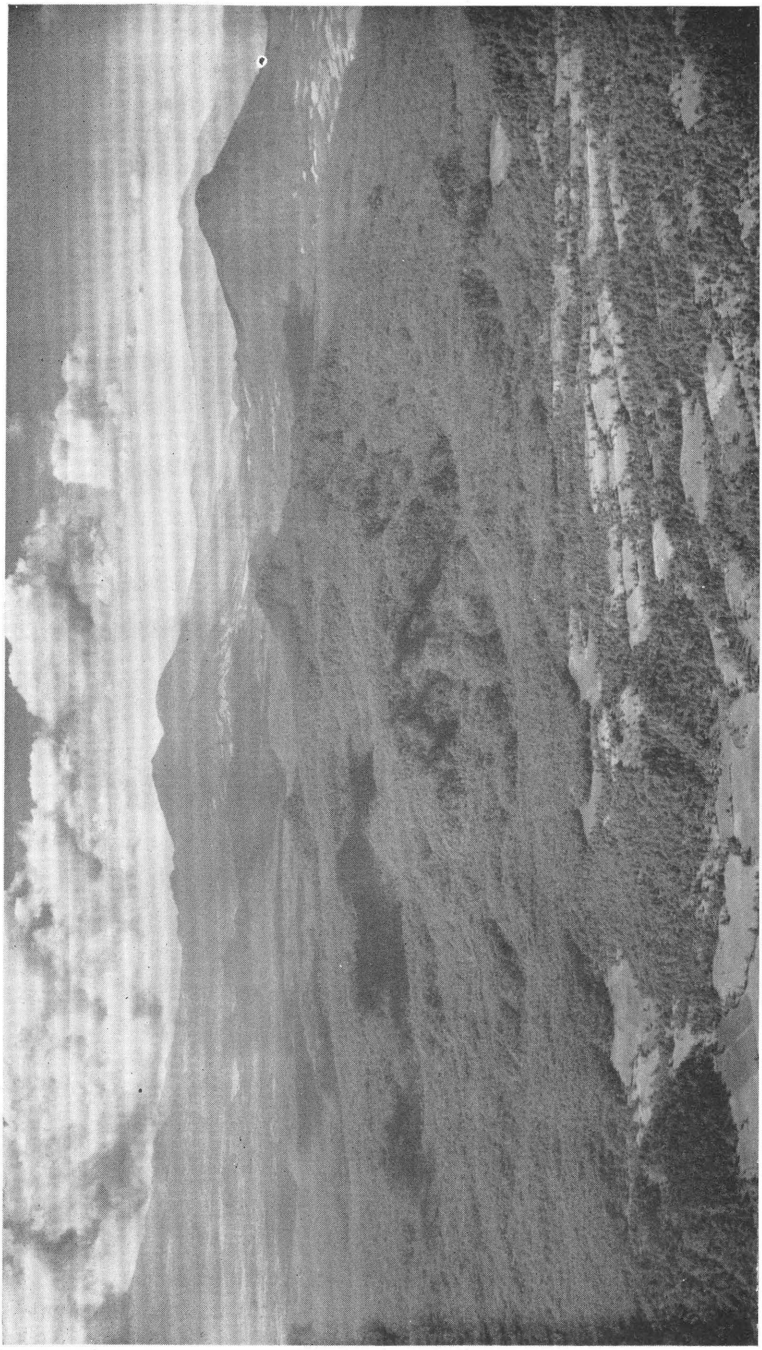
As might be expected from their high glass content, all the flows are true block lavas. Their upper parts consist of a jumble of smooth-faced blocks, many more than 6 feet across, loosely bound together by a rubble of comminuted lava chips. Downward the blocky crust grades into brecciated lava which merges in turn into massive andesite below.

Although heavily forested, the lavas are free from all but a thin, patchy cover of ash. Hence they are younger than all the cinder cones in the immediate vicinity. Their surface features are so well preserved that it seems safe to say that the flows were erupted either within the present or the preceding millennium.

CERRO DE CAPATACUTIRO

The youthful cone of Cerro de Capatacutiro lies close to the western base of Cerro del Aguila. From a breach in the western side, several flows of basalt descended toward the Mexico City highway. The earliest ones spread as far as Paracho Viejo; the later ones encircled the cone of Sicapen and flooded the valley north of the Cerros de Los Hornos (fig. 77).

The lavas of Capatacutiro are the least siliceous of any in the Parícutin region. They are coarse-grained olivine-augite basalts, and except for thin skins of glass they are entirely holocrystalline. In many places they exhibit crude pahoehoe forms, and their surfaces are marked by pressure ridges and collapse depressions caused by foundering of the roofs of tunnels. Here and there miniature lava tubes are still to be seen. No other flows within the area show these features; all other basalts and basaltic andesites are of the blocky or aa type.



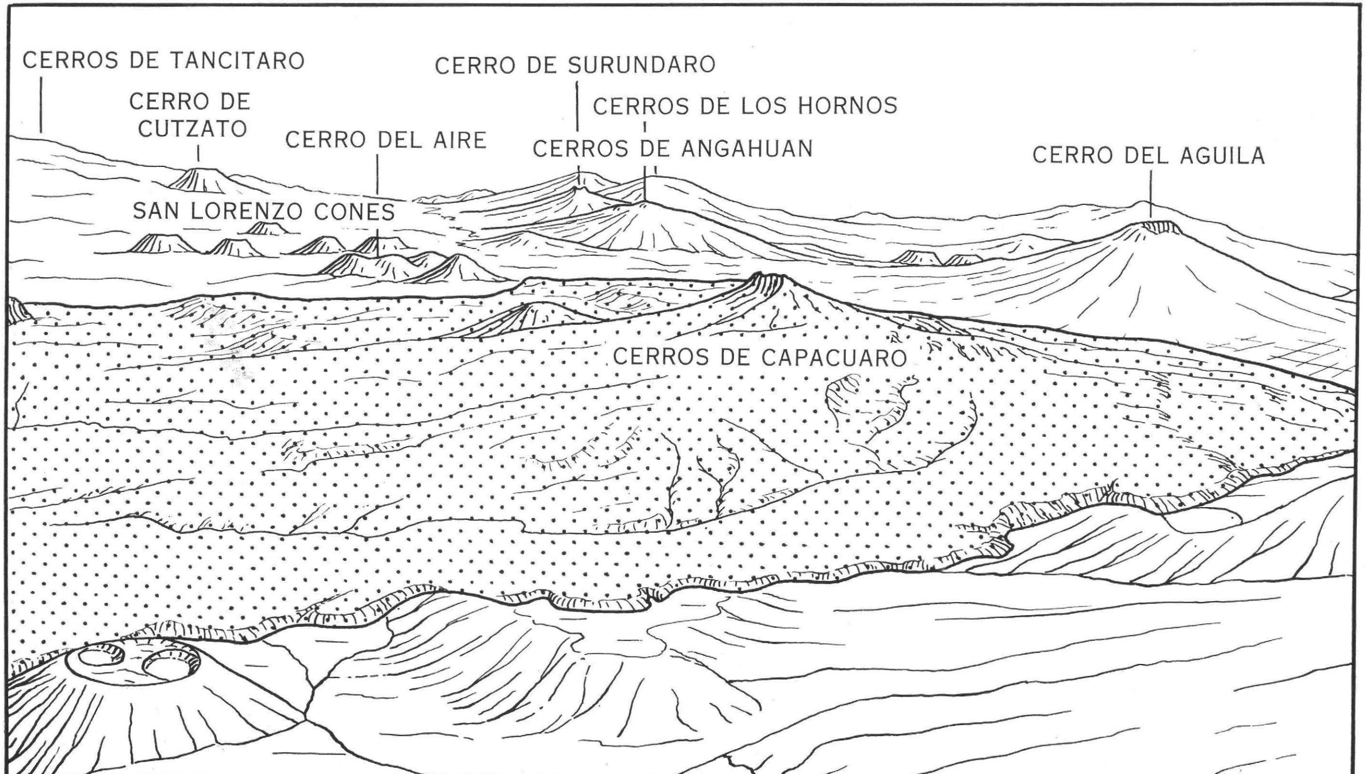


FIGURE 81.—Cerros de Capacuaro from the east. Area covered by the recent andesite flows of Cerros de Capacuaro is shown by stippling. Beyond lie the older andesitic volcanoes of Cerro del Aguila and Cerros de Angahuan and Cerros de Los Hornos; also the young andesite cone of Cerro de Surúndaro. View looking west. Photograph above (p. 204) by the Compañia Mexicana Aerofoto, 1934.

FIGURE 82.—Great flow of andesite from Cerros de Capacuaro, as seen from the southeast. The flow is more than 10 miles long and locally more than a mile wide. Note the marginal levees. In the foreground the flow is crossed by the railroad to Mexico City. To the left (west) lies Cerro Colorado, composed of iddingsite-rich basalts, and, behind it, Cerro de La Cruz, composed mainly of andesitic lavas. Both peaks are erosional forms cut in the Zumpinito formation. The intervening valley is occupied by recent flows of olivine basalt. Photograph by the Compañía Mexicana Aerofoto, 1934.

The excellent state of preservation of the features just mentioned is enough to indicate that these flows are among the youngest of the Parícutin region. However, they are older than the explosive eruptions that formed the nearby cones of Cumbuén, Pelón, and Paracho Viejo, and they are partly overridden by the lavas of the Surúndaro volcano.

CERRO DE SURUNDARO

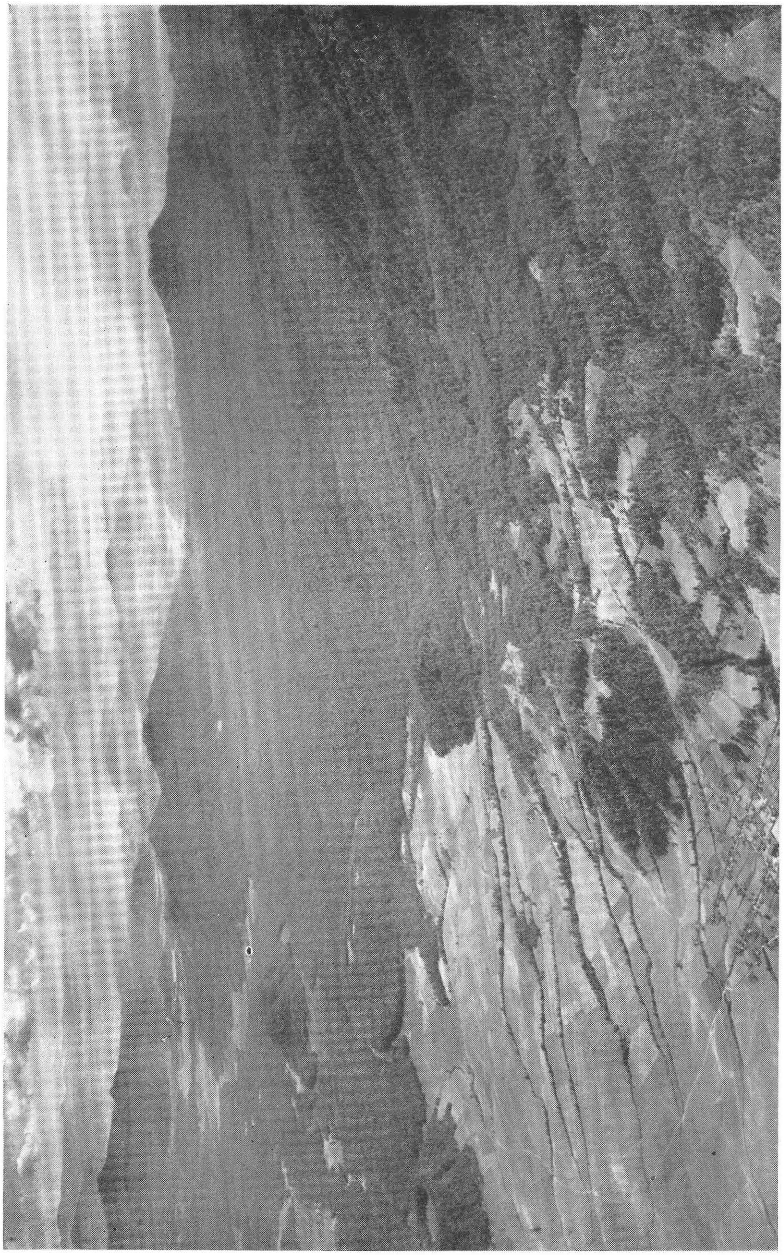
The eroded eastern slopes of the Angahuan volcanoes are buried by widespread sheets of recent lava that form a malpais difficult to cross. These accumulated to build a broad, flattish, shield-shaped volcano around the summit cinder cone of Surúndaro (fig. 83). Because the flows emptied into the depression between the older volcanoes of Angahuan and the Cerros de Los Hornos, they were obliged to spread chiefly to the north and south. In the former direction they extended for about 5 miles, and near their snouts they eddied round the semicircular butte known as Loma Colorada. This peculiary shaped butte, which is approximately 300 feet high and has a flattish top, appears to be an old scoria cone downfaulted on its southern flank. A short distance to the southeast, the lavas of Surúndaro also eddied round the youthful cone of Cerro de Los Amoles and spread over the front of the olivine basalts erupted by Cerro de Capatacutiro.

Southward the lavas extended as far as San Lorenzo, near which they were deflected in their advance by another cinder cone.

Despite their wide extent, the flows of Surúndaro vary little in composition and texture. All are dark, blocky to scoriaceous lavas typified by a glass-rich matrix and an abundance of porphyritic olivine. In the field they would be classed without hesitation as olivine basalts, yet chemical analysis shows them to be andesites. As to their age, they are younger than the cone cluster of San Lorenzo and the basalts of Capatacutiro, and probably they are also younger than the andesites of Cerro de Capacuaro. Only the last flows of Cerro Prieto and the Jabalí cones and those now issuing from Parícutin are more recent.

CERRO PRIETO

The symmetrical, shield-shaped volcano of Cerro Prieto lies at the eastern foot of Cerros de Tancítaro (figs. 75, 85). Impeded on three sides by the opposing slopes of Cerros de Tancítaro, Cerro de Tzirapan, and the Cerro de Pario cones, the lavas discharged from the central vent of Cerro Prieto spread mainly to the south and southeast. These flows were augmented by others that issued from three parasitic cones. From the southernmost parasite, a narrow tongue of lava



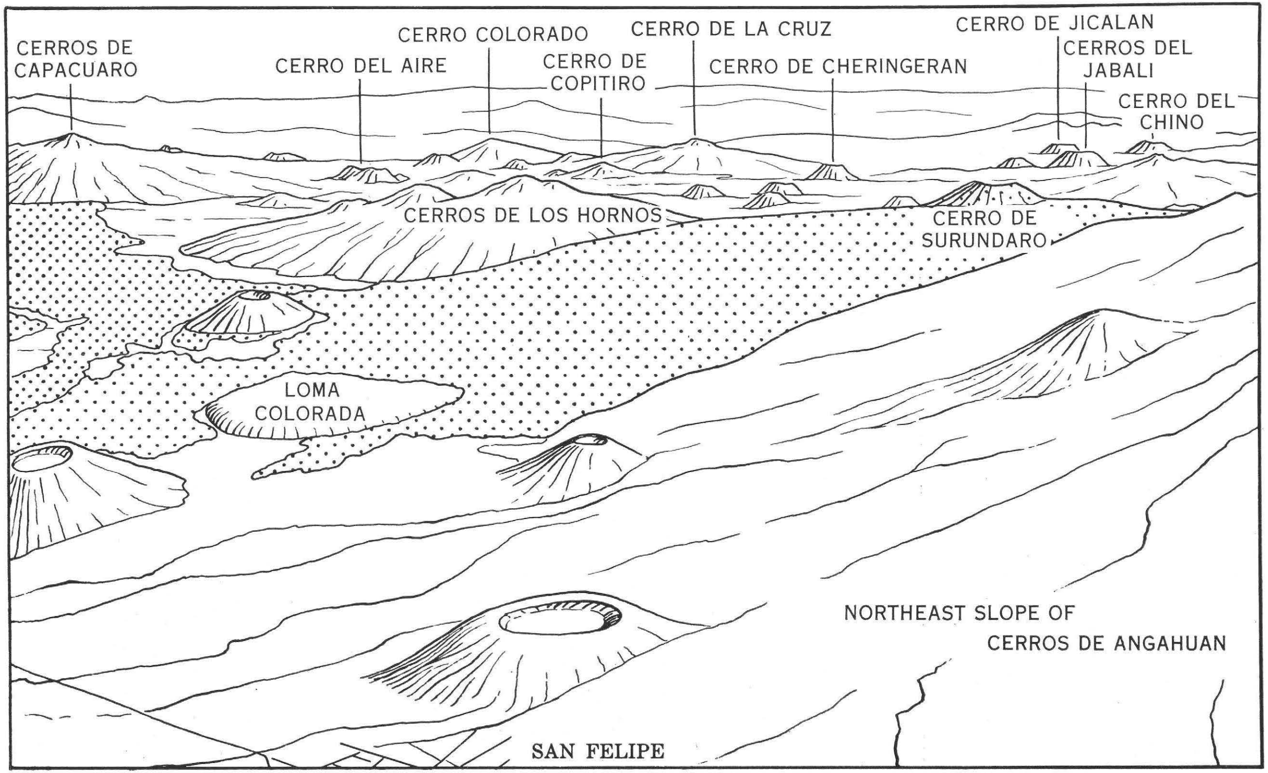


FIGURE 83.—Cerro de Surúndaro from the northwest. The young andesitic lavas of Cerro de Surúndaro, shown by stippling, lie between the older andesitic volcanoes of Cerros de Angahuan and Cerros de Los Hornos. The youthful andesitic cone of Cerros de Capacuaro appears in the distance, on the left. Photograph above (p. 208) by the Compañía Mexicana Aerofoto, 1934.

moved for 3 miles down a steep-sided canyon cut in the beds of the Zumpinito formation before coming to a halt in the flats near Santa Catarina. Hardly less impressive are several blocky flows that ran down other valleys toward Los Lobos.

The earliest and longest of the flows of Cerro Prieto were those that extended to Los Conejos. These are thickly covered with weathered ash. On the other hand, most of the later flows, which are confined to the upper flanks of the volcano on the south side and descend to the flats of Teruto on the opposite side, are only patchily covered with weathered ash, and some are so recent that they are mantled by no more than the thin veneer of ejecta from Parícutin. The surface forms of these younger flows are strikingly preserved; the fronts of successive flows stand out distinctly, and marginal levees and median gutters are well defined. Both in appearance and composition the lavas are almost identical with those of Parícutin; all are dense, vesicular, blocky, olivine-bearing basaltic andesites.

The cinder cone capping the lava shield had already ceased its explosive activity before most of the flows were extruded; hence its exposed top is probably only part of a much larger cone that began to grow early in the history of the volcano.

CERROS DEL JABALI CONE CLUSTER

A particularly youthful cluster of cones is to be seen a few miles northwest of Uruapan (fig. 84). Surrounding it is a rugged malpais of lava, some of which is of such recent origin that it supports only a scant cover of vegetation. Indeed, the last flow, a tongue of black, barren lava skirted by the road between Cerro del Chino and Los Conejos, may well have been erupted within the last century. Marian Storm (1945, p. 340) records a conversation with the Tarascan Indian who cultivated the corn patch in the crater of Cerro del Chino in the following words:

> * * * When the old people of my family were little this Hill of El Chino burst open and tons of mud poured out. Then freezing cold came over all this country; the animals in corral died of it. Snow fell, but ashes covered the land as well, shutting out the sun, and plants withered and trees lost all their leaves. We often tell again the story of those times. * * * Look where dark, hot rivers moved down El Chino on this side and stood still in what must have been a pretty valley, to make that malpais!

If this account is interpreted in the light of geological evidence, it seems clear that the informant was mistaken in referring to an outburst of Cerro del Chino, for the lavas from that cone are covered to a great depth with weathered ash. It is far more likely that the Indian referred to the final explosions of one of the Cerros del Jabalí cones and to the black tongue of lava mentioned above which abuts against the base of Cerro del Chino. No one seeing the Jabalí cones can doubt that they are younger than Cerro del Chino, for their slopes are still only slightly scored by erosion and the cinders that form them are scarcely decomposed. Considering the climate of the region and recalling how quickly vegetation reoccupied the country devastated by Jorullo in 1759, one cannot escape the view that several of the Jabalí cones may have erupted within the last few centuries. The surprising thing is that the people of the town of Uruapan preserve no legends concerning them.

The area covered by the flows of the Jabalí cones approximates that inundated during the last 5 years by Parícutin. They poured over the southeast slopes of Cerro de La Alberca from five closely spaced cones. The largest of these, Jabalí itself, rises to a height of about 350 feet. Cerro de Sapien, a short distance to the east, and the southernmost cone are slightly smaller; the other two are merely low mounds of scoria.

The oldest flows erupted by these vents are mantled with rotten yellowish ash from a few inches to several feet in thickness; hence they form cultivated islands and grassy patches between the younger flows whose thin and patchy cover of less weathered ash supports only a light growth of ferns, cacti, and pines. For the same reason, the older flows are easy to cross, whereas the younger ones make a blocky wilderness difficult of access. Despite the variability of the ash cover, however, the entire activity of the Jabalí cones may have taken place within a few centuries or a few millennia at most. Much greater variation in the depth of ash is to be seen on the flows now being discharged by Parícutin.

Among the first lavas of the Jabalí cluster are those exposed in the gorge of the Río de Cupatitzio where it runs through the national park on the outskirts of Uruapan. In this part of its course the river is floored by spheroidally weathered olivine basalt, perhaps derived from Cerro de La Alberca. Resting upon this is a layer, up to a few feet thick, of thoroughly decomposed clayey ash. Above this is a flow of columnar basalt, undoubtedly from one of the Jabalí cones. The copious springs that gush from the west bank of the Cupatitzio gorge, giving sudden birth to a full-fledged river, issue from the contact of the columnar lava with the underlying clayey ash.

All the flows from the Sapien cone are heavily blanketed with yellow ash. The last of them broke from a breach in the east flank of the cone, a short distance from which is a large mound of lava that represents a domical accumulation over a separate vent.

The youngest flows from the main Jabalí cone escaped from fissures close to the base, one on the north and the other on the east side. A large stream flowed from the northern fissure, spreading eastward for about 3 miles. Close to the outlet a spectacular lava gutter, between

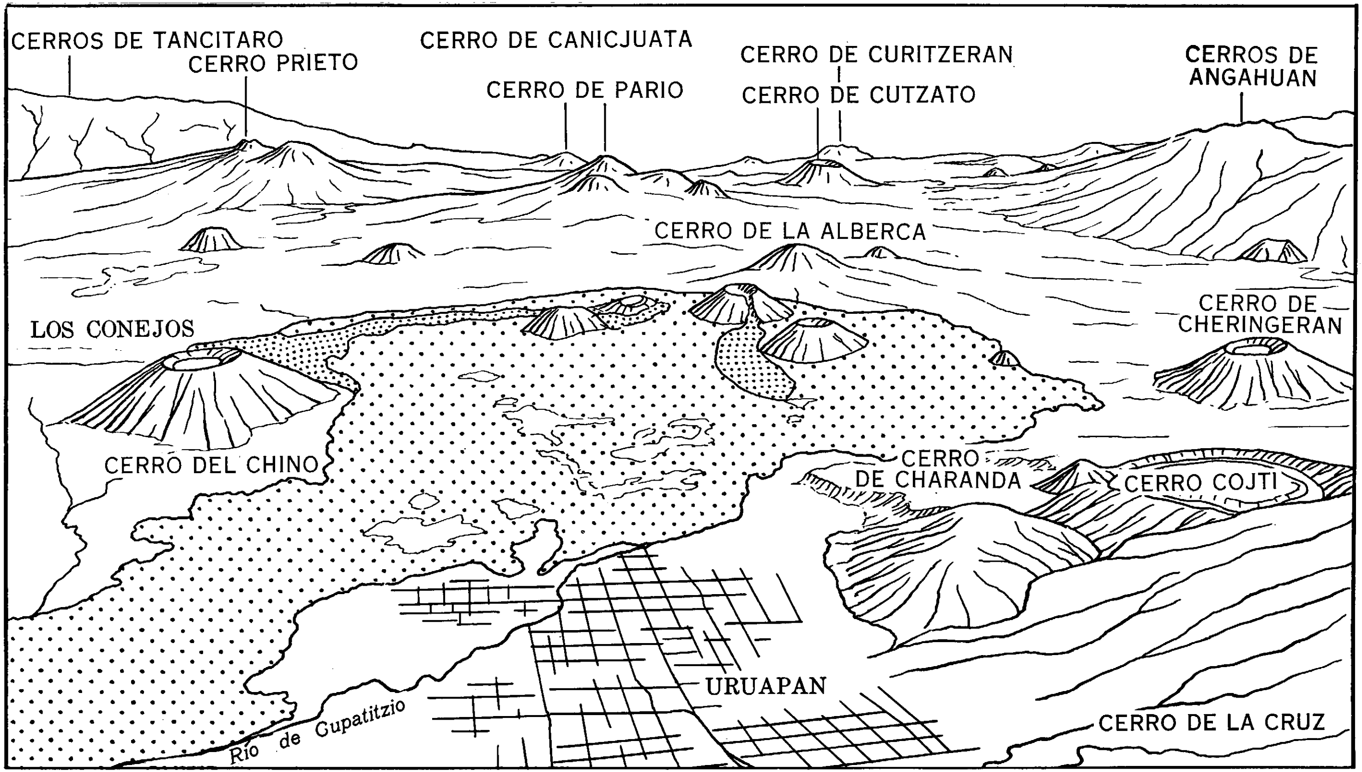


FIGURE 84.—Cerros del Jabalí cone cluster and its lavas, looking west over Uruapan. Older flows of the Jabalí cones are shown by light stippling; younger flows, by darker stippling. The flow that descends to Los Conejos may be less than a century old. The "Ringwall" and central lava mound of Cerro Cojti may be seen on the right. The eroded andesitic volcanoes of Cerros de Tancítaro and Cerros de Angahuan appear in the distance; between them lie younger cones and flows of basaltic andesite. Photograph above (p. 212) by the Compañía Mexicana Aerofoto, 1934.

150 and 200 feet deep and up to 250 feet wide, is bordered by precipitous walls. Smaller gutters have been observed on many flows of the Parícutin volcano where early congelation of marginal levees confines the moving currents to a central channel, the level of which is lowered by drainage as the supply at the vent becomes exhausted. Following this flow, lava escaped from the fissure at the east base of the Jabalí cone. Its extent is shown on the map (pl. 8). Here also the source is marked by a lava mound and central gutter, in this case of smaller dimensions. Both these late flows are exceptionally thick and have steep fronts up to 250 feet in height. Their surfaces consist of a litter of smooth-faced blocks of dense, glass-rich basalt stippled with iridescent olivines.

By far the largest of the younger flows of the Jabalí cone cluster is one that issued from fissures at the foot of the lowest and westernmost cone. This moved first southward and then eastward for more than 6 miles, descending to the gorge of the Rio de Cupatitzio near Jicalán. The roads linking Uruapan with Jicalán and Los Conejos cut across it, revealing the scoriaceous, rubbly, oxidized character of its interior.

The last flows of the Jabalí cones, the malpais negro to which Marian Storm's account almost surely applies, also issued from the foot of the westernmost cone. Its limits are depicted on the map (pl. 8). Probably at the same time, a short tongue of lava broke from a fissure at the east base of the same cone, piling up in the valley that separates it from the foot of Jabalí itself.

Fully three-quarters of the visible lavas erupted by the five Jabalí cones were discharged after the cones themselves had ceased their explosive activity. If all five cones were not formed simultaneously, they certainly grew in quick succession. The Sapien cone was the first to become extinct, but the order in which the others expired has not been determined. More thorough study of the cluster is much to be desired.

The lavas of the Jabalí cones vary so little in texture and mineral content that it is impossible to distinguish between specimens from adjacent flows or from different parts of the same flow, yet chemical analyses show that the most extensive flow is an olivine basalt, whereas the youngest is a basaltic andesite. Only additional analyses will indicate whether there is a regular sequence.

Despite the recency of the final flow, no signs of solfataric activity remain in the vicinity.

CONES ON THE WEST AND SOUTH FLANKS OF CERROS DE TANCITARO

As far as was possible, the volcanoes of the Parícutin region described in the preceding pages were discussed in the order of their formation. The relative ages of those to be referred to in this section are uncertain, since they were examined only in a cursory way.

Mention has already been made (p. 180) of the fans of bouldery debris, the products of lahars or volcanic mudflows, that spread for miles beyond the foot of Cerros de Tancítaro toward the northwest, west, and south. Similar deposits of more limited extent may underlie the cones and lavas near Parícutin. The oldest of these laharic deposits was laid down during the growth of Tancítaro itself, but it was not until discharge of ash from the encircling cinder cones began to accelerate erosion that most of them were formed. Today the fans near Peribán are being rapidly enlarged as an indirect result of the activity of the new volcano.

Evidence that the fans were developed chiefly during the period of basaltic eruptions is to be seen in the canyons along the west and south sides of Cerros de Tancítaro, where flows of olivine basalt and layers of basaltic ash are interbedded with the bouldery detritus. Around Peribán the detritus consists mainly of andesitic rocks derived from Tancítaro; locally it is interbedded with basaltic ash and tongues of lava. To the south, on the wooded Cerro de Parástaco, is a cluster of eroded cinder cones surrounded by dark, vesicular, olivine-bearing basaltic andesites, some of which interfinger with tuff breccias and bouldery sediments. The four largest cones stand almost in line, suggesting growth over a common feeding fissure that trends slightly north of west.

Near the village of Apo rises an exceptionally large cinder cone with a small parasite at its northwest base. Wide sheets of olivine basalt poured westward from these vents, and Apo itself is partly built on one of them. The adjacent country is buried to depths of more than 50 feet with weathered, yellowish-brown ash erupted from the same sources.

Where the road crosses the first gorge south of Apo, the bouldery fans are composed chiefly of basaltic debris and are interbedded with layers of basaltic ejecta and lava. Still farther south are two conspicuous mesas surrounded by alluvial fans, detached a short distance from the foot of Cerros de Tancítaro. Rare exposures beneath the ubiquitous mantle of decomposed ash suggest that these mesas were formed by viscous effusions of basaltic andesite, one from a fissure and the other from a cinder cone at its eastern end.

Around the village of Tancítaro and Rancho de Codémbaro the bouldery fans are particularly large, and they are rapidly burying the youthful cinder cones nearby. A short distance south of the former village is an extensive field of blocky lava, probably basalt. Unfortunately, circumstances prevented a close examination of the field, but the barren appearance and remarkably fresh aspect of its surface suggest that the lava may have been erupted within the last few centuries.

Turning to the east, along the south flank of Cerros de Tancítaro, the trail to Araparícuaro first crosses a broad apron of fanglomerate and then passes over tongues of vesicular olivine basalt related to the small cinder cones to the north. From Araparícuaro to the gorge of the Río del Fresno the trail climbs over a hummocky highland of basaltic lava built by effusions from Cerro de la Alberca and adjacent vents. The successive flows, with their gently sloping tops and steep fronts, form a giant staircase leading to the foot of Tancítaro. Many of these flows and the parent cones are only slightly modified by erosion, but the oldest ones are to be counted among the first of the post-Tancítaro lavas. For instance, near the top of the gorge of the Río del Fresno, on the west wall, is a flow of pale-gray holocrystalline basalt unusually rich in olivine, erupted so long ago that the river has incised a channel below it to a depth of about 150 feet.

From the Río del Fresno eastward the trail passes onto the underlying Zumpinito formation until it reaches Santa Catarina, where it climbs onto the recent flow of basalt erupted by Cerro Prieto (pp. 207–208).

CONES AND FLOWS NEAR PARICUTIN VOLCANO

Nowhere along the periphery of Cerros de Tancítaro is the cluster of cinder cones denser than in the vicinity of the new volcano. Although these cones vary widely in age, so that the periods of their activity overlap those of most of the "younger" volcanoes discussed in the preceding pages, they are here considered together in order to bring out more clearly the setting of Parícutin itself.

In attempting to date the cones near Parícutin on the basis of the degree of dissection, it must be borne in mind that erosion was greatly accelerated by the ash falls attending their growth. Account must also be taken of the torrential character of the rains in this region. During the wet seasons the volume of the streams increases a thousandfold. Moreover, as Segerstrom (1950) has emphasized, 90 percent of the summer rains fall in periods of no more than 30 to 60 minutes' duration. At times 2 inches of rain may fall in as many hours. As a result, loose ash is rapidly swept into the canyons to form torrents of great erosive power. In addition, the protective cover of vegetation is destroyed by the eruptions, and the water-soaked ash, even on gentle slopes, is subject to large-scale creep and recurrent slides. It is enough to witness the havoc caused by a single summer storm to be convinced that the deepest gullies on the oldest cones may have been excavated in a few thousand years. Many of the younger cones must have been active within the present millenium, and perhaps Loma Larga and the three Jarátiro craters ceased activity no more than a few centuries ago. Why the Tarascan Indians have no legends concerning these eruptions is difficult to understand.

On the map, plate 9, the cones near Parícutin are divided into two groups, an older one comprised of cones that are deeply dissected and devoid of summit craters and a younger one in which the cones and craters are well preserved.

OLDER GROUP

Among the oldest and largest of the cones near Parícutin are the three Cerros de Zirosto, the biggest of which is Cerro de La Máscara. Long, thick flows of gray, olivine-rich basalt issued from the feet of these cones to pour down the valleys of the Río de Itzícuaro, Río de Xundan, and Río del Agua Blanca at least as far as Peribán and San Francisco. In the canyon walls of the Río del Agua Blanca they rest on bouldery laharic deposits and are overlain by more than 100 feet of weathered basaltic ash. Elsewhere they are likewise heavily blanketed with ash, within which several soil horizons may be recognized. Similar olivine basalts flowed down the Itzícuaro valley past Barranca Seca from the coeval cone of Tiripan.

A short distance south of Parícutin rise Cerro de Camiro and Cerro de Tzirapan, two eroded cones of approximately the same age. The crater of Cerro de Camiro has been obliterated, and the flanks are deeply cut by ravines. Lavas from the base of the cone form a pedestal no less than 800 feet in thickness. Despite their large volume, however, the Camiro flows spread only a few hundred yards to the west, coming to a halt at the edge of Llano de Teruto. Northward they stretch for about a mile to Cerro de Nuréndiro at the margins of the Parícutin lava field. Clearly they must have been extremely viscous. No chemical analyses have been made, but the microscope shows them to be olivine-poor, hypersthene-rich lavas, and if they are not true andesites they are surely not less siliceous than basaltic andesites. Other thick, olivine-poor flows, possibly andesites, form Mesa de Cocjarao; these escaped from concealed fissures near Cátacu.

Cerro de Tzirapan consists of a principal cone and a parasite. The former rises about 600 feet above the encircling flows, most of which moved to the south and east through a breach in the flank. Probably the activity of this cone began shortly after Camiro had expired.

East of Tzirapan, in the region extending from the foot of Cerro Prieto northward to Cerro de Curupichu, all the lavas are basaltic andesites. They form a series of north-trending ridges with gently sloping, hummocky tops that descend in steps at the snouts of successive flows. Presumably they issued from Jurítzicuaro and adjacent cones after the last flows of the Pario volcano but before those of Cutzato.

Not far to the north of Parícutin is a ridge of lavas capped by Cerro de Jarátiro, Cerro de Equijuata, and Cerro de Capatzin (fig. 85). Most of this ridge has been submerged by the lavas of the new volcano. The northern end, from Cerro de Equijuata to Cerro de Capatzin, runs north for about a mile and is bounded by steep sides that rise between 300 and 400 feet above the adjacent flats. It consists of olivine basalts with or without basaltic andesites devoid of porphyritic feldspars. Contrasted with other lavas in the vicinity, these are much less vesicular, and it may be that this feature, coupled with the absence of interbedded ashes, accounts for the fact that the topographic ridge is also a ridge of high gravity values (Barnes and Romberg, 1948). The lack of craters and scoria cones on the crest suggests that Cerro de Capatzin and Cerro de Equijuata, together with the two small peaks west of the latter, represent domical accumulations of the last-extruded viscous lava over the feeding vents.

The saddle between Cerro de Equijuata and Cerro de Jarátiro is now buried by flows from the Parícutin volcano, but as late as 1945 northeast-trending ridges of oxidized and autobrecciated olivine basalt were to be seen there, separated by steep-walled, narrow depressions resembling lava gutters.

During the present survey, the Jarátiro ridge was so thickly covered by ash from Parícutin volcano that no exposures of lava were visible. At its eastern base was a perfectly preserved, almost circular crater, approximately 600 feet across at the rim and about 150 feet deep. In December 1944 lava from Parícutin poured over the rim and cascaded to the floor. Since then the crater has been almost completely filled. Two smaller craters, one 400 feet to the south and the other 800 feet to the southeast, were buried by lava from Parícutin at an earlier date. Their positions are indicated in plate 9, and the topographic map made by Segerstrom (1950) shows their forms. All three craters are much younger than the lavas of the Jarátiro ridge through which the largest was blasted; indeed, they were probably produced by the last explosions preceding the outbreak of the new volcano.

Of the lavas now buried by the cone of Parícutin, all that can now be said is that they include basaltic andesites, fragments of which were blown out during the first days of activity.

A short distance to the west of Parícutin are five large, eroded scoria cones: Cerro de Canicjuata, Cerro de Corucjuata, Cerro de Cuaxándaran, Cerro de Turajuata, and an unnamed cone nearby. Their locations and forms are indicated on the map (pl. 8) and in the photograph (fig. 85). Even the smallest of these cones rises to a height of 400 feet, whereas the largest, Canicjuata, is between 800 and 900 feet in height. All are craterless and deeply incised by radial barrancas. They appear to have been formed in quick succession, Canicjuata and Corucjuata perhaps being the last to erupt. The flows from all five cones moved principally to the north and northwest, and, as far as sporadic outcrops permit judgment, they all consist of olivine basalts or basaltic andesites closely resembling those now issuing from Parícutin.

Much of the ash from this older group of cones has been stripped by erosion and carried into the valleys of the Río de Itzícuaro and its tributaries; much has been washed from the flanks of the cones to accumulate in the adjacent canyons to depths of as much as 300 feet. In one of these canyons, 1.8 miles northwest of Parícutin, Segerstrom examined a 97-foot section of ash within which he recognized nine weathered zones. These indicate that periods of explosive activity alternated with long intervals of rest, probably to be measured in centuries.

YOUNGER GROUP

In marked contrast to the denuded cones just enumerated are five smaller ones with craters still intact. These are Cerro del Pueblo Viejo, Loma Larga, Cerro de Huachángueran, Cerro de Cátacu, and an unnamed cone nearby. Cerro del Pueblo Viejo is the oldest of this group, but even its activity took place long after the cones of the earlier group had become extinct. Its crater has been breached on the north side by the sapping action of a large spring; Cerro de Huachángueran and Loma Larga have been breached to a smaller extent by the headward erosion of streams. Indeed, Segerstrom (1950) observed that the flanks of Loma Larga had not been appreciably gullied prior to the eruptions of Parícutin. Presumably, therefore, it was formed after all the others. Cerro de Cátacu and the neighboring cone are also very well preserved, and their shallow, saucerlike craters are hardly modified by denudation. The flows from all five cones spread northward. However, the youngest flows in the vicinity were not discharged from any of these cones but from a fissure at the base of Cerros de Tancítaro, a short distance west of Cerro de Cátacu (pl. 9). These issued in two gushes; the first sent a stream northward for about a mile, whereas the second, overriding the first, came to a halt a little closer to the source. Both ended with steep, blocky fronts up to 300 feet in height. Their tops are covered by 3 to 4 feet of weathered ash, perhaps blown from Loma Larga and Cátacu, and by 6 to 7 feet of ejecta from Parícutin. They are composed of dark, vesicular, olivine-rich basalt or basaltic andesite.

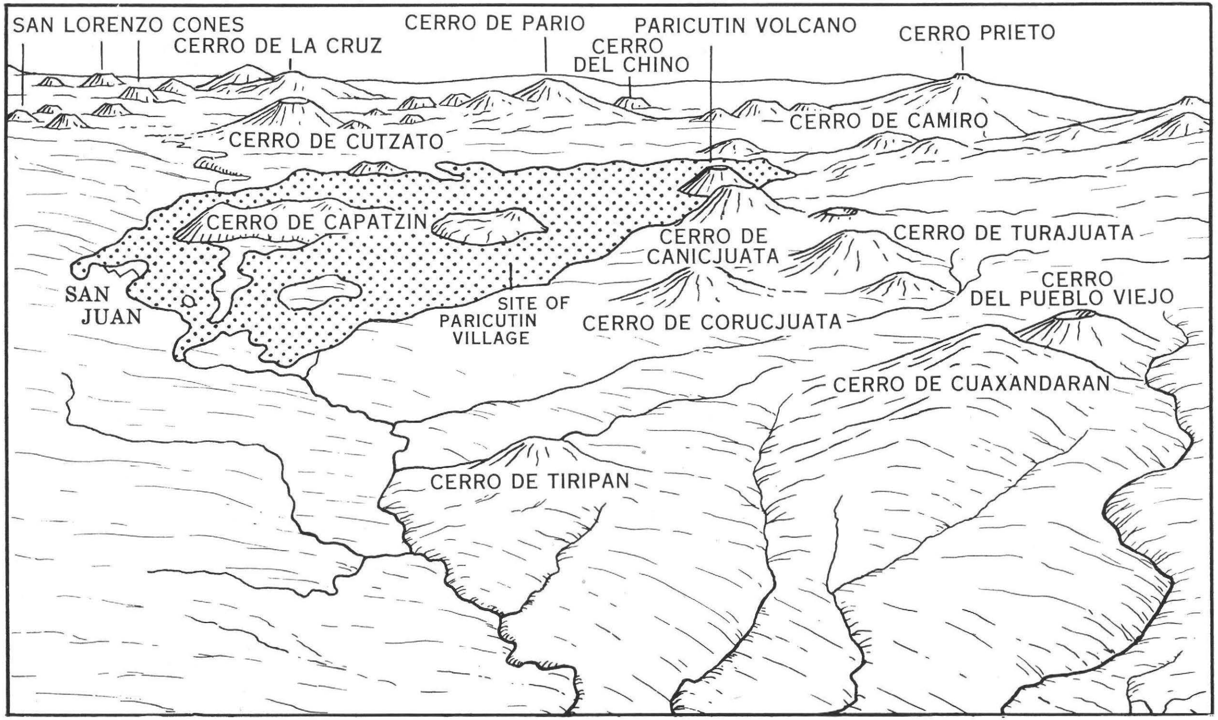


FIGURE 85.—Parícutin volcano and vicinity. Flows of Parícutin volcano, up to August 1947, shown by stippling. Photograph above (p. 220) taken in 1934, nine years before the birth of Parícutin, by the Compañía Mexicana Aerofoto.

Cerro de Lópizio, approximately 2 miles south of Parícutin volcano, is another youthful cone with a crater about 200 yards across, girdled by a low rim. From a breach in the eastern wall a flow of olivine basalt descended to Llano de Teruto.

Had the region close to Parícutin been studied before the cover of new ash became thick, a much clearer picture might have been drawn of the sequence of events preceding the present activity. This much, however, seems clear: The first eruptions in the vicinity took place from Cerros de Zirosto and Cerro de Tiripan, and the lavas discharged were olivine-rich holocrystalline basalts. Activity then shifted to Cerro de Camiro, from which viscous flows of olivine-poor, hypersthene-rich andesites or basaltic andesites were erupted. About the same time other viscous flows of olivine-poor lava escaped from fissures to the west to from Mesa de Cocjarao. A little later the double cone of Cerro de Tzirapan was formed, and perhaps the lavas of the Jarátiro-Equijuata-Capatzin ridge belong to the same period. Then five large cones—Canicjuata, Corucjuata, Turajuata, Cuaxándaran, and an unnamed cone—developed west of Parícutin, discharging flows of basaltic andesite. A long interval of quiet ensued. Subsequently the cones of Pueblo Viejo and Huachángueran were built. Cátacu and the unnamed cone nearby erupted next, and perhaps Lópizio was active at approximately the same time. The youngest cone to develop was Loma Larga, but the final eruptions prior to the growth of Parícutin were probably those that produced the three craters close to Cerro de Jarátiro, about a mile north of the new volcano. The lavas of all these younger cones are essentially similar to those now issuing from Parícutin itself.

PARICUTIN AND ITS FIRST FIVE YEARS OF ACTIVITY

For many years a small hole on the lands of Rancho de Tepicua had "emitted a pleasant warmth" (González and Foshag, 1947). The first signs of impending disaster were quakes on February 5, 1943. For 2 weeks they increased in number and intensity. On February 19, no less than 300 were felt (Trask, 1943). On the next day, Dionisio Pulido left the village of Parícutin to prepare his land for sowing. At 4 o'clock that afternoon, much to his surprise, he noticed that a fissure half a meter deep, trending slightly north of west, had opened there, and "in the hole the ground swelled and raised itself—2 or 2½ meters high—and a kind of smoke or fine dust—gray, like ashes—began to rise" (González and Foshag, 1947). Trees nearby swayed, and some, 30 meters from the hole, began to burn. When Dionisio's brother reached the spot at 6 p. m., "smoke" was rising from the hole, and low mounds of fine ash were beginning to accumulate. By 10 p. m. showers of incandescent rocks were visible from the village of San Juan Parangaricutiro. At 8 o'clock the next morning the volcano was already 10 meters high. By midday it had grown to a height between 30 and 50 meters. Later in the day the first flow appeared, escaping from a vent at the northeast base of the cone.

Thereafter the cone grew with amazing rapidity. By February 26 it was more than 160 meters high. Its explosive violence was awesome; the noise could be heard even in Guanajuato, 350 kilometers away. Every few seconds showers of glowing ejecta rose from the crater. Most of the bombs were a few feet across, but some measured 50 feet in diameter. Most of them were angular and smashed into fragments when they struck the ground; a few were tear-shaped, and some were fluid enough to flatten when they landed. Mixed with these clots of new magma were lumps of old andesite and plutonic rock torn from the walls of the conduit. Ash-laden clouds of vapor rose a mile or more above the cone.

On the twelfth day the volcano measured 1,500 feet across the bottom (Ordóñez, 1943), and lava had covered more than half a square kilometer. Explosive activity reached a climax on March 18; for a month the sky was turbid with dust. Heavy showers of ash fell on Uruapan, and early in April fine ejecta fell on Mexico City.

In mid-April a second crisis took place, and a new tongue of lava broke from the southwest base of the cone. On June 9 a slight change in the shape of the crater rim heralded a break; by the next morning the upper part of the cone had slumped and was being carried away on the crust of a flow that had escaped during the night. On June 14 a lava fountain burst out 300 feet below the crater rim, and a flow cascaded from it for several weeks, passing under the crusted flow of June 9 so as to upheave and float it downstream. During early July other flows were injected under earlier ones, carrying them along for as much as 1,200 feet (Ordóñez, 1947). At no other time in the history of the volcano has lava broken out part way up the flank of the cone; all other flows have issued from vents at or close to the base on the northeast and southwest sides.

The most violent period in the life of the new volcano was probably July and August of 1943. Lava then stood higher in the central crater than at any subsequent period. On June 19 it was within 50 feet of the rim (Trask, 1943). According to Foshag (1947), each flow was preceded by strong explosions that ended shortly before the lava issued; while the lavas emerged, explosions were relatively few.

On October 19, 1943, the activity of Parícutin diminished and a parasitic vent, Sapichu (fig. 86), opened at its northeast foot. For 79 days, until January 6, 1944, while Parícutin lay comparatively quiet, Sapichu erupted with vigor, building a cone 200 feet in height and discharging fluid lava northward to the base of Cerro de Equijuata. No sooner did Sapichu die than the parent cone renewed its violent activity. New vents opened on the opposite side, and the adjacent area was riven by fissures. For the next 3 years, until January 19, 1947, all the lavas emerged from closely spaced vents on this, the southwest side of the cone. Hardly did one flow stop before another broke from a new orifice close at hand.

By the end of the first year, Parícutin was approximately 1,100 feet high. The greatest discharge of fragmental ejecta certainly took

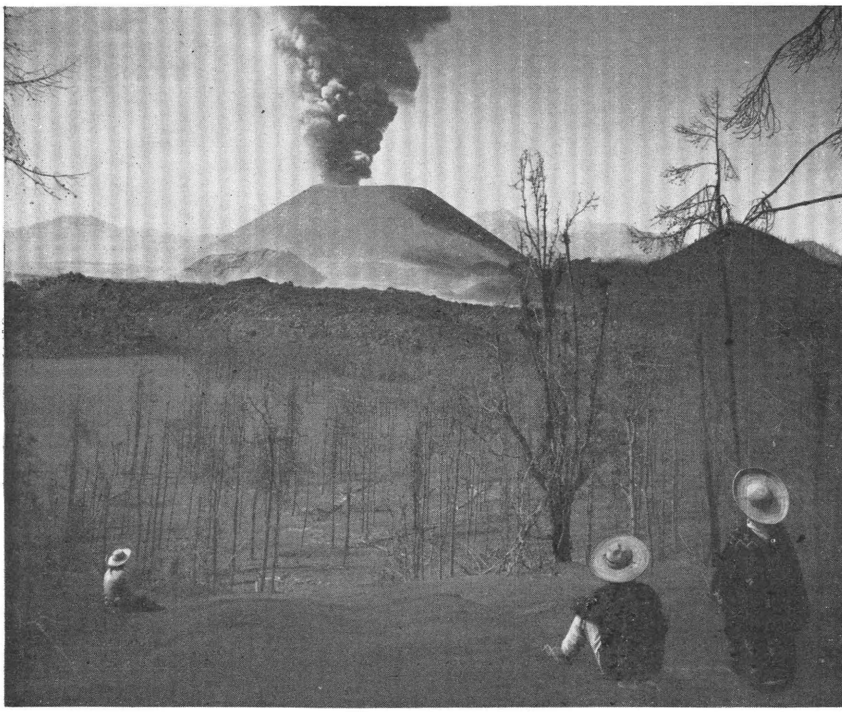


FIGURE 86.—Parícutin volcano from the south, April 1944. Parasitic cone of Sapichu at the northeast (left) base of the main cone; ash-covered flow of June 1943 at the northwest base. To the right (west) of Parícutin volcano, the denuded cone of Cerro de Canicjuata. Photograph by A. Brehme.

place during these first 12 months; since then effusion of lava has been the dominant process.

The flows that issued early in 1944 soon accumulated to build the so-called Mesa de Los Hornitos adjacent to the southwest vents. Most of the lavas moved first to the east and then northward around the foot of the cone, and many buried themselves by injection under older flows. During April, lava moved around the east side of the Equijuata-Capatzin ridge, then turned westward to reach the outskirts of San Juan Parangaricutiro in May. By the end of July most of the town had been buried. Subsequently the flows continued in the same direction for more than a mile before coming to a standstill in August. This flow that covered San Juan Parangaricutiro was the most voluminous of all the flows discharged by Parícutin volcano; its total length was about 7 miles.

In September 1944 another vent opened on Mesa de Los Hornitos close to the source of the flow that buried San Juan Parangaricutiro; spectacular lava cascades descended from it to inundate most of the village of Parícutin and spread beyond to unite with the lava of the San Juan flow near its snout (Bullard, 1947).

On November 7, 1944, the Ahuán vent opened, again close to the source of the flow that covered San Juan Parangaricutiro. The lava from this new orifice followed the same course, but it traveled a shorter distance, coming to a halt near the eastern foot of Cerro de Capatzin. Another flow broke from a nearby vent in February 1945, following the course of the September–October 1944 flow so far as to cover most of the village of Parícutin not previously inundated. Throughout this period explosive activity was irregular. At times the summit crater lay quiet for 24 hours at a stretch; at other times the explosions were almost as violent as at any previous period.

A succession of short-lived flows issued from the southwest vents during the remainder of 1945, throughout 1946, and until March 2, 1947. Some poured northward to Parícutin village and beyond; others moved around the south and east sides of the cone.

On January 19, 1947, when the activity of the southwest vents was diminishing, new vents developed on the opposite side of the cone, not far from Sapichu, at an elevation approximately 100 meters lower than that of the southwest vents. Slow but continuous effusions of lava issued from these northeast vents until October 1947, the flows moving northward along the west side of the Equijuata-Capatzin ridge. Then once more, as the activity of these vents waned, new ones broke open on the southwest side of the cone. From August to the close of 1947 these continued to emit slow-moving tongues of lava.

Such in brief has been the history of Parícutin during its first 5 years. Detailed accounts of its activity have appeared in the various publications listed at the end of this report. It may be appropriate, however, to summarize some of the principal features.

Explosive activity.—As stated already, most of the fragmental ejecta were expelled during the first 12 months. Comparison of the isopach map of the ash blanket made in May 1945 (Krauskopf and Williams, 1946) with that prepared in October 1946 by Segerstrom and here reproduced as plate 9 shows that the amount of ash added during the intervening 18 months was extremely small. By the latter date, the volume of ash was 0.65 cubic kilometer. Since then the increase has been slight. Thus far, therefore, Parícutin has repeated the history of most of the adjacent cones, its main explosive period occurring in the early stages.

At the close of the first year the main cone was already about 1,100 feet high. During the next 4 years its height increased by only a small amount. Meanwhile, the lower part of the cone was rapidly buried by lava. Between May 1945 and June 1947, while the rim of the crater rose only 140 feet, the visible height of the cone was reduced between 262 and 306 feet by accumulation of flows around the base (Wilcox, 1948a). If, as seems likely from the record of adjacent volcanoes, effusive activity continues increasingly to dominate over explosive discharge, the visible portion of the cone will be much further reduced. The present activity, therefore, suggests that the small cones that cap many of the neighboring volcanoes are not the result of weak concluding eruptions but are simply the exposed tops of large cones whose growth began at an early stage.

Apart from the foreign fragments of andesite and plutonic rock torn from the basement and the walls of the conduit, the pyroclastic ejecta consist entirely of olivine-bearing basaltic andesite either identical with the lavas or differing only in the degree of vesicularity and higher content of glass. Most of the lapilli and bombs are angular or subangular and were erupted either in a solid state or in an extremely viscous condition. At times more fluid clots have been expelled. The lateral variations of the ejecta have been studied in detail by Segerstrom (1950). Highly vesicular, pumiceous material has been thrown out at intervals, especially by Sapichu, but most of the larger fragments are dense, glassy types. No systematic variation in texture or composition has been detected.

Lavas.—These also have varied little in composition (table 3). All are olivine-bearing basaltic andesites. Typically they are of the aa type, varying from aa rubble and clinkers to massive aa, as defined by Jones (1946). The peculiar surface textures of the lava that buried the San Juan flow have been described by Ordóñez (1947), Bullard (1947), and Krauskopf (1948b).

Of particular interest has been the repeated injection of new lavas into and under older flows. These more or less sill-like injections have caused upheaval, doming, and extensive lateral displacements of old flows by younger ones. Where such injections have occurred, fumarolic activity has been especially long lived. For instance, the lava injected under the flow of June 1943 continued to emit fumarolic vapors for more than 3 years, and where the flow from Sapichu in late 1943 was injected early in 1944 by the San Juan lava there were extremely hot gas vents at the surface as late as 1945.

The areal extent of the lavas has not increased much since October 1944, but the thickness, especially near the cone, has continued to increase rapidly. By the close of 1947, the lava around the foot of the cone had reached a thickness of approximately 800 feet at the southwest base and 500 feet at the northeast base. From these places the thickness diminishes to between 20 and 50 feet around most of the periphery of the lava field. In October 1946, the total volume of the lavas was estimated to be between half and a third of the volume of the ash; that is, it amounted to about a quarter of a cubic kilometer. By the close of 1947, the total volume of ash and lava exceeded a cubic kilometer.

The rate of flow of the lava has varied with the gradient, volume, proximity to the source, gas content, and temperature. Krauskopf observed a typical flow in 1945 which moved at 6 to 15 meters a minute down a slope of 12° to 19° close to the source, whereas at its snout the movement was reduced to 45 meters a day on a 1° slope. Another flow moved at 0.7 meter to 8 meters a minute on slopes of 2° to 15° near the source, whereas the snout moved 100 meters a day down slopes of 5° to 6°, diminishing to a standstill as the supply at the source was cut off. Comparable estimates were made by Bullard (1947) on flows of 1944 and 1945.

As for the temperature of the lava, Zies (1946) recorded 1,110° C. in a flow in November 1944 at a distance of 3 miles from the vent. At the vent itself, he estimated that the temperature might have been close to 1,200° C. Krauskopf recorded vent temperatures of 1,026° and 1,060° C. during 1945—1,010° C. in lavas far from their sources. Bullard (1947) found temperatures of 1,043° to 1,057° C. at the vent of a flow in September 1944 and observed that a crust began to develop on the lava at approximately 950° C.

Satisfactory estimates of viscosity are difficult to make. Krauskopf (1948b) calculated that lavas near their vents have viscosities between 10^5 and 10^6 poises. Near the snouts of the flows it is hard to make an impression on red-hot lava with the blow of a pick. In later stages of advance the lavas move by shearing; there is nothing approaching turbulent flow even at the vents, only a slow laminar motion.

Primary sublimates from fumaroles on the lavas have consisted chiefly of ammonium chloride. By reaction with the lava, crusts of yellow, orange, and red iron-bearing chlorides have been produced (Foshag and Henderson, 1946). Krauskopf noted a predominance of HCl in gases from the lava vents and of SO_2 in those discharged by the summit crater during 1945. Incrustations of monoclinic sulfur were then seen in fissures within the crater. Where fumarolic activity is long continued, the lavas are considerably decomposed. In this connection, it is noteworthy that the older lavas of the region show little or no sign of such alteration. Beyond the confines of the flows from Parícutin there are no solfataras or hot springs, nor is it likely that any will develop after the new volcano dies.

Other features.—Emphasis should be placed on the observation made repeatedly by many observers that explosive activity can seldom be correlated closely with effusive activity. For a brief period in 1943, White (1945) noted a cyclic activity during which such a correlation could be made, but throughout most of the history of the volcano the summit crater appears to have behaved independently of the lava vents at the base of the cone. Sometimes an increase in intensity of explosive activity has preceded the opening of a new lava vent, but this has been far from a general rule. Krauskopf (1948a) has suggested an explanation for the erratic relations between outflow and explosions. At times the amount of water vapor discharged from the crater has been abnormally great in proportion to the amount of lava escaping from the basal vents. The presumption is that much of the vapor is derived from underground water, but proper interpretation of this phenomenon, which lies at the basis of an understanding of volcanism, must await more thorough studies.

No consistent correlation can be drawn between the activity of the volcano and either barometric pressure or tide-producing force, although, as Wilcox (1948a) has observed, sympathetic variations may exist for short intervals.

Finally, it should be pointed out that although the summit crater measures approximately 300 meters in diameter, the explosive vents within it are extremely small, seldom measuring more than a few meters in width. The position and number of these small vents have varied, but all tend to lie on the northeast-trending line connecting the lava vents on opposite sides of the cone.

PETROGRAPHY

ROCKS OF THE ZUMPINITO FORMATION

The following notes refer to the main rock types of the Zumpinito formation exclusive of the tuffaceous clays. For the sake of convenience the rhyolites are described first, then the andesitic lavas, and finally the basaltic lavas.

RHYOLITE TUFFS NEAR CALTZONTZIN

The upper part of the rhyolite tuff near Caltzontzin is a white, friable, pumiceous material devoid of stratification. About a third of a typical sample consists of clear, colorless, curved shards of glass and pumiceous shreds; an equal amount consists of impalpable glass dust clouded by specks of ore and blotches of limonite. Small lithic chips of pyroxene andesite comprise 3 percent of the volume. The remainder is made up of phenocrysts up to 2 millimeters in length. These are present in the following percentages by volume: calcic andesine, 17; quartz, 8; sanidine, 5; and biotite, 1.

Beneath this incoherent tuff and contrasting strongly with it are pink tuffs that are completely devitrified and intensely welded. In these, vitroclastic texture is only faintly discernible, the shards being flattened into subparallel streaks that wind around the phenocrysts in a manner suggestive of the fluidal banding of lava. Approximately 80 percent of the volume of a representative sample consists of cryptofelsite, in which some relic shards show replacement by fibrous quartz and sanidine. Approximately 10 percent is composed of sanidine phenocrysts, 2 percent of calcic andesine, 6 percent of quartz, and 1 percent of biotite. In the overlying tuff the mica is fresh and pseudouniaxial, but here it is deep red, is partly rimmed with magnetite, and has optic angles that range up to 15°. The welded tuff is characterized further by abundant tridymite in lenticular streaks parallel to the banding. The pink color comes from finely divided hematite dust, presumably, like the tridymite, a product of fumarolic vapors. These petrographic features corroborate the view gained by examination in the field that the tuffs were laid down by glowing avalanches of the Katmai type.

ANDESITIC LAVAS

In the mountainous country bordering the road to Apatzingán and along the trail joining Los Conejos with Tancítaro village, the dominant lavas are coarsely porphyritic pyroxene andesites similar to those that form Cerros de Tancítaro, to be described on pages 235–238. In brief, they are hyalopilitic to pilotaxitic lavas studded with zoned crystals of sodic bytownite-calcic labradorite up to 3 millimeters in length and smaller phenocrysts of augite and hypersthene. Olivine is present as a minor constituent in some flows; in others a little oxyhornblende can be found.

A markedly different type of andesite is widespread on Cerro de Las Ventanas. This lacks porphyritic feldspar. Between 85 and 90 percent of the volume is made up of a fluidal felt of sodic andesine microliths associated with granular ore, specks of augite, flakes of hematite, and interstitial cristobalite. The remainder is composed of oxyhornblende phenocrysts largely replaced by augite and ore.

A third kind of andesite forms the bulk of Cerro de La Cruz. In this, hypersthene preponderates over augite and the texture varies from hyalopilitic to vitrophyric. The analyzed specimen (table 1, analysis 14) is illustrated in figure 87*H*. Approximately 45 percent of the volume consists of plagioclase microphenocrysts up to 0.5 millimeter long, mostly ranging from An_{60} to An_{65} but occasionally

TABLE 1.—*Analyses of lavas from volcanoes near Parícutin*

[L. C. Pick, analyst, University of Minnesota]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Constituents																		
SiO_2	50.85	51.38	51.49	52.85	54.58	55.28	55.68	56.51	56.80	57.84	57.91	58.46	59.18	59.54	59.70	60.78	61.10	61.30
Al_2O_3	18.04	17.46	18.56	18.46	18.65	20.07	17.77	17.72	18.54	18.59	17.81	18.35	17.35	18.19	18.01	17.92	18.06	17.46
Fe_2O_3	2.72	1.24	2.38	1.72	1.41	3.05	1.91	3.50	1.88	2.98	1.60	2.20	2.67	1.98	1.75	.97	2.53	.97
FeO	6.19	6.41	6.57	5.58	5.54	2.89	5.07	3.07	4.50	2.83	4.36	3.30	2.99	3.19	3.39	4.00	2.31	3.67
MgO	5.73	9.13	5.63	6.06	5.00	3.11	4.94	5.48	5.03	3.50	4.86	3.37	4.33	3.45	2.89	2.55	2.56	3.11
CaO	9.10	8.95	9.56	8.85	8.39	8.00	6.78	7.17	7.06	6.70	6.60	7.00	6.39	6.81	6.04	5.83	4.89	5.75
Na_2O	3.59	3.03	3.23	3.56	3.45	3.69	3.65	3.78	3.98	3.90	3.65	4.03	3.70	3.61	3.66	3.62	4.25	3.41
K_2O	1.31	.54	.58	.86	.98	1.04	1.33	1.40	1.01	1.43	1.48	1.66	1.53	1.44	1.69	1.92	1.75	1.99
H_2O+	.10	.30	.29	.26	.37	1.27	.56	.20	.07	.54	.51	.40	.73	.93	1.45	.97	.90	.93
H_2O-	.05	.06	.11	.05	.08	.24	.24	.06	.04	.43	.20	.04	.06	.10	.16	.10	.55	.11
CO_2	----	----	----	----	----	.01	----	.01	.02	.02	----	.00	.01	----	----	.00	----	----
TiO_2	1.81	.89	1.22	1.10	1.02	.88	1.20	.85	.78	.82	.87	.72	.70	.73	.79	.75	.59	.71
P_2O_5	.43	.34	.19	.28	.45	.29	.70	.28	.23	.23	.24	.31	.21	.09	.23	.20	.20	.37
Cl	----	----	----	----	----	.07	----	.05	.03	.00	----	.07	.02	----	----	.02	----	----
F	----	----	----	----	----	.03	----	.03	.02	.03	----	.04	.01	----	----	.02	----	----
S	----	----	----	----	----	.02	----	.01	.01	.01	----	.01	.01	----	----	.02	----	----
MnO	.15	.13	.15	.13	.12	.10	.12	.11	.11	.09	.11	.10	.10	.09	.09	.09	.10	.08
BaO	----	----	----	----	----	.03	----	.05	.04	.06	----	.04	.05	----	----	.07	----	----
Total	100.07	99.86	99.96	99.76	100.04	100.07	99.95	100.28	100.15	100.00	100.20	100.10	100.04	100.15	99.85	99.83	99.79	99.86
Niggli values																		
si	125	119	127	134	147	162	158	156	159	177	169	178	181	188	198	207	211	207
al	26	24	27	27.5	29.5	35	29	29	30	33.5	30	33	31	34	35	36	37	35
fm	39	47	39	38.5	35.5	28	37	37.5	36	30.5	36	29	34	29	23	27	27	29
c	24	22	25	24	24	25	21	21	21	22	21	23	21	23	22	21	18	21
alk	11	7	9	10	11	12	13	12.5	13	14	13	15	14	14	15	16	18	15
k	.19	.11	.10	.14	.15	.16	.19	.20	.15	.19	.21	.22	.21	.20	.23	.26	.21	.29
mg	.54	.68	.54	.60	.57	.50	.59	.61	.59	.53	.60	.53	.59	.56	.51	.48	.50	.55
qz	−19	−9	−9	−6	+3	+14	+6	+6	+7	+21	+17	+18	+25	+32	+38	+43	+39	+47

1. Olivine-augite basalt from Cerro de Capatacutiro cone (95). On main highway, approximately 4 miles northwest of Capacuaro (fig. 88*E*).
2. Olivine-rich basalt. Main flow from the Cerros del Jabalí cone cluster (20). On road between Uruapan and Jicalán (fig. 89*A*).
3. Olivine-rich basalt (45). Near summit of Cerro Colorado (fig. 88*D*).
4. Olivine-rich basalt (63). Flow from Cerro de Tzintzungo, approximately 1 mile east of San Juan Parangaricutiro (fig. 88*C*).
5. Olivine-augite basaltic andesite (35). Lava mound near east base of Cerro del Aire (fig. 88*B*).
6. Hornblende andesite (113). East edge of Mesa de Zirimóndiro, approximately 1½ miles northeast of village of Tancítaro (fig. 87*D*).
7. Olivine-rich basaltic andesite (10). Thick flow from Cerro de Cutzato, 3 miles southeast of San Juan Parangaricutiro (fig. 88*F*).
8. Olivine-bearing basaltic andesite (121). South slope of Cerro Prieto, on trail between Tejamanil and Los Conejos (fig. 88*G*).
9. Olivine-rich basaltic andesite (23). Most recent flow from the Cerros de Jabalí cone cluster, approximately 1 mile east of Los Conejos (fig. 89*B*).
10. Hypersthene-augite andesite (79). Peña del Horno (fig. 87*A*).
11. Olivine-rich basaltic andesite (38). Cascada de Tzaráracua, Río de Cupatitzio (fig. 88*A*).
12. Pyroxene-hornblende andesite (91). Flow from Cerros de Capacuaro, on road between Capacuaro and Arantepacua (fig. 87*E*).
13. Olivine-bearing andesite (92). Cerro de Surúndaro near San Lorenzo (fig. 88*H*).
14. Augite-hornblende andesite (58). South edge of Mesa de Huanárucua, approximately 1 mile north of San Juan Parangaricutiro (fig. 87*C*).
15. Pyroxene andesite (65). Near north summit of Cerros de Angahuan (fig. 87*G*).
16. Hypersthene-augite andesite (90). Southeast slope of Cerro del Aguila (fig. 87*F*).
17. Hypersthene-augite andesite (111*A*). Summit of Cerros de Tancítaro (fig. 87*B*).
18. Hypersthene andesite (14). Near summit of Cerro de La Cruz (fig. 87*H*).

with rims of An_{55}. Oscillatory zoning is common, and the cores of many crystals are spongily replaced by glass. Prisms of hypersthene ($2V=80°$), of the same dimensions, make up about 15 percent of the volume. A few are enclosed by jackets of augite on the vertical faces. The rest of the andesite consists of brown glass relieved by acicular laths of calcic andesine, anhedral specks of augite, and minute grains of ore. Chemical analysis shows the andesite to be similar to those composing the Tancítaro, Angahuan, and Capacuaro volcanoes.

LAHARIC DEPOSITS

The tuff breccias of the Zumpinito formation include a wide variety of andesitic fragments with subordinate dacites and basalts. Most of the larger fragments in the deposits near Peribán and Los Reyes are of pyroxene andesite; in the deposits along the Río de Cupatitzio they consist chiefly of hornblende-bearing andesites. The fine matrix between the lapilli and blocks is crystalvitric tuff, mostly composed of broken chips of labradorite, hypersthene, and augite and shards of brownish glass.

BASALTS

The lavas of Cerro Colorado are subophitic to intersertal, olivine-rich augite basalts marked by extensive development of iddingsite.

The specimen illustrated in figure 88*D* is a coarsely crystalline variety from the summit of the mountain. Its chemical composition is shown in table 1. Micrometric analysis reveals the following percentages by volume: plagioclase, 55.2; olivine, 15.8; diopsidic augite, 10.1; interstitial ore-charged glass, 18.9. Some of the larger plagioclase laths are normally zoned from An_{62} in the cores to An_{54} at the margins; the smaller, unzoned laths consist of sodic labradorite. The gray-green augite is partly intergranular and partly in subophitic relation to the feldspar. One phenocryst has an extinction angle, Z to c, of 42° and an optic angle of 52°. Axial angles of other grains range from 48° to 58°. The olivines vary in size between 0.5 and 1.5 millimeters. Their optic sign is invariably negative, the angle ranging from 82° to 76° and suggesting a range in composition from Fo_{54} to Fo_{64}. A few crystals exhibit zoning from cores of Fo_{63} to rims of Fo_{55}. Many of the smaller olivines are fresh, but most of the larger ones are more or less altered to iddingsite, particularly in the cores. The rest of the lava consists of a brownish-black glass containing dusty titaniferous magnetite and thin plates of ilmenite.

The highly vesicular, spheroidally weathered basalts that form the bulk of Cerro Colorado differ from the above mainly in the more abundant development of iddingsite. In the larger olivines only the cores are altered; in the smaller ones alteration is usually lacking.

Hence the iddingsite appears to have been formed at an early stage by oxidation and hydration resulting from escape of volatiles from an iron-rich interstitial liquid. Edwards (1938) has noted elsewhere that it is especially in basalts with iron-rich glass that iddingsite develops; in chemically identical basalts in which the iron ores are completely crystallized he found the mineral to be absent. In the Parícutin region, this rule does not hold except among the basalts of Cerro Colorado. For instance, iddingsite is plentiful in holocrystalline lavas erupted by Cerro de Cutzato, Cerro Prieto, and Cerro de Cópitiro. What characterizes all these iddingsite-rich rocks is, not the presence of iron-rich glass, but the late crystallization of the abundant iron ores.

Other olivine basalts occur in the Zumpinito formation near Jucutacato. In these, olivine is the only porphyritic mineral, making up between 5 and 8 percent of the volume of typical specimens. Generally it is rimmed with either antigorite or bowlingite. The groundmass is a trachytoid felt of slender microliths of medium labradorite with intergranular specks of augite and ore. On Cerro de Las Ventanas, coarse-grained olivine-augite basalts are interbedded with tuffaceous clays; on Cerro de Charanda, there are holocrystalline basalts with the following percentages by volume: porphyritic olivine ($2V=80°$, negative), marginally altered to bowlingite, 5; calcic labradorite, 50; diopsidic augite, 30; and magnetite, 15.

INTRUSIVE ROCKS OF UNDETERMINED AGE

Discussion of the fragments of plutonic rock blown out of Parícutin is deferred to pages 258–259. Here attention is confined to the intrusive rocks found on the Bolita de La Magdalena, a short distance south of Uruapan.

Nothing is more characteristic of these rocks than their rapid variation both in texture and mineral composition. Three specimens are selected for brief description. In the first, phenocrysts of plagioclase (An_{65} to An_{75}), up to a centimeter in length, predominate. All are rendered turbid by clouds of irresolvable pinkish dust, possibly hematite. The other porphyritic constituent is olivine, partly altered to bowlingite and bordered by reaction rims of diopsidic augite. The groundmass is composed of a dense intergrowth of labradorite, hypersthene, augite, and iron ore with interstitial patches of quartz and orthoclase.

The second type is much finer grained and more nearly equigranular. Crystals of augite and hypersthene, commonly in parallel intergrowth, exhibit marked schillerization due to exsolution of hematite; they reach a length of 1 millimeter and constitute about 20 percent of the volume. Subhedral crystals of calcic labradorite make up 60 percent by volume; olivine, 3 percent; and ore, 4 percent. Interstitial quartz and orthoclase with accessory apatite constitute the remainder.

The third type, like the first, is marked by dust-filled laths of labradorite, some of which measure as much as 3 millimeters in length. These are much fractured and veined with clear, granular andesine. No porphyritic ferromagnesian minerals are present. Minute augite grains are enclosed by the feldspar phenocrysts, and, along with hypersthene, they are intergrown with anhedral grains of andesine in the dense, allotriomorphic groundmass. Unlike the other types, this one is devoid of late-crystallizing quartz and orthoclase. All three types are classed as gabbros.

ROCKS OF POST-ZUMPINITO AGE

GENERAL STATEMENT

The post-Zumpinito rocks of the Parícutin region show only a limited range in composition—from olivine basalts to olivine-free pyroxene andesites. Indeed, throughout the Neo-Volcanic Zone of Mexico, dacites and rhyolites are notably rare in comparison with those present among the older Tertiary volcanic rocks.

The present survey has shown, however, that in the Parícutin region andesites are more plentiful among the lavas of Pleistocene and Recent age than was previously supposed. It may well be that more detailed studies in other parts of the Neo-Volcanic Zone will show the same to be true there. Pale-gray, porphyritic and pilotaxitic pyroxene andesites are easy to recognize even in the field, but many dark, hyalopilitic and vitrophyric andesites are only to be distinguished by chemical analysis.

The naming of fine-grained and glass-rich lavas is a notoriously troublesome business. Usually, though not always, an abundance of porphyritic olivine denotes either a basalt or a basaltic andesite, but the distinction between basalt and andesite on the basis of the composition of the feldspar is unsatisfactory. Certainly the presence of labradorite is not to be regarded as diagnostic of basalt; if it were, then no lava in the Parícutin region would be classed as andesite despite the compositions revealed by analyses (table 1). There is such a wide range in the composition of the feldspar in most flows, not only within individual phenocrysts but between porphyritic and microlithic crystals, that it becomes virtually impossible to estimate an average composition. Besides, the composition of the interstitial glass and cryptocrystalline material is only approximately known.

Separation of basalt, basaltic andesite, and andesite must therefore be based on the bulk composition as revealed by chemical analysis. In the present report, lavas containing less than 54 percent silica, with negative *qz* values and without normative quartz, are classed as "basalts." Lacking chemical analyses, flows abnormally rich in olivine and in calcic labradorite or more calcic feldspar are also grouped as "basalts." Lavas with positive *qz* values of less than 20 (generally less than 10) and with modal olivine are named "basaltic andesites." Lavas with positive *qz* values of more than 20, but still carrying modal olivine, are referred to as "olivine andesites." Finally, lavas with more than 55 percent silica and with high positive *qz* values and devoid of olivine are termed "andesites."

OLIVINE-FREE ANDESITES

All the lavas of the oldest volcanoes of the region belong to this group—those of Cerros de Tancítaro, Cerros de San Marcos, Cerro del Aguila, and Cerros de Angahuan. Many flows of the next-oldest volcanoes, those of the Cerros de Los Hornos, belong to the same category. However, eruption of olivine-free andesites continued to a much later time, forming Mesa de Zirimóndiro and Mesa de Huanárucua and the most voluminous of all the recent flows of the Parícutin region—those of Cerros de Capacuaro. In the following notes the andesites are discussed in the order of their eruption insofar as that can be determined.

ANDESITES OF CERROS DE TANCITARO AND CERROS DE SAN MARCOS

The lavas of these volcanoes are coarsely porphyritic, pilotaxitic pyroxene andesites. Except for slight variations in texture and in the ratio of hypersthene to augite, and save for the presence in a few flows of a little oxyhornblende, they are remarkably uniform. None contains either biotite or quartz unless some of the latter is included in the cryptocrystalline groundmass. They resemble the principal lavas of such better-known Mexican volcanoes as Colima, Popocatépetl, Orizaba, and Nevado de Toluca, and they are similar to the pyroxene andesites of such coeval cones in the Cascade Range as Mounts Shasta, Rainier, Baker, and Hood.

The principal type is represented by the analyzed sample from Peña del Horno, illustrated in figure 87*A*. This has the following percentages by volume: (phenocrysts) plagioclase, 36; augite, 4; hypersthene, 6; (groundmass) granular ore, 8; augite, 6; microlithic feldspar, 38; oxyhornblende, 1; and cristobalite, 1.

The range in composition of the porphyritic feldspar is particularly striking. Even unzoned crystals vary in composition from An_{48} to An_{70}. Most of the phenocrysts are strongly zoned in an oscillatory fashion, the rims being notably more calcic than the cores. For example, one phenocryst has a core of An_{52} surrounded by shells

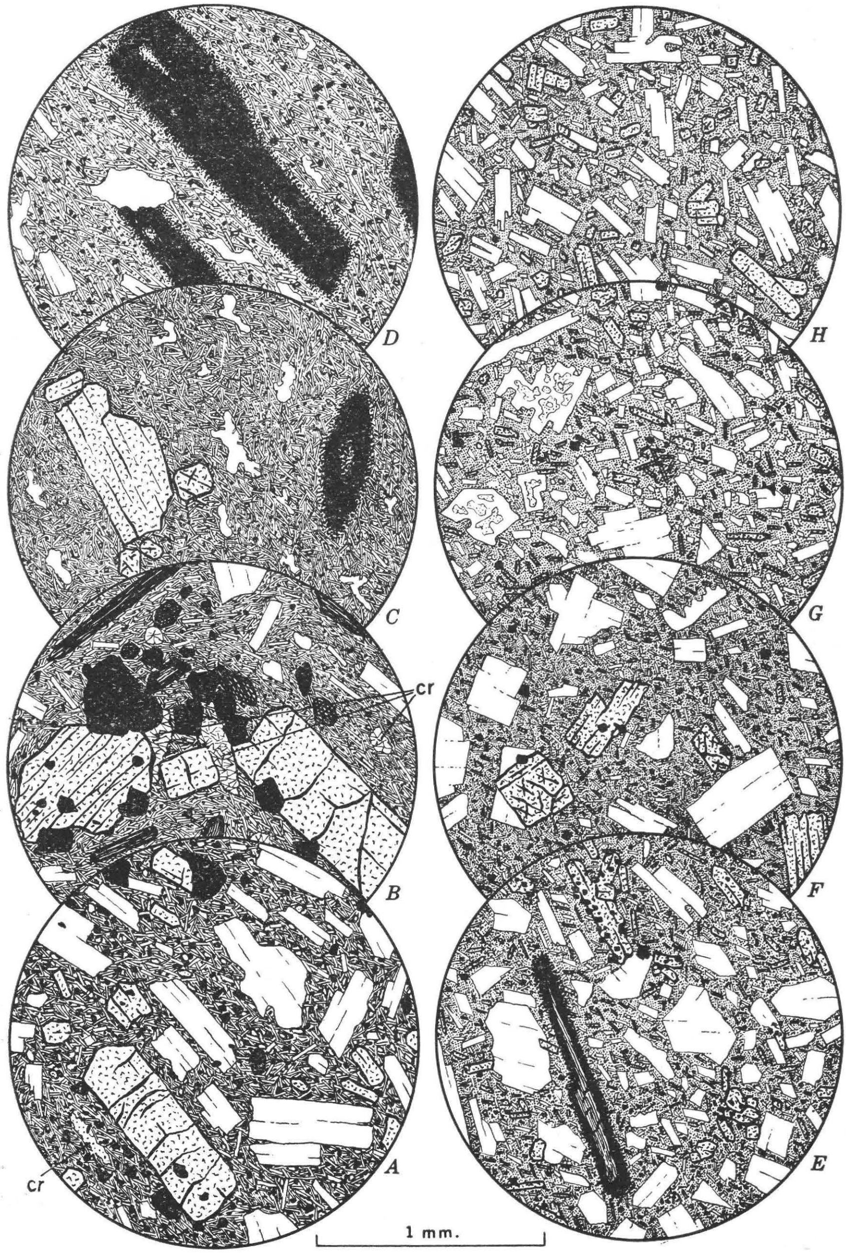


FIGURE 87.—Andesites from vicinity of Parícutin.

first of An_{48} and then of An_{62}, enclosed by a rim of An_{68}. An adjacent crystal shows an outward change from An_{47} through An_{57} and An_{50} to a rim of An_{56}. Along with the phenocrysts that show reverse zoning are others that exhibit normal oscillatory zoning. Many crystals of both types are spongily replaced by pale-yellow glass. These features denote a complex magmatic history. Elsewhere, Wenk (1945) has observed that oscillatory zoning of feldspar is especially well developed where hornblende also is present, and although that mineral is now rare among the lavas of Tancítaro, it may have been more plentiful prior to eruption and may have been almost completely resorbed during the rise of the lavas to the surface. This, however, cannot be the entire explanation of the many kinds of zoning. More likely much of the variation is to be ascribed to mingling of magmas before extrusion.

In contrast to the porphyritic feldspars, the microliths are relatively uniform, varying only between An_{49} and An_{54}. Precise determination of the cryptocrystalline matrix is impossible, but since the lava contains 1.43 percent K_2O, orthoclase is presumed to be an important constituent. Minute cracks and irregular pores are partly occupied by cristobalite and hematite, products of fumarolic vapors.

Explanation of Figure 87

A, Pilotaxitic hypersthene andesite (79). Peña del Horno. Hypersthene, augite, and calcic plagioclase phenocrysts in a matrix of granular ore, augite, and andesine-labradorite laths with interstitial cristobalite (Cr). Table 1, analysis 10.

B, Hornblende-bearing pyroxene andesite (111a). Near summit of Cerros de Tancítaro. Phenocrysts of oxyhornblende, hypersthene, augite, and labradorite in a matrix resembling that of the preceding lava. Table 1, analysis 17.

C. Augite-hornblende andesite (58). South edge of Mesa de Huanárucua, approximately 1 mile north of San Juan Parangaricutiro. Phenocrysts of augite and altered hornblende in a dense hyalopilitic matrix of plagioclase, granular ore, and augite with interstitial pale-buff glass. Table 1, analysis 14.

D, Hornblende andesite (113). East edge of Mesa de Zirimóndiro. Phenocrysts of oxyhornblende, largely replaced by magnetite, in base of plagioclase laths, granular ore, augite, and interstitial cryptofelsite. Table 1, analysis 6.

E, Pyroxene-hornblende andesite (91). Flow from Cerros de Capacuaro, between villages of Capacuaro and Arantepacua. Oxyhornblende, hypersthene, and labradorite phenocrysts in a glass-rich base carrying plagioclase, augite, and ore. Table 1, analysis 12.

F, Hypersthene andesite (90). Southeast slope of Cerro del Aguila. Phenocrysts of hypersthene and labradorite in a glass-rich base stippled with augite, ore, and laths of andesine. Table 1, analysis 16.

G, Pyroxene andesite (65). Near summit of Cerro de La Purísima. Microphenocrysts of augite and hypersthene, in about equal amount, and phenocrysts of labradorite in a glass-rich base carrying granular ore, augite, and microlithic plagioclase. Table 1, analysis 15.

H, Hypersthene andesite (14). Near summit of Cerro de La Cruz. Phenocrysts of labradorite and hypersthene in a glass-rich matrix carrying microliths of andesine and rare granules of augite and ore. Table 1, analysis 18.

Phenocrysts of augite rarely exceed 1 millimeter in length. They are pale yellowish green in color and are devoid of sensible pleochroism. One crystal has an optic angle of 55° and an extinction angle, Z to c, of 43°; another has an optic angle of 52° and an extinction angle of 40°, together with a birefringence of .038. These properties indicate the augite to be diopsidic.

Porphyritic hypersthene occurs in prisms of about the same dimensions as the augite. Optic angles denote molecular percentages of 32 to 33 $FeSiO_3$. Some prisms show marginal alteration to hematite as a result of oxidation.

Almost identical andesites are widespread along the summit ridge of Cerros de Tancítaro and on the upper, southern flank of the volcano. The flow forming Cerro de San Pedro, about a mile north of Peña del Horno, is noteworthy both for its high content of cristobalite and tridymite and for the intense pleochroism of its hypersthene, the optic angle of which indicates a molecular percentage of 38 $FeSiO_3$. Among the flows along the eastern base of the volcano are some in which hypersthene is ten times as plentiful as augite, and in several specimens both pyroxenes are almost completely replaced by magnetite and hematite.

True hornblende andesites have not been seen on Cerros de Tancítaro. Among the flows that carry up to 5 percent porphyritic hornblende are those on the ridge below Cerro de San Pedro, in the canyon of the Río del Barranco, and on the south side of the volcano about halfway down.

The analyzed specimen of hornblende-bearing pyroxene andesite is illustrated in figure 87*B*. It comes from the trail on the south side of the mountain. Approximately a third of the rock consists of oscillatory zoned crystals of plagioclase, ranging from An_{50} to An_{65} in composition and up to 6 millimeters in length. Prismatic hypersthenes, up to 2 millimeters long, are four times as common as augite; together they make up 10 percent of the volume. Oxyhornblende phenocrysts, largely replaced by ore and augite, measure up to 1 millimeter in length and constitute 3 percent of the volume. The pleochroism is as follows: X = pale yellow; Y and Z = deep reddish brown. The extinction angle, Z to c, varies up to 10°, and the optic angles range between 70° and 75°.

The fine groundmass consists of a pilotaxitic felt of andesine microliths and cryptocrystalline material stippled with specks of augite and ore and with slender needles of apatite. To judge from the chemical analysis (table 1, analysis 17), the interstitial material probably contains much orthoclase.

The andesites of the San Marcos volcanoes are essentially like those just discussed from Cerros de Tancítaro. A representative sample has already been illustrated by Schmitter (1945).

ANDESITES OF CERRO DEL AGUILA

Chemical analysis (table 1, analysis 16) reveals that the lavas of this volcano resemble the principal type on Cerros de Tancítaro, and the microscope shows that they are also hypersthene-augite andesites. Their field appearance, however, is quite different. The lavas of Tancítaro and San Marcos are typically pale-gray, pilotaxitic flows devoid of conspicuous vesicles; the flows of Cerro del Aguila, on the other hand, are black, highly vesicular and glass-rich andesites only to be distinguished from the basalts of adjacent cones by the absence of olivine. Except that they are much richer in porphyritic feldspar, they more nearly resemble the cceval andesites of the Angahuan volcanoes and the much younger andesites of the Capacuaro cone. In brief, they are classed as vitrophyric pyroxene andesites.

Despite their wide extent they show little variation. It is enough, therefore, to describe the analyzed specimen illustrated in figure 87*E*. This has the following percentages by volume: plagioclase, 44; hypersthene, 8; augite, 4; ore, 4; interstitial glass with microliths of feldspar and augite, 40.

The glass is of a clear, warm-brown color. Its refractive index, $1.524 \pm .002$, suggests a silica percentage of approximately 62 (George, 1924). The plagioclase phenocrysts range in length up to 2 millimeters, the larger ones showing normal zoning from sodic bytownite to medium labradorite, while the smaller ones consist of medium to sodic labradorite. Hypersthene forms euhedral and subhedral prisms, mostly less than 0.25 millimeter long but occasionally up to 1 millimeter in length. Measurements on the universal stage reveal a wide range in composition. One unzoned prism has an optic angle of 68° (= 34 percent $FeSiO_3$); one zoned crystal has a core with 14 percent $FeSiO_3$ and a rim with 24 percent. Augite occurs in minute anhedral specks too small for accurate optical reading.

ANDESITES OF CERROS DE ANGAHUAN

The flows composing the twin volcanoes of Angahuan vary from black, aphyric, glassy types that break with a splintery or conchoidal fracture to more abundant varieties that carry phenocrysts of augite and feldspar large enough to be seen by the unaided eye. None, however, are as strongly porphyritic as the andesites of El Aguila.

Characteristic of the glass-rich flows are those of the western flank of the northern cone. These are hyalopilitic lavas in which brown glass with indices of about 1.53 (= 60 percent SiO_2), stippled with specks of augite and ore, makes up about half the volume. Microphenocrysts of augite ($2V = 60°$; Z to $c = 42°$), mostly between 0.1

and 0.3 millimeter across, constitute no more than 2 percent by volume. The rest is made up of fluidally arranged microliths of sodic labradorite.

Typical of the vitrophyric flows are those seen along the margins of the summit plateau of the northern volcano, such as the one analyzed (table 1, analysis 15) and illustrated (fig. 87*G*). About 40 percent of the volume of this specimen is composed of brown glass dotted with euhedral grains of magnetite and anhedral specks of augite. Refractive indices of 1.519 to 1.523 ± 0.002 suggest that the glass has a silica percentage of approximately 63. Fifteen percent of the lava consists of phenocrysts of plagioclase up to 1 millimeter long. Almost all these phenocrysts are riddled with blebs and stringers of pale-buff glass, and some are almost completely vitreous. While most plagioclase phenocrysts show normal zoning from cores of sodic bytownite to rims of medium labradorite, many, particularly those that show interior vitrifaction, are marked by reverse zoning within the same range of composition. Perhaps the latter are xenocrysts derived by commingling of magmas prior to extrusion. Approximately a third of the specimen is made up of microliths of calcic andesine. The remaining 10 percent is comprised in equal amounts of diopsidic augite ($2V = 55°$ to $60°$; Z to $c = 43°$) and hypersthene ($2V = 75°$ to $80°$) in grains up to 1 millimeter in length.

ANDESITES OF CERROS DE LOS HORNOS AND CERROS DE PARACHO

The multiple cones of Cerros de Los Hornos are composed in part of olivine-bearing basaltic andesites but mainly of olivine-free, hyalopilitic and vitrophyric andesites. On the north and east flanks of the cluster, flows of vitrophyric hypersthene andesite predominate. Half of a representative sample consists of laths of calcic to medium labradorite between 0.1 and 0.5 millimeter in length. Hypersthene, the only porphyritic constituent, makes up 7 percent of the volume, occurring in stumpy prisms up to 0.5 millimeter long and as slender needles of much smaller dimensions. The latter contain from 22 to 26 percent $FeSiO_3$ and are distinctly more pleochroic than the phenocrysts, the optic angles of which denote molecular percentages of 14 to 18 $FeSiO_3$. The remaining 40 percent of the andesite is made up of dark-brown glass, with a refractive index of 1.520 ± .002 (= 63 percent SiO_2), stippled with ore and augite and sporadic needles of apatite.

On the south and southwest sides of the cone cluster, similar andesites again predominate, but some carry more and larger phenocrysts of labradorite and in them the hypersthene is accompanied by sparse phenocrysts of diopsidic augite.

On Cerros de Paracho a comparable association of olivine-bearing basaltic andesites and olivine-free hypersthene andesites is to be seen.

The latter resemble those from the Cerros de Los Hornos already described.

HORNBLENDE ANDESITE OF MESA DE ZIRIMONDIRO

The only hornblende andesites in the Parícutin region are those forming Mesa de Zirimóndiro, close to Tancítaro village. The analyzed specimen (table 1, analysis 6), which is depicted in figure 87*D*, is typical of the gray, unoxidized, microvesicular lava making up the greater part of the flow. Phenocrysts of oxyhornblende, between 0.5 millimeter and 2 millimeters in length, constitute 8 percent of the volume, though in other specimens the mineral is twice as abundant. Most of the hornblende is replaced by a dense intergrowth of magnetite, augite, and yellow glass; where relics are preserved, the pleochroism is from X = pale yellow to Y and Z = deep russet. Extinction angles, Z to c, range up to 5°. The only other porphyritic constituent is feldspar, which is normally zoned from calcic to medium labradorite. It makes up 2 percent of the volume. Approximately two-thirds of the volume consists of slender laths of sodic labradorite, between 0.1 to 0.2 millimeter long, in subparallel arrangement. Minute grains of augite ($2V = 55°$; Z to $c = 44°$) total 5 percent, the remainder being composed of interstitial glass and cryptocrystalline material stippled with dusty ore and sporadic spheroids of cristobalite.

Where the andesite of Zirimóndiro has been oxidized by fumarolic vapors, cristobalite is more plentiful and finely divided hematite is scattered throughout the matrix. In these rocks the oxyhornblende phenocrysts are almost completely converted to hematite and limonite, and the augite, which is pale green in the unoxidized lava, has a faint brownish tint and lower birefringence.

Chemical analysis (table 1, analysis 6) shows the andesite of Mesa de Zirimóndiro to be less siliceous than most of the olivine-bearing basaltic andesites of the region.

AUGITE ANDESITE OF MESA DE HUANARUCUA

The thick flow forming Mesa de Huanárucua is a fine-grained, microvesicular andesite in which the only phenocrysts are sporadic crystals of diopsidic augite. Where oxidized by residual vapors, the lava is pale pink; elsewhere it is light gray.

The analyzed specimen of pink lava (table 1, analysis 14) is shown in figure 87*C*. Phenocrysts of diopsidic augite ($2V = 55°$; Z to c = 43°), up to 1 millimeter long, constitute 3 percent of the volume. Occasional clusters of granular magnetite with forms suggestive of derivation by break-down of hornblende make up 1 percent. The dense groundmass has the following percentages by volume: microlithic plagioclase (Ab_1An_1), 65; granular augite, 10; interstitial glass, 13; grains of ore and flakes of hematite, 8.

Except for the lack of hematite, the gray unoxidized lava is not essentially different, although in one sample a few prisms of hypersthene accompany the augite.

VITROPHYRIC ANDESITE OF CERROS DE CAPACUARO

The voluminous lavas recently erupted by the Capacuaro cone are dark-gray to black, glass-rich andesites with a sugary, diktytaxitic texture. Save for minor variations in the proportions of the constituents, none of the specimens examined differs from the one analyzed (table 1, analysis 12) and illustrated (fig. 87*E*). This has the following percentages by volume: plagioclase, 55; hypersthene, 5; augite, 15; oxyhornblende, 1; ores and apatite, 4; interstitial glass, 20.

Most of the plagioclase laths measure between 0.2 and 0.3 millimeter in length; they consist of unzoned sodic labradorite. The larger feldspars, some of which reach a length of 1 millimeter, show normal oscillatory zoning, and the cores of some are spongily replaced by glass. One zoned phenocryst has a nucleus of An_{76} enclosed by a thin shell of An_{65}; others show zoning within smaller limits.

The hypersthene occurs as stumpy euhedral prisms up to 1 millimeter in maximum dimension. Its pleochroism is distinct, and the optic angle indicates a molecular percentage of 26 $FeSiO_3$. A few crystals of augite reach the same size, but mostly the mineral is in anhedral grains less than a quarter as large. One of the larger augite grains has an optic angle of 52° and an extinction angle, Z to c, of 42°; another has an optic angle of 58° and an extinction angle of 44°. Sporadic phenocrysts of oxyhornblende show marginal alteration to iron ore. Their cores are pleochroic from pale yellow to deep brown; they show straight extinction and have optic angles of 70° to 75°. Finally, the interstitial glass varies in color from pale to dark brown and in refractive index from 1.518 to 1.522 $\pm$ .002, suggesting a silica percentage of about 63.

OLIVINE-BEARING ANDESITES: LAVAS OF CERRO DE SURUNDARO

The youthful lavas of Cerro de Surúndaro are extremely uniform both in texture and mineral composition. All are dark-gray to black, vesicular flows liberally spotted with phenocrysts of olivine but only sparsely relieved by porphyritic feldspar. In the field they are readily mistaken for olivine basalts; however, chemical analysis (table 1, analysis 13) shows that they are andesites with a positive qz value of 25.

The analyzed specimen is depicted in figure 88*H*. Phenocrysts make up 14.8 percent by volume, as follows: olivine, 4.3; hypersthene, 0.4;

plagioclase, 10.1. All the olivine is fresh; optic angles suggest a range in composition between Fo_{67} and Fo_{76}. Most of the hypersthenes have optic angles of 70° ± 2°, but some show reverse zoning, cores with an optic angle of 64° (= 40 percent $FeSiO_3$) being surrounded by narrow rims with an angle of 82° (= 20 percent $FeSiO_3$). For the most part, the porphyritic feldspar is medium labradorite (An_{60-62}), but a few crystals exhibit normal zoning from An_{60} to rims of An_{55}.

The groundmass of the lava is comprised of the following percentages by volume: microliths of calcic andesine, 24; euhedral prisms of augite, 30; euhedral hypersthene, 5; magnetite, 6; apatite, 1; and clear brown glass with an index of 1.530 ± .002 (=60 percent SiO_2), 35 percent.

Some specimens of andesite from Cerro de Surúndaro differ from the foregoing in containing as much as 8 percent by volume of porphyritic olivine; in such rocks the amount of hypersthene is correspondingly reduced.

OLIVINE-BEARING BASALTIC ANDESITES

Among the younger lavas of the Parícutin region, those belonging to the group of olivine-bearing basaltic andesites are probably the most abundant. It should be repeated, however, that it is impossible to distinguish them in the field either from olivine-bearing andesites or from true olivine basalts; even with the aid of the microscope the distinction may be impossible.

CERROS DE LOS HORNOS AND CERROS DE PARACHO

Reference has already been made (p. 240) to the fact that the lavas of these volcanoes are partly olivine-free andesites and partly olivine-bearing basaltic andesites. On Cerros de Los Hornos the latter are found chiefly on the southeast flank. They are black, aphyric flows carrying approximately 4 percent by volume of olivine crystals, up to 0.1 millimeter across, many of which are marginally altered to antigorite. Equally small grains of augite and hypersthene together constitute 9 percent of the volume. Between 60 and 65 percent consists of slender microliths of medium labradorite, and 4 percent is composed of granular ore. The remainder is brown glass with a refractive index of 1.530 ± .002 (= 60 percent SiO_2).

Similar flows are widespread on Cerros de Paracho. With them are others that carry up to 10 percent by volume of olivine and contain abundant glass with indices approximating 1.550 (= 54 percent SiO_2). Such are the lavas exposed half a mile southeast of the village of Paracho. Still other flows, including those near the village of Aranza, are equally rich in olivine but are holocrystalline. Probably chemical analyses would reveal these to be true basalts rather than basaltic andesites.

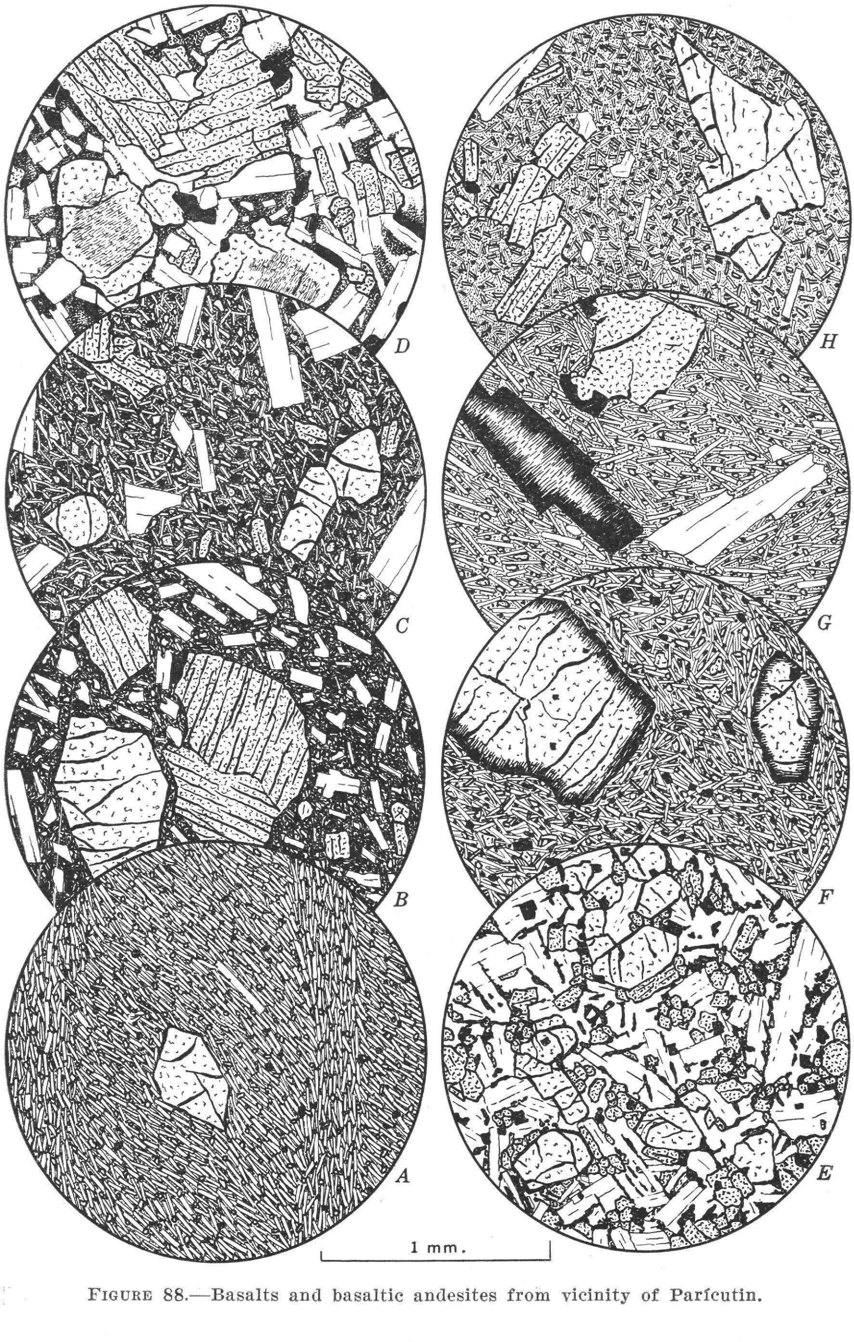


FIGURE 88.—Basalts and basaltic andesites from vicinity of Parícutin.

TZARARACUA FLOW

The lava discharged from the foot of Cerro de Jicalán into the valley of the Río de Cupatitzio to form Cascada de Tzaráracua is a dense, pale-gray basaltic andesite in which a few crystals of plagioclase and olivine are the only constituents discernible by means of the hand lens.

The analyzed sample (table 1, analysis 11) is illustrated in figure 88*A*. It comes from the upper part of the flow where it is crossed by the trail leading to the base of the falls. Phenocrysts make up only 5 percent of the volume, as follows: calcic labradorite, up to 1 millimeter long, 1 percent; diopsidic augite, up to 0.5 millimeter across, with an optic angle of 58° and an extinction angle, Z to c, of 43°, 1 percent; and olivine, up to 1 millimeter across, 3 percent. Optic angles of the olivine vary from 85° (negative) to 90°, and some of the crystals are altered marginally to hematite and bowlingite. The rest of the lava is a dense fluidal felt, percentages by volume of which are: microlithic calcic andesine, 63; augite, 16; hypersthene, 6; ore, 4; apatite, 1; and cristobalite, 1; with interstitial yellowish glass flecked with hematite, 4.

The most arresting feature of the lava is the evidence of shearing produced during the final stages of movement. Within adjacent lenses,

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EXPLANATION OF FIGURE 88

A, Olivine-bearing basaltic andesite (38). Cascada de Tzaráracua. Olivine phenocrysts set in a fluidal, intergranular matrix of plagioclase, augite, and ore, showing the effects of shearing prior to solidification. Table 1, analysis 11.

B. Olivine-augite basaltic andesite (35). Lava mound near east base of Cerro del Aire. Large phenocrysts of olivine and augite set in a glass-rich base stippled with plagioclase, augite, and ore. Table 1, analysis 5.

C, Olivine-augite basalt (63). Flow from Cerro de Tzintzungo, approximately 1 mile east of San Juan Parangaricutiro. Phenocrysts of olivine, augite, and calcic labradorite in a glass-rich base charged with granular ore, augite, and microlithic plagioclase. Table 1, analysis 4.

D, Coarse-grained olivine-augite basalt (45). Near summit of Cerro Colorado. Phenocrysts of olivine, with cores of iddingsite, and augite, with labradorite and titaniferous ore and black, iron-rich interstitial glass. Table 1, analysis 3.

E, Olivine-augite basalt (95). Recent flow from Cerro de Capatacutiro, on main highway approximately 4 miles northwest of Capacuaro. Holocrystalline lava composed of olivine, augite, labradorite, and granular ore. Table 1, analysis 1.

F, Olivine-rich basaltic andesite (10). Flow from Cerro de Cutzato, 3 miles southeast of San Juan Parangaricutiro. Phenocrysts of marginally serpentinized olivine in a dense holocrystalline matrix of labradorite laths, granular ore, augite, and rare hypersthene. Table 1, analysis 7.

G, Olivine-bearing basaltic andesite (121). South slope of Cerro Prieto. Phenocrysts of olivine, marginally altered to hematite and magnetite, and of calcic labradorite in a holocrystalline matrix of plagioclase, augite, and ore. Table 1, analysis 8.

H, Olivine-bearing andesite (92). Cerro de Surúndaro, near San Lorenzo. Phenocrysts of olivine and hypersthene in a glass-rich base studded with granular ore, prismatic augite, and plagioclase laths. Table 1, analysis 13.

0.3 to 0.5 millimeter thick and up to 2 or 3 centimeters long, the orientation of the feldspar laths differs markedly, so that the texture resembles cross bedding on a minute scale. Seen in the field, one set of laminae is almost horizontal, lying parallel to the lava surface, while the other is inclined at angles up to 40°. Nowhere do the laminae cross each other as bands of microliths often do in obsidians that have moved by shearing (Philipp, 1936), nor is there any difference in the mineral content of the laminae as there is in certain sheared basalts described from Vesuvius. Between 150 and 200 feet below the top of the flow the sheared texture disappears; at lower levels the fluidal banding is much less distinct and in general horizontal.

A specimen from the base of the flow at the foot of the falls is typical of the quickly chilled bottom. Aside from the absence of shearing effects, it differs from the foregoing chiefly in the much larger proportion of interstitial glass, the refractive index of which suggests a silica percentage of between 62 and 63.

CERRO DEL AIRE AND CERRO DE COPITIRO

The long flows discharged by the triple cone of Cerro del Aire and adjacent vents are characterized by abundant phenocrysts of plagioclase, augite, and olivine in a dark, vesicular matrix. The sample selected for analysis (table 1, analysis 5) and illustration (fig. 88*B*) comes from the lava mound built over the vent a short distance east of the triple cone. In composition it lies close to the border line between basalt and basaltic andesite, having a *qz* value of 3. Probably other flows from the same source are true basalts.

The analyzed lava is an intersertal olivine-augite basaltic andesite unusually rich in phenocrysts. Together these make up 42 percent of the volume (olivine, 6; augite, 6; feldspar, 30). Most of the olivines measure between 0.25 and 0.3 millimeter, though a few reach 1 millimeter in length. All are fresh. Three zoned crystals have optic angles suggesting cores of pure forsterite and rims of Fo_{72}. One phenocryst has a core of Fo_{67} surrounded by a narrow rim of Fo_{50}. No other lava in the region has been found to exhibit such a wide variation in the composition of its olivine.

The pale-green phenocrysts of diopsidic augite are stumpy subhedral prisms, commonly twinned on 100, of approximately the same dimensions as the olivine. Optic angles range from 47° to 53°, with corresponding extinction angles of 41° to 43°.

The feldspar phenocrysts are of the same dimensions. Unzoned phenocrysts vary from An_{72} to An_{78}; some of the larger crystals show normal, nonoscillatory zoning from An_{75} to An_{60}.

The groundmass has the following percentages by volume: microlithic labradorite (An_{52-55}), 22; augite, 19; ore, 8; apatite, 1; and brownish-black glass, 8.

A bomb collected from the peak where the three craters of Cerro del Aire join differs from the lava just described in the absence of porphyritic feldspar and augite. It is a scoriaceous rock, fully two-thirds of which is composed of black glass dotted with specks of augite, minute needles of plagioclase, and sporadic grains of hypersthene. Scattered throughout the matrix are slender laths of An_{65-68} and sparse phenocrysts of olivine ($2V = 90°$).

The lavas that extend southward from Cerro del Aire at least as far as Cheringerán are too much like the analyzed specimen to call for special description. Resting on them is a thick flow erupted from the foot of Cópitiro. This differs radically in texture, being a coarse, intergranular lava entirely devoid of glass. Phenocrysts of olivine total between 8 and 10 percent by volume; many show peripheral change to antigorite and hematite. Plagioclase ranges in length up to 0.5 millimeter, the composition departing little from An_{70}. It makes up approximately 55 percent of the volume. Green granules of augite, rarely more than 0.1 millimeter across, account for another 25 percent, the remainder consisting of granules of ore and a little apatite. Perhaps chemical analysis would reveal this lava to be basaltic rather than andesitic.

LAVAS OF CERRO DE PARIO AND CERRO DE LA ALBERCA

The flows composing Cerro de Pario and Cerro de La Alberca are notably uniform, and, except for a smaller content of phenocrysts, they are hardly to be distinguished from those of Cerro del Aire. In brief, they are hyalopilitic olivine-augite basaltic andesites either lacking in hypersthene or carrying no more than a few minute prisms of that mineral.

A representative specimen, collected in the saddle northeast of the top of Cerro de Pario, carries the following phenocrysts: olivine, up to 4 millimeters long, with $2V$ of 90°, 3 percent by volume; augite, up to 1 millimeter long, with $2V$ of 55° and extinction angle of 42°, 4 percent; plagioclase showing normal oscillatory zoning from sodic bytownite to medium labradorite in laths up to 1 millimeter long, 10 percent. The dense groundmass is made up of fluidally arranged microliths of sodic labradorite and granules of augite and ore embedded in dark-brown glass.

LAVAS OF CERRO DE CURITZERAN, CERRO DEL ANILLO, AND CERRO DE SICUIN

The dark, vesicular flows erupted by Curitzerán and its parasitic cones are marked especially by their low content of phenocrysts, particularly of olivine, and by their richness in glass. Seldom does olivine make up more than 2 percent of the volume or exceed 1 millimeter in length. Slender laths of sodic to medium labradorite constitute

60 to 65 percent by volume, few measuring more than 0.3 millimeter in maximum dimension. Exceptionally, augite forms phenocrysts up to 1 millimeter across, almost all of it occurring as minute anhedral specks between the laths of feldspar. In amount it varies between 12 and 15 percent. Minute prisms of hypersthene are invariably present, but they form only 2 or 3 percent of the volume. The remaining 20 to 30 percent of the lava consists of interstitial glass, the color of which changes from brown to black as the included grains of magnetite diminish in size. The refractive index of the clearest glass varies from 1.539 to 1.543 $\pm$ .002, suggesting a silica percentage of approximately 56.

LAVAS OF CERRO DE PARASTACO, CERRO DE MATANCERO, AND CERRO DE APUPAN

The flows belonging to the Cerro de Parástaco group of cones and to those between Cerros de Angahuan and Cerro de Surúndaro, of which Cerro de Matáncero and Cerro de Apupan are the two largest, closely resemble those of Cerro de Pario and Cerro de La Alberca, already described. In other words, their characters are intermediate between those of the lavas of Cerro del Aire and Cerro de Curitzerán.

LAVAS OF CERRO DE CUTZATO

The thick flows erupted by Cutzato are dense basaltic andesites, pale gray where fresh but changing to pink where oxidized by fumarolic vapors. They are totally devoid of porphyritic feldspar and augite, the only mineral recognizable by the naked eye being olivine, crystals of which average 1 millimeter across and occasionally reach a length of 3 millimeters. In the fresh lava the mineral is pale green; in the oxidized varieties it is iridescent and deep red in color.

The analyzed specimen (table 1, analysis 7) is shown in figure 88*F*. It typifies the pink variety. The percentages by volume are as follows: olivine, 6; slender laths of An_{70-80}, up to 0.2 millimeters long, 60; subhedral prisms of augite up to 0.15 millimeter long, 18; hypersthene, 3; magnetite and hematite, 5; interstitial cryptocrystalline material rich in acicular apatite, 8.

Of particular interest is the alteration of the olivine. The cores are fresh and have optic angles suggesting compositions between Fo_{86} and Fo_{88}. In some crystals the fresh nuclei are enclosed by sharply defined, narrow rims that show pleochroism in greens and an optic angle of 50° (positive). In other crystals the fresh cores grade into the colored fringes, the optic angle changing outward from 89° (negative) to less than 32° (positive), the position of the optic plane remaining constant. Concurrently the birefringence diminishes from 0.035 to 0.020. In still other crystals the rims are composed of magnetite and hematite. Apparently one is dealing here with early stages in the conversion of olivine to serpentine as a result of oxidation and hydration. Comparable changes have been described by Foslie (1931), who suggests that H_2 replaces the base metals of the olivine with preference for iron, which is liberated to form the marginal magnetite and hematite.

The gray facies of the lava of Cerro de Cutzato differs from the foregoing in the freshness of its olivine, the paucity of hematite, and the presence of a considerable amount of interstitial glass. Olivine makes up approximately 5 percent by volume; microporphyritic augite ($2V = 58°$; Z to $c = 43°$), about 1 percent; granular ore, 5 percent; microliths of calcic labradorite, 59 percent; interstitial glass with apatite needles, 15 percent. The refractive index of the glass is notably low (1.508 ± 0.002), indicating a silica percentage of about 65.

LAVAS OF CERRO PRIETO

Since only two samples from this volcano were studied microscopically and only one was analyzed chemically, it may be that there is more variety than appears from the general similarity of the flows as seen in the field.

The analyzed specimen (table 1, analysis 8), shown in figure 88*G*, is an intergranular basaltic andesite lightly sprinkled with phenocrysts of olivine, augite, and feldspar. The olivine, which constitutes 4.6 percent by volume, shows effects of oxidation and hydration like those seen in the lavas of Cerro de Cutzato. Some of the smaller grains are wholly replaced by magnetite and hematite, and most of the larger ones show a marginal development of these minerals. In other crystals a fringe of hematite passes inward to a zone of pale-green antigorite, and this in turn merges into a shell of hydrated olivine of low birefringence which envelops the fresh core.

Diopsidic augite occurs in anhedral phenocrysts up to 0.25 millimeter across with optic angles of $56° \pm 3°$ and an extinction angle of 44°. It makes up 2.5 percent of the volume. Porphyritic plagioclase ($An_{70\text{-}75}$), in laths up to 0.5 millimeter long, accounts for 2 percent. The remainder is a trachytoid felt of medium labradorite microliths with minute prisms of augite, granules of ore, and a little tridymite.

LAST OF THE FLOWS FROM CERROS DEL JABALI

The final flow from the Cerros del Jabalí vents was discharged probably within the last century. A sample from its snout near Los Conejos is shown by analysis (table 1, analysis 9) to be a basaltic andesite with a positive qz value of 7. As figure 89*B* indicates, it is decidedly rich in porphyritic feldspar but devoid of porphyritic augite. Plagioclase phenocrysts, showing normal zoning from cores of $An_{65\text{-}67}$ to rims of An_{60}, make up 9.1 percent of the volume. Phenocrysts of olivine, which also range between 0.2 and 1 millimeter in length, make up 7.1 percent. These vary in composition between pure forsterite and Fo_{86}. The groundmass has the following percentages by volume: medium to sodic labradorite laths, 50.3; brownish-black glass, 23.1; ore, 4.6; and granular augite, 3.8. Hypersthene was not observed in this or any other of the Jabalí flows.

BASALTIC ANDESITES AND ANDESITES NEAR PARICUTIN

Probably all the lavas in the region between Parícutin and Cerro Prieto on the south and Cerro de Pario on the east are basaltic andesites. They are dark, vesicular, hyalopilitic flows stippled with phenocrysts of olivine, augite, and labradorite. In none of them does the content of hypersthene exceed 2 percent. Their resemblance to the lavas of Curitzerán makes it needless to give a special description of them.

The thick lavas forming the Equijuata-Capatzin ridge vary in texture from almost holocrystalline to hyalopilitic, the content of glass in some specimens rising as high as 20 percent. Phenocrysts of olivine usually make up about 5 percent of the rocks, but porphyritic feldspar and augite are either absent or present only in quite minor amount.

A specimen of glass-poor lava from the north slope of Cerro de Equijuata has the following percentages by volume: olivine, up to 1 millimeter across, slightly serpentinized, 5; laths of medium labradorite, rarely more than 0.5 millimeters long, 67; augite granules, 15; hypersthene, partly as reaction rims around olivine and partly as discrete grains, 3; ore, 8; interstitial glass, 2.

In a typical specimen of hyalopilitic lava from the Cerro de Capatzin ridge, the proportions of the constituent minerals remain approximately the same, but glass makes up between 15 and 20 percent. Its refractive index of $1.530 \pm .002$ suggests a silica percentage of 59. Unfortunately, microscopic study does not rule out the possibility that some of the flows forming the Equijata-Capatzin ridge are basalts rather than basaltic andesites.

In the region immediately to the south and west of the new volcano, the heavy mantle of ash from Parícutin has obscured all but a few exposures of the earlier lavas. This is much to be regretted, since the available specimens show a greater variety of lavas than elsewhere in the region studied. Along with the usual olivine-augite basaltic andesites there are olivine-poor, hypersthene-rich lavas which chemical analyses would probably reveal to be true andesites.

Among the latter are some of the flows near the southern margin of the Parícutin lava field, halfway between the Cocjarao triangulation station and the Nuréndiro spring, the source of which was either the cone of Cerro de Camiro or a fissure to the west. The phenocrysts of a typical sample had the following percentages by volume: olivine, 1; augite, 5; hypersthene, 3; magnetite pseudomorphs after oxyhornblende, 1; and normally zoned sodic bytownite-calcic labradorite, 5. The groundmass is composed of laths of medium labradorite, specks of augite and ore, and a minute amount of interstitial glass.

Closely associated with this supposed andesite, and perhaps representing the basal portion of the same flow, is a specimen containing four times as much porphyritic olivine but only rare phenocrysts of hypersthene and devoid of large augites and feldspar crystals. By comparison with lavas already described, this is classed as a basaltic andesite.

Another olivine-poor flow occurs near the southern base of Cerro de Canicjuata. Its phenocrysts are present in the following percentages by volume: olivine, 2; hypersthene, 5; diopsidic augite, 2; and calcic labradorite, 5. Laths of sodic labradorite in the groundmass make up approximately 55 percent of the volume; granules of augite, 10 percent; and brownish-black glass, 21 percent. This may be a true andesite.

The thick flow forming Mesa de Cocjarao may also be andesitic. Two specimens were examined under the microscope. One is holocrystalline and the other vitrophyric. The former was collected 200 yards south of the Cocjarao triangulation station. Phenocrysts of olivine, hypersthene, and calcic labradorite in equal amounts total 9 percent of the volume. The groundmass consists of microlithic labradorite with intergranular specks of augite and ore. The glassy specimen from the same flow, 100 yards north of the triangulation station, carries the same phenocrysts in about the same amounts, but here brown glass makes up 30 percent of the volume. Its refractive index, 1.520 ± .002, suggests a silica percentage of 63.

OLIVINE BASALTS

To this group are assigned all lavas with a negative *qz* value and those devoid of normative quartz, together with those particularly rich in olivine and calcic plagioclase. Just how common true basalts are in the Parícutin region will not be known until many more chemical analyses are available. Meanwhile it should be repeated for emphasis that many lavas are too near the proposed border line between basalts and basaltic andesites for safe identification. Among these doubtful lavas some have already been noted; others include many of the later flows of the Cerros del Jabalí cones. In the notes that follow, first the analyzed lavas are described, then those classed as basalts solely on the basis of microscopic study.

LAVAS OF CERRO DE TZINTZUNGO

The lavas of Cerro de Tzintzungo are among the most porphyritic of the younger flows of the Parícutin region, and most of them are especially rich in porphyritic feldspar. The analyzed specimen (table 1, analysis 4) is illustrated in figure 88*C*. It is an intersertal olivine-augite basalt with a negative *qz* value of 6. Phenocrysts make up 22.5 percent of the volume. Of these, olivine (6 percent) occurs in crystals up to 2 millimeters in length. All are fresh and clear except for inclusions of magnetite and a little secondary hematite. They range in composition between Fo_{72} and Fo_{82}. The porphyritic augite (5.5 percent) is mostly between 0.5 and 1 millimeter in diameter although a few crystals reach a maximum dimension of 1.5 millimeters. Optic angles vary between 56° and 58°, with corresponding extinction angles, Z to c, of 43° and 45°. The feldspar phenocrysts are of about the same size. Some show normal zoning from core to rim; others show normal oscillatory zoning in the cores and normal nonoscillatory zoning in the outer parts. The limits of composition are An_{80} inside and An_{70} outside.

The groundmass comprises 77.5 percent of the volume. Microliths of An_{70-75} total 39 percent; granules of augite, 18 percent; whereas the remainder consists of brownish-black glass charged with magnetite.

Four other specimens of lava from Tzintzungo, collected near San Juan Parangaricutiro and Cuezeño, closely resemble the above, but one sample, collected a quarter of a mile east of the analyzed rock (see map, pl. 8), deserves brief notice on account of its unusual richness in olivine and its low content of porphyritic feldspar and augite. In this lava the olivines reach a length of 3 millimeters and make up 10 percent of the volume. Optic angles indicate that the composition varies only between Fo_{74} and Fo_{76}. Phenocrysts of diopsidic augite and sodic bytownite total only 3 percent. The groundmass is a dense felt of calcic labradorite laths, anhedral specks of augite and ore, and interstitial black glass.

PAHOEHOE LAVA OF CERRO DE CAPATACUTIRO

The basalt of Cerro de Capatacutiro is the least siliceous lava in the entire region. The analyzed specimen (table 1, analysis 1) is shown in figure 88*E*. It is a holocrystalline, intergranular olivine-augite basalt of unusually coarse texture despite the fact that it comes from just below the thin glassy crust of the flow. Apart from a few exceptionally large crystals of feldspar, the texture is seriate. Micrometric analysis shows the following percentages by volume: olivine, 7.2; diopsidic augite, 22.2; plagioclase, 59.2; ore and accessory apatite, 11.4. Of two unzoned phenocrysts of feldspar 5 millimeters long, one consists of An_{77} and the other of An_{72}. Even the nonporphyritic feldspars range up to 4 millimeters in length, most of the larger ones showing normal zoning from sodic bytownite to medium labradorite, whereas the smaller ones are all of the latter composition. Few olivine crystals exceed 1 millimeter in width; some exhibit marginal development of magnetite and hematite, but most are fresh. They vary from Fo_{76} to Fo_{81}. The augite is of approximately the same size as the olivine and occurs as anhedral granules between the feldspars; its optic angles range from 55° to 58°. Only a little magnetite is included in the ferromagnesian minerals; almost all of it formed late, along with thin plates of ilmenite, in the groundmass.

A vesicular, more quickly chilled sample from near the western edge of the main flow of Cerro de Capatacutiro differs from the preceding specimen in containing about 20 percent black, ore-charged glass. In this lava, porphyritic olivines up to 1 millimeter long make up 12 percent of the volume. The percentage of augite is reduced to 15, and except for sporadic microphenocrysts all of it is in the form of minute specks in the glassy matrix. Laths of medium to calcic labradorite make up the remainder.

BASALTS FROM THE CERROS DEL JABALI CONE CLUSTER

The field appearance of the flows from the Jabalí cones resembles that of the lavas of Parícutin volcano, but although they show little variation in hand specimens, chemical analyses show that some are basalts and others are basaltic andesites.

Among the basalts is the lava forming the great flow that descends to the Río de Cupatitzio south of Uruapan. A specimen taken on the road between Uruapan and Jicalán has been analyzed (table 1, analysis 2) and illustrated (fig. 89*A*). It is a black, vesicular, hyalopilitic basalt lacking porphyritic feldspar but rich in phenocrysts of olivine. Indeed, no other lava in the region contains a larger amount of olivine, for here it makes up no less than 14 percent of the volume, ranging in size between 0.2 and 1 millimeter. Optic angles suggest compositions of Fo_{86-88}. Few grains of augite measure as much as 1 millimeter long, and most are less than half this length. Their optic angles approximate 60°, and their extinction angles vary from 42° to 45°. They total 17.2 percent of the volume. In contrast to the lavas of Parícutin volcano, this one is devoid of hypersthene. Laths of unzoned calcic labradorite comprise 52.3 percent of the volume, the rest being composed of magnetite-charged glass with indices of 1.548 to 1.553 $\pm$ 0.002 (= approximately 54 percent SiO_2).

The last flow to issue from the vent at the eastern foot of the main Cerros del Jabalí cone differs so little from the above that it also may be classed as a basalt.

FIGURE 89.—Lavas from Cerros del Jabalí cones and Parícutin volcano. *A,* Olivine-rich hyalopolitic basalt (20). Main flow of Cerros del Jabalí cones, on highway between Uruapan and Jicalán. Phenocrysts of olivine in a dense base of labradorite laths, granular augite, ore, and dark brownish-black interstitial glass. Table 1, analysis 2. *B,* Olivine-bearing basaltic andesite (23). Latest flow of Cerros del Jabalí cones, approximately 1 mile east of Los Conejos. Labradorite and olivine phenocrysts in a glass-rich matrix carrying microlithic plagioclase, granular ore, and rare specks of augite. Table 1, analysis 9. *C,* Lava from Parícutin volcano, April 26, 1945, near Ahuán vent. Phenocrysts of olivine in a dense matrix of labradorite laths, hypersthene, and ore with a little augite and glass. *D,* Lava from Parícutin volcano, the flow that buried San Juan Parangaricutiro in July 1944. Glass-rich variety containing phenocrysts of olivine with microliths of plagioclase and hypersthene and rare grains of augite.

Reference is made, in conclusion, to the lava exposed along the paved highway where it makes a hairpin bend a short distance north of Uruapan. Its provenance is uncertain, but it is more likely an early flow from the Jabalí cones than a product of the older Alberca volcano. It is a holocrystalline lava containing 8 percent by volume of olivine crystals up to 3 millimeters across, with optic angles of 90° ± 2°, marginally altered to iddingsite, hematite, and magnetite. Fluidally arranged laths of calcic labradorite make up approximately half the rock and intergranular augite about a quarter, the remainder consisting of ore and a little apatite.

OTHER POSSIBLE BASALTS

Most of the flows discharged from fissures and cinder cones on the northwest flank of Cerros de Tancítaro are massive, pale-gray, vesicular lavas characterized by an abundance of large olivines, a great scarcity of porphyritic feldspar and augite, and an absence of hypersthene. Generally they are holocrystalline, and at most the content of glass amounts only to a few percent.

These flows spread down the valley of the Río de Itzícuaro from Tiripan via Zirosto and Barranca Seca beyond San Francisco; they include the long, thick flows erupted from the Cerros de Zirosto and those exposed on the canyon walls of the Río del Agua Blanca and other streams that descend toward Peribán. The trails linking Zirosto with Peribán and Apo reveal them in many places beneath a heavy cover of weathered ash.

Typical of these olivine-rich lavas are those that issued from Cerro de La Máscara, the largest cone of Cerros de Zirosto. A representative sample contains 10 percent by volume of olivine phenocrysts, up to 2 millimeters in length, marginally altered to iddingsite and hematite. Optic angles denote compositions between Fo_{94} and Fo_{98}. Phenocrysts of feldspar are completely lacking; slender laths of calcic labradorite, making up two-thirds of the volume, are restricted to a length of 0.3 millimeter. Anhedral grains of augite, rarely more than 0.1 millimeter across, occupy spaces between the feldspars. They total 15 percent of the volume. The remainder is made up of granules of magnetite with minor amounts of apatite and cristobalite.

With only trivial modifications, the above account applies to all the lavas on the lower, northwest flank of Cerros de Tancítaro, to those adjoining the road between Angahuan and Corupo, and to several of the flows far down the southern flank of Tancítaro, such as the one revealed on the walls of the Río del Fresno (p. 216).

Finally, it may be repeated for emphasis that some of the lavas of the Equijuata-Capatzin ridge and of the Cerro Prieto volcano are perhaps basalts rather than basaltic andesites.

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LAVAS OF PARICUTIN VOLCANO

Some of the flows and fragmental ejecta of the new volcano have already been described by Schmitter (1945) and Milton (1945). The salient features of these 1943 products do not differ materially from those displayed by later ones. Indeed, during the first 5 years of activity there has been singularly little variation in the mineralogical composition of the lavas from Parícutin volcano, the main differences being textural. No regular variation has been detected between successive flows or between the early and late flows of any particular vent. It must be admitted, however, that more detailed studies might reveal minor though significant differences related to changes in the nature of the pyroclastic ejecta. As far as the present studies go, all that can be said is that the fragmental ejecta and lavas contain the same minerals in approximately the same proportions but that the former usually contain more glass.

In the field all the flows from Parícutin volcano would be classed without hesitation as olivine basalts, and probably microscopic examination would not modify this designation. Yet chemical analyses (table 3) show that all but one of the lavas have positive qz values and contain normative quartz. (The exception has a qz value of zero.) Hence all are considered here as basaltic andesites. In a few flows small phenocrysts of plagioclase are present, as in the lavas of March 1943, but normally the only porphyritic constituent is olivine. This scarcity of porphyritic feldspar and the lack of pyroxene phenocrysts serve to distinguish the flows of Parícutin volcano from most of those erupted earlier in the immediate vicinity. Almost all the recent flows are rich in glass.

Two specimens have been selected for description and illustration (figs. 89*C*, 89*D*) : one of the dominant glass-rich type and the other of the almost holocrystalline type. The first comes from the edge of the great flow that buried San Juan Parangaricutiro, on the outskirts of the town. Olivine makes up 5 percent of its volume. Most of the crystals measure about 0.5 millimeter across, but they range in size from almost irresolvable specks to phenocrysts 1.5 millimeters in maximum dimension. The larger ones vary in composition between Fo_{63} and Fo_{84}. A few are tabular parallel to the base, and many are deeply embayed by corrosion. The smaller olivines do not exhibit these features, being more or less spheroidal grains; their composition varies from Fo_{82} to Fo_{90}. In other words, though they crystallized later than the phenocrysts, they are more magnesian.

Next in order of abundance among the ferromagnesian minerals is hypersthene, which constitutes 4 percent of the volume. It occurs in subhedral prisms, mostly less than 0.05 millimeter long and rarely more than 0.1 millimeter in length. One of the larger prisms has an optic angle of 74°, indicating a content of 28 percent $FeSiO_3$. Rounded grains of augite total less than 1 percent of the whole; unfortunately they are too small for accurate optical reading.

Subparallel, slender laths of plagioclase, mostly between 0.1 and 0.2 millimeter long, comprise approximately half of the lava. The larger ones vary from An_{62} to An_{68}; the smaller ones range between An_{51} and An_{60}. Most of them are unzoned, but a few are normally zoned within the limits mentioned. Oscillatory zoning of the feldspars is notably rare, not only in this particular flow, but among all the lavas and fragmental ejecta of Parícutin. In this respect they differ from most of the older lavas of the vicinity.

The remaining 40 percent of this specimen is made up of brownish-black glass clouded with dusty ore. Satisfactory determinations of refractive index are not possible, but it is approximately 1.545 ± 0.005, suggesting a silica percentage of about 55.

The above description applies with trivial changes to most of the lavas erupted by Parícutin during the present study—that is, from November 1944 to May 1945. It applies also to specimens taken from the narrow dike which was exposed at the base of the main cone close to the Ahuán vent during the same period.

The second of the illustrated specimens (fig. 89*C*) comes from the Ahuán flow and was collected near the vent on April 26, 1945. This is as nearly holocrystalline as any of the lavas from the Parícutin volcano. Olivine again constitutes 5 percent of the volume, and again many of the larger crystals (Fo_{76-81}) show the effects of the solution The smaller olivines range in composition from Fo_{82} to Fo_{92} for the most part, but one has a core of Fo_{86} enclosed by a narrow rim of Fo_{72}. A few euhedral grains of ore are included in almost all of them. Subhedral to euhedral prisms of hypersthene total 10 percent of the volume; most measure less than 0.05 millimeter, and none exceeds 0.1 millimeter in length. Occasionally the mineral forms reaction rims around the olivines. Specks of augite of about the same size form approximately 1 percent of the whole. Slender laths of feldspar between 0.1 and 0.2 millimeter long, in subparallel arrangement, account for 70 percent of the volume, their composition varying from An_{60} to An_{65}. Granules and minute dendritic clusters of magnetite and ilmenite (?) total 7 percent; acicular apatite, less than 1 percent; whereas the remaining 5 percent is composed of dark-brown glass. Neither in this nor in any other flow from Parícutin volcano has orthoclase been detected. Presumably the potash revealed by analysis is largely contained in the interstitial glass.

In view of the fact that all other specimens studied, both lavas and bombs, are intermediate in character between the two varieties just discussed, particular mention seems to be unnecessary. The chief features of all, in comparison with the older flows of the neighborhood, are summarized as follows: a paucity of porphyritic feldspar; a scarcity of oscillatory zoning in the feldspars; a lack of porphyritic pyroxenes and scarcity of microgranular augite; a relative abundance of microlithic hypersthene; and the corrosion phenomena displayed by the olivine phenocrysts.

The chemical analyses listed in table 3 give further emphasis to the uniformity of the lavas from Parícutin volcano. Specimens taken from a single flow would probably show as much variation as do the analyzed lavas from different flows.

INCLUSIONS IN LAVAS AND BOMBS OF PARICUTIN

The first ejecta of the new volcano included blocks of basaltic andesite torn from the walls of the conduit close to the surface. Possibly some were derived from flows within the Zumpinito formation, but more probably they represent fragments of lavas of post-Zumpinito age like those exposed in the vicinity.

Accompanying these accidental pieces of andesite among the early ejecta were fragments of plutonic rock. At first these were abundant and large, many measuring several feet across. Later their number and size diminished. By 1945 it was rare to find plutonic chips more than a few inches across; by 1947 it required long search to find any at all. Moreover, during the early stages of activity many of the fragments were almost or quite unaltered; later it was exceptional to see fragments that were not largely altered to glass.

Concerning the partly vitrified xenoliths discharged during the first phases of eruption, Ordóñez (1947) states that

> some of them appeared to have been originally monzonite, others true granite, and a few porphyritic monzonite. These masses exhibited a very peculiar cellular structure and contained elongated fibers or fine filaments and delicate needles of colorless glass. The hornblende or augite that they contained appeared less altered than the feldspars, and the quartz looked as if it had actually been remelted.

Trask (1943), writing of the foreign fragments among the ejecta of February 28, 1943, says that they were angular, nonvesicular pieces of "a light medium-grained granitic rock that looked like diorite." Milton (1945) described white inclusions varying from dense porcelanic to fragile, clear, glassy pumice containing aggregates of shattered quartz and turbid areas probably representing partly vitrified feldspars. He noted that the contacts of these siliceous inclusions with the enclosing lava were extremely sharp, and the high silica content of the pumiceous glass suggested to him that the inclusions were fragments of rhyolitic breccia partly remelted by the Parícutin magma.

Schmitter (1945) described one inclusion with a hypidiomorphic granular texture composed of orthoclase, quartz, albite-oligoclase, andesine, magnetite, and accessory hornblende and biotite. This he classed as quartz monzonite.

All the inclusions collected by the writer between November 1944 and May 1945 are cellular, pumiceous, angular fragments measuring up to 6 inches across. Almost all consist essentially of strained and cracked anhedral grains of quartz up to 3 millimeters across, orthoclase, occasionally a little microcline and oligoclase, and accessory grains of ore immersed in a matrix of spongy, colorless glass. None contains ferromagnesian minerals. Other inclusions, up to 4 inches across, are composed entirely of sugary quartz; both in the field and under the microscope these resemble dense quartzites.

In the partly vitrified inclusions, the refractive index of the clear glass ranges from 1.490 to 1.502 ± .002. Probably the glass developed mainly by vitrifaction of potash feldspar and oligoclase and partly by solution of quartz. Spongy relics of feldspar can be seen in all stages of conversion, and some quartz grains show corrosion and veining by glass. The rocks bear a notable resemblance to vitrified arkoses (buchites) like those found around the margins of volcanic necks in the Navajo-Hopi country of Arizona and New Mexico (Williams, 1936).

As Milton observed, there is a notable absence of reaction between most of the inclusions and the surrounding lava. Rims of diopside around xenocrysts of quartz, such as are common in basalts, were not detected. The only change noted around some inclusions was a slight brownish discoloration of the pumiceous glass within a few microns of the enclosing lava.

There is no means of telling whether the plutonic fragments came from a basement beneath the beds of the Zumpinito formation or from a stock intrusive into those beds. Nor is it certain that the quartzitelike inclusions are actually of plutonic origin; they may be products of some process of differentiation of the Parícutin magma not yet understood.

Finally, reference should be made to the discovery by Krauskopf of small inclusions of anhydrite among the products of the volcano in 1945. Anhydrite-bearing inclusions have been described by Kôzu (1934) among the pumice erupted by Komagatake in 1929. It does not seem probable that the anhydrite fragments from Parícutin are xenoliths derived from beds in the Zumpinito formation; more likely they owe their origin to fumarolic action on the walls of the conduit.

SUMMARY OF PETROGRAPHY

The lavas of post-Zumpinito age in the Parícutin region range from olivine-augite basalts through basaltic andesites to hornblende and pyroxene andesites. The oldest volcanoes, those of Cerros de Tancítaro, Cerros de San Marcos, Cerro del Aguila, and Cerros de Angahuan, are the largest and were built entirely by effusions of olivine-free pyroxene andesite. The next-oldest volcanoes, those forming Cerros de Los Hornos, also erupted pyroxene andesite, but in addition they discharged flows of olivine-bearing basaltic andesite.

Following the extinction of these volcanoes, there developed a younger series of cones characterized by a wider variety of flows. The variation did not follow a regular pattern; on the contrary, the most diverse types of lava were extruded in quick succession by closely spaced volcanoes. Most of the younger flows are olivine-bearing basaltic andesites essentially like those now pouring from Parícutin volcano itself. However, eruptions of olivine-free and olivine-poor andesites persisted at intervals to within a few thousand years ago, beginning with the augite andesites of Mesa de Huanárucua and the hornblende andesites of Mesa de Zirimóndiro, continuing with the hypersthene andesites of Cerro de Camiro and adjacent vents, and ending with the colossal outpourings of vitrophyric pyroxene andesite by the Cerros de Capacuaro volcano. Still later, copious flows of olivine-rich andesite escaped from Cerro de Surúndaro.

While these eruptions of andesite and basaltic andesite were going on, there was intermittent effusion of olivine basalt from widely scattered cones. First came the basalts related to the Cerros de Zirosto cones and Cerro de Tiripan, then those erupted by the youthful cones of Cerro de Capatacutiro and Cerro de Tzintzungo, and finally, perhaps within the present millennium, the basalts that issued from some of the Jabalí cones near Uruapan.

Petrographically the younger andesites and basalts of the Parícutin region closely resemble those composing most of the coeval volcanoes of the circum-Pacific belt, such as those described from other parts of Mexico (Burri, 1930), from Nicaragua (Burri and Sonder, 1936), Patagonia (Larsson, 1940), and the Cascade Range (Williams, 1932, 1933, and 1942). They also resemble the principal lavas of the Lesser Antilles (MacGregor, 1938).

Mineralogically these younger basalts and andesites are marked by the absence of biotite. Hornblende is confined to a few andesitic lavas, occurring as a minor porphyritic constituent in both the youngest and the oldest of the region, those of Cerros de Tancítaro and the Cerros de Capacuaro. Only in one andesite, that of Mesa de Zirimóndiro, does it form the principal ferromagnesian constituent. All of it is of the oxyhornblende variety, and generally it is either rimmed or almost wholly replaced by augite and granular ore.

Hypersthene is generally more plentiful in the more siliceous lavas. It is absent from all the basalts and from many of the basaltic andesites. In other basaltic andesites it is present only as microliths, usually varying in amount between 1 and 6 percent of the total volume, though in the most crystalline of the lavas from Parícutin it makes up 10 percent of the volume. In the olivine andesite of Cerro de Surúndaro it is extremely rare and minute; in the andesites of Cerro de Zirimóndiro and Mesa de Huanárucua it is absent. It forms phenocrysts only in the olivine-poor and olivine-free andesites. The composition shows no correlation with the bulk composition of the containing lavas, the percentage of $FeSiO_3$ varying between 14 and 40. Among the phenocrysts of the andesites of Cerros de Tancítaro, the percentage of ferrosilite ranges from 32 to 38; in those of the andesites of Cerros de Angahuan, it approximates 25; in those of Cerro del Aguila, there is a normal zoning from 14 to 34. The larger hypersthenes of the andesites of Cerros de Los Hornos contain 14 to 18 percent of the ferrosilite molecule, whereas the microliths carry 22 to 26 percent. In the andesites of Cerros de Capacuaro the hypersthene is more uniform, the ferrosilite content departing little from 26 percent. The greatest variation and the only examples of reverse zoning in hypersthene are to be seen in the olivine andesites of Cerro de Surúndaro, in which some of the small prisms have cores with 40 percent $FeSiO_3$ enclosed by rims with only 20 percent. Among the basaltic andesites the hypersthene grains are generally too small for proper optical reading, but in one of the flows of Cerro de Canicjuata the mineral contains 32 percent $FeSiO_3$ and in a glass-rich flow from Parícutin the mineral carries 28 percent of this molecule. Only in one specimen, an andesite from Cerros de Tancítaro, does the hypersthene show any alteration. Here it is partly changed to magnetite and hematite, presumably as a result of fumarolic action.

Monoclinic pyroxene is present in every lava examined. It is pale yellowish green and without sensible pleochroism. Rarely the optic angle is as low as 47° and as high as 60°; normally it varies between 52° and 58°. The extinction angles, Z to c, range from 41° to 45°. In other words, pigeonite is absent. According to the classification suggested by Benson (1944), the clinopyroxenes of the Parícutin region are augites. None falls into his category of subcalcic augite. All are included in the field of olivine basalt clinopyroxenes, as distinguished from tholeiitic clinopyroxenes by Wager and Deer (1939). They are referred to here as iron-poor diopsidic augites with approximately 30 to 50 percent by weight of the wollastonite and enstatite molecules.

Larsson (1940), in studying somewhat similar lavas from the Andes of Patagonia, observed that the clinopyroxenes in olivine-free andesites are usually richer in iron and poorer in lime than they are in olivine-bearing basalts. He noted further that lime-rich diopsidic augites are predominantly associated with magnesia-rich olivines and that hypersthene occurs mainly with clinopyroxenes richer in iron and with intermediate content of lime. All that can be said of the augites of the Parícutin region is that they tend to be richer in lime among the basalts. It would require far more study than has been possible to correlate their variations with those of the hypersthenes and olivines and to show how the porphyritic augites differ from the microliths.

There is no tendency for the augite to be more porphyritic or more plentiful in any particular group of lavas, but no flows contain less than do those of Parícutin volcano itself. Euhedral forms are least common among the basaltic lavas.

Alteration of augite is extremely rare. In one specimen of andesite from Cerro de Tancítaro and in the pink variety of the andesite of Mesa de Huanárucua, the mineral shows marginal discoloration, presumably caused by oxidation of iron under the influence of residual vapors.

The mineral olivine is absent from all the andesites of the region except those erupted by Cerro de Surúndaro and by Cerro de Camiro and adjacent vents. Even in these it rarely makes up more than 4 percent of the volume. Among the basaltic andesites it generally constitutes between 3 and 7 percent by volume; among the basalts it increases in amount to between 6 and 14 percent. There is, however, no corresponding increase in size. Generally the mineral occurs as ovoid phenocrysts between 0.5 millimeter and 2 millimeters across; exceptionally it reaches a maximum length of 4 millimeters. Typical forms have been illustrated by Schmitter (1945). In many basaltic andesites, especially those of Cerro de Cutzato and Parícutin volcano, the crystals are tabular parallel to the base and elongated along the *b* axis; in these and many other basaltic andesites the larger phenocrysts are deeply embayed by magmatic corrosion, whereas the smaller ones are approximately spheroidal.

The olivines range in composition from pure forsterite to Fo_{50}, as calculated from optic angles. They tend to be more magnesian in the basalts, among which the range is from Fo_{72} to Fo_{98}. Among the basaltic andesites the range is from Fo_{50} to Fo_{100}; in the olivine andesite of Cerro de Surúndaro it is from Fo_{67} to Fo_{76}.

Particularly striking is the wide variation within individual specimens of lava, adjacent crystals often differing in forsterite content by as much as 10 to 15 percent. Nowhere is the variation greater than in the lavas of the new volcano. For instance, in the glass-rich variety of lava from Parícutin volcano described in pages 256–258, the larger olivines vary between Fo_{63} and Fo_{84}, whereas the smaller ones vary between Fo_{82} and Fo_{90}. In the more crystalline variety the larger olivines range between Fo_{76} and Fo_{82}; the smaller vary from Fo_{82} to Fo_{92}. One phenocryst has a core of Fo_{87} enclosed by a rim of Fo_{72}. These measurements serve to account for the strong corrosion embayments seen in many of the olivine phenocrysts of Parícutin, the larger crystals commonly being more ferriferous than the late-forming, smaller granules. It may be that the lack of equilibrium denoted by this resorption of the phenocrysts indicates a sharp rise in temperature of the Parícutin magma upon extrusion.

In other basaltic andesites all the zoning in the olivines is normal. For example, in a lava from Cerro del Aire, one phenocryst has a core of pure forsterite and a rim of Fo_{72}; another has a core of Fo_{67} surrounded by a thin shell of Fo_{50}.

In most lavas the olivine is quite fresh, but in the basaltic andesites of Cerro de Cutzato and Cerro Prieto especially, the effects of oxidation and hydration are pronounced. Here much of the olivine is either marginally or almost entirely replaced by magnetite and hematite. In other crystals the fresh cores grade outward through hydrated olivine of lower birefringence to green antigorite that may in turn be enclosed by rims of magnetite. Peripheral alteration of olivine to antigorite and hematite is also to be seen in the lava of Cópitiro, but development of iddingsite among the post-Zumpinito lavas was observed only in some of the basalts erupted from Cerros de Zirosto. Even here the mineral is restricted to the rims of the olivines. Among the basalts of the Zumpinito formation from Cerro Colorado (pp. 232–233), iddingsite is extremely abundant and much of it occurs in the cores of the olivines. Replacement of olivine by talc was not observed.

Turning next to the silica minerals, it should be repeated that porphyritic quartz is completely absent. Cryptocrystalline quartz may be present in the dense groundmass of the pilotaxitic andesites of Cerros de Tancítaro and Cerros de San Marcos and in the matrix of a few basaltic andesites such as those of Cerro de Cutzato. Cristobalite and, in smaller amount, tridymite are minor constituents in the pores of many andesites of Cerros de Tancítaro, but both minerals are surprisingly rare in other lavas of the region considering how plentiful they are in the groundmass of otherwise similar basaltic andesites and basalts of the circum-Pacific volcanic belt. Opal and chalcedony appear to be entirely lacking.

Orthoclase has not been identified with certainty in any of the lavas, but on the basis of chemical analyses its presence is suspected in the cryptocrystalline matrix of several andesites.

Plagioclase is invariably the most abundant mineral in all lavas. No general rule can be established relating its size either to its own composition or to that of the enclosing lavas, except that in the basaltic andesites it is exceptional to find crystals more than 1 millimeter in length. Among the olivine-free andesites, the oldest—that is, those of Cerros de Tancítaro, Cerros de San Marcos, and Cerro del Aguila—are especially rich in porphyritic plagioclase, many crystals reaching a length of 3 millimeters. Among the younger andesites feldspar laths more than 0.5 millimeter long are unusual. Among most of the basaltic lavas, also, it is rare to find laths more than 0.5 millimeter long; however, in those of Cerro de Tzintzungo phenocrysts reach a length of 1.5 millimeters, and in those of Cerro de Capatacutiro they attain a length of 5 millimeters.

In composition the feldspar ranges from An_{50} to An_{80}. A rough correlation can be drawn between the silica content of the lavas and the anorthite content of the included feldspars. Thus, among the basalts, the range is from An_{65} to An_{80}; among the basaltic andesites, from An_{52} to An_{80}; among the olivine andesites, from An_{55} to An_{62}; and among the olivine-free andesites, from An_{50} to An_{70}.

Zoning is particularly marked in the coarsely porphyritic, older pyroxene andesites. In these, many of the phenocrysts show strong oscillatory zoning throughout, and in some the zoning is reversed. The groundmass feldspars in these lavas are always of about the same composition or more sodic than the rims of the phenocrysts. Among the younger andesites, zoning of the feldspars is less distinct and is usually normal rather than normal oscillatory. In view of Wenk's observation (1945) on the influence of the crystallization of hornblende on the development of oscillatory zoning in the feldspars, it may be noted that the plagioclase in the hornblende andesite of Mesa de Zirimóndiro shows only very weak normal zoning. Among the basaltic andesites and basalts, oscillatory zoning of the plagioclase is not as common as normal zoning; in the lavas of Parícutin itself, oscillatory zoning of feldspar is extremely rare and even normal zoning is only weakly developed. Usually, as Foshag and Schmitter have observed, the albite content increases as the feldspar microliths diminish in size.

Iron ores are invariably present. In the older, pilotaxitic andesites they form subhedral microphenocrysts, as they do in the holocrystalline basaltic andesites and basalts. Although seldom absent as inclusions within the early forming olivines, they developed mostly at a late stage, and in the glassy lavas they occur as irresolvable specks and dendritic clusters. Only in the pahoehoe basalt of Cerro de Capatacutiro was ilmenite recognized with certainty; in the other lavas the ore appears to be weakly titaniferous magnetite. Except where fumarolic action has converted part of the ore to hematite, as in the pinkish lavas of Mesa de Zirimóndiro, Mesa de Huanárucua, and Cerro de Cutzato, the mineral is always fresh.

Apatite was identified as a minor accessory in a few flows, being most plentiful in the basaltic andesite of Cerro de Cutzato.

Reference has already been made to the occurrence of tridymite, cristobalite, and hematite in many lavas as products of fumarolic activity, but nothing is more striking than the complete absence in all lavas of the Parícutin region of minerals resulting from the action of hydrothermal solutions, such as kaolin, sericite, alunite, calcite, and chlorite. In contrast to many other regions of recent volcanism in Mexico and elsewhere in the circum-Pacific belt, there exists in the Parícutin region no trace of former hot-spring or solfataric activity. By analogy, none should be expected to follow when the eruptive phase of Parícutin itself comes to an end.

PETROCHEMISTRY

The lavas of the Neo-Volcanic Zone of Mexico, including those of the Parícutin region, belong to the calc-alkalic igneous series as defined by Peacock (1931). The alkali-lime index—that is, the silica percentage at which the content of lime equals that of soda plus potash—is 60. For coeval lavas in the Cascade volcanic belt the indices are as follows: Crater Lake, 62; Mount St. Helens, 63.2; Mount Shasta, 63.7; and the Lassen Peak region, 63.9. These belong to Peacock's calcic series, as do the lavas of the Lesser Antilles and the Patagonian Andes. On the other hand, the Mexican lavas closely resemble those of Nicaragua, for which the index also approximates 60.

According to the classifications proposed by Niggli (1923 and 1936), the Mexican lavas range from the quartz dioritic magma type through the normal dioritic to the normal gabbrodioritic. In brief, they are dominantly calc-alkalic basalts and andesites. Burri's detailed study (1930) emphasizes their similarity to most of the circum-Pacific lavas and indicates further their affinities with the slightly alkalic type represented by the San Francisco Mountains volcanic suite. Along with Sonder (1936), Burri also examined the lavas of Nicaragua and the Panama Canal Zone, finding that there, as in Mexico, the younger flows tend to be more calcic than most of the lavas of Tertiary age.

Table 2 shows the general resemblance of the lavas of the Parícutin region and of Nicaragua to those of Mont Pelée, Lassen Peak, and the Sierra Nevada and demonstrates how all these differ from the lavas of the North American Cordillera. Figure 90, in which the *si* values are plotted against the *mg* values, emphasizes the similarity between the flows of the Parícutin region and those of the Pelée-Lassen areas and the Sierra Nevada. The lower *mg* values of the Nicaraguan lavas are reflected partly by the more ferriferous character of the pyroxenes and olivines.

The low *k* values of the rocks of the Parícutin region are only to be expected in view of the scarcity of modal orthoclase and the absence of biotite. Low *k* values also characterize the lavas of Nicaragua, the

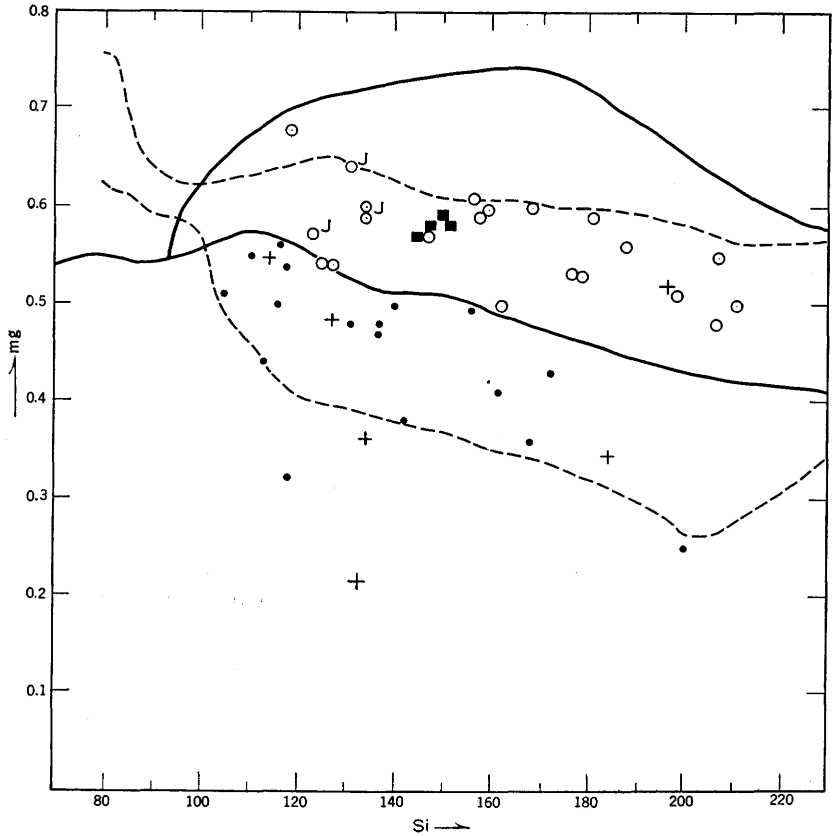

FIGURE 90.—*Si–mg* diagram, Mexican and other lavas. Open circles represent lavas of the Parícutin region and Jorullo (J); dots, lavas of Nicaragua; crosses, lava of the Panama Canal Zone; squares, lavas of the Parícutin volcano. Area between solid lines includes all but two lavas of the Sierra Nevada-Lassen Peak area, California. Area between dashed lines includes all other young lavas of Mexico not indicated separately. Diagram partly after C. Burri and R. A. Sonder, Zeitschrift für Vulkanologie, Band 17, p. 87, 1936.

TABLE 2.—*Niggli values for lavas of the Parícutin region and other areas of Pacific type*

[Values for other areas taken from C. Burri and R. A. Sonder, Zeitschrift für Vulkanologie, Band 17, p. 85, 1936]

Region	si	al	fm	c	alk	al-alk	c-(al-alk)	qz
Parícutin		24	45	22	8	16	+6	−10
Nicaragua		25	41	28	6	19	+9	−12
Pelée-Lassen	120	25	41	26	8	16	+10	−12
Sierra Nevada		22.5	43	24.5	9.5	13	+11.5	−16
North American Cordillera		22.5	42.5	25	10	12.5	+12.5	−20
Parícutin		29	36	22.5	11	18	+4.5	+5
Nicaragua		29	34	26	11	18	+8	+6
Pelée-Lassen	150	28.5	36	25	10	18.5	+6.5	+10
Sierra Nevada		27	36	24	13	14	+10	−2
North American Cordillera		27	35	23	15	12	+11	−10
Parícutin		35	28	21.5	15	20	+1.5	+40
Nicaragua		35	26	21	18	17	+8	+28
Pelée-Lassen	200	34	28	22.5	15	19	+6.5	+40
Sierra Nevada		33	28	21	18	15	+10	+28
North American Cordillera		34	26	18	22	12	+11	+12

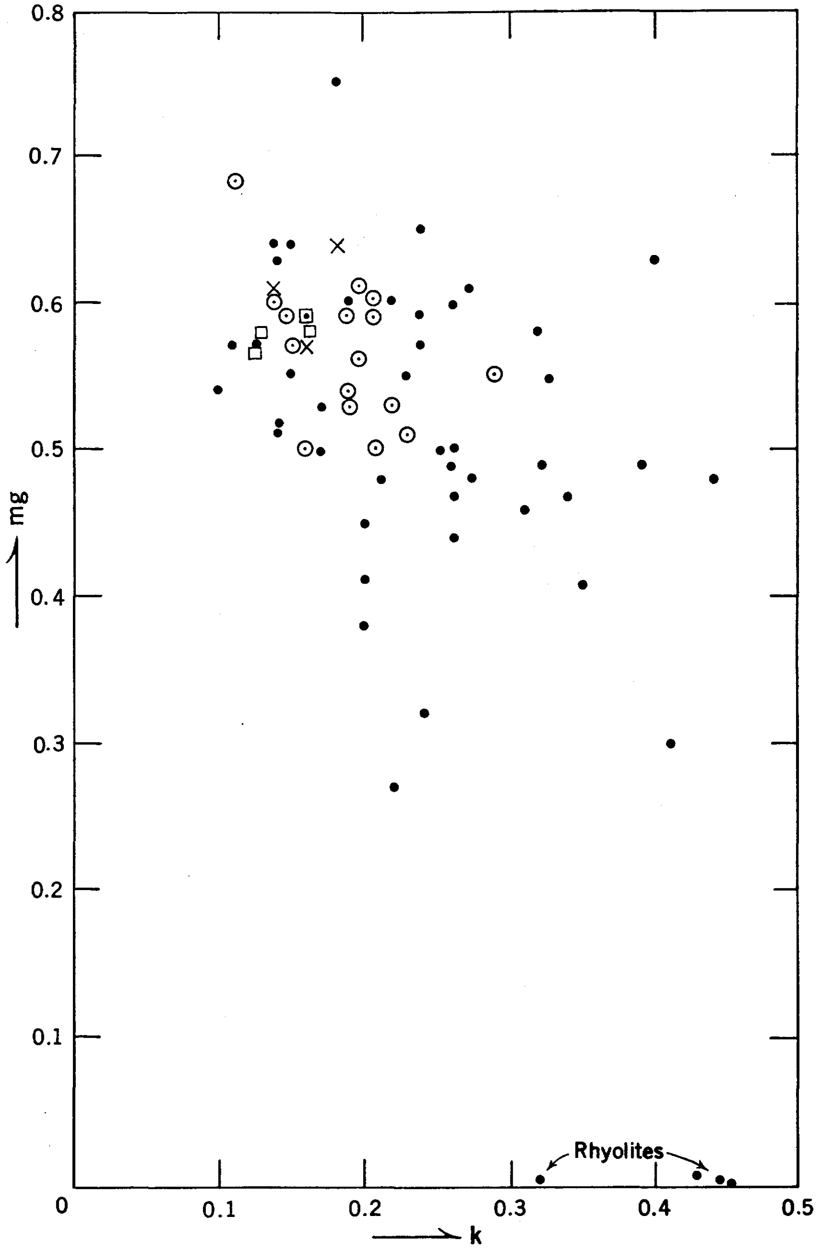

FIGURE 91.—*K–mg* diagram, Neo-Volcanic Zone of Mexico. Crosses represent lavas of Jorullo; circles with dots, lavas of the Parícutin region; squares, lavas of Parícutin volcano; dots, other lavas of the Neo-Volcanic Zone.

Lesser Antilles (MacGregor, 1938), and Crater Lake (Williams, 1942). The *k–mg* ratios (fig. 91) of the Parícutin region are essentially the same as those of the Cascade and West Indian lavas. The similarity extends to the character of the normative feldspar (fig. 92).

Certain peculiarities serve, however, to distinguish the lavas of the Parícutin region from coeval flows in other parts of the Neo-Volcanic Zone of Mexico. Examination of figures 93 and 94 shows that the former are richer in alumina and poorer in both total iron and potash than the latter. With respect to these constituents, the lavas of the Parícutin region are almost identical with those of Lassen Peak and Crater Lake. The magnesia and soda curves of the variation diagrams are almost the same for all. Just why the lavas of the Parícutin

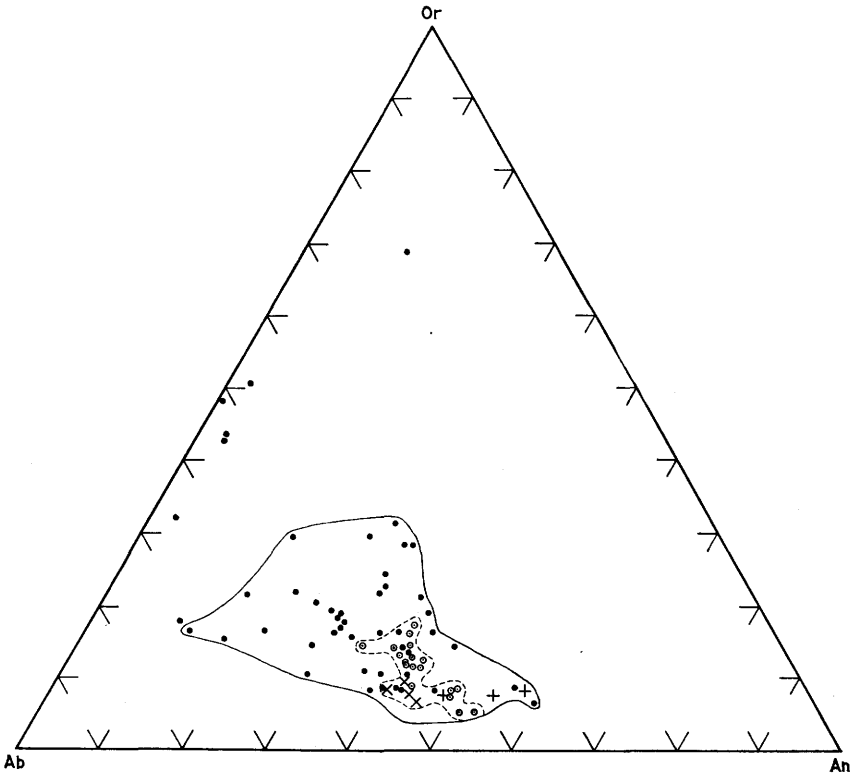

FIGURE 92.—Normative feldspar diagram of Mexican lavas. Dots outside solid line represent rhyolites of Mexico of late Tertiary age; dots inside line, coeval andesites and basalts. Dots within circles represent lavas of the Parícutin region. Diagonal crosses represent lavas of Parícutin volcano; other crosses represent products of Jorullo volcano.

region are richer in alumina and poorer in iron than other young lavas of Mexico is not clear. Table 2 shows that the *c′* [*c*-(*al*-*alk*)] values of the lavas of the Parícutin region are strikingly low, indicating poverty of normative diopside, yet the modal clinopyroxenes are rich in the wollastonite molecule. It may be that the high alumina content of these lavas reflects a tendency toward more plagioclase and less pyroxene; on the other hand, it may be related in part to the composition of the augites; but until more is known concerning the

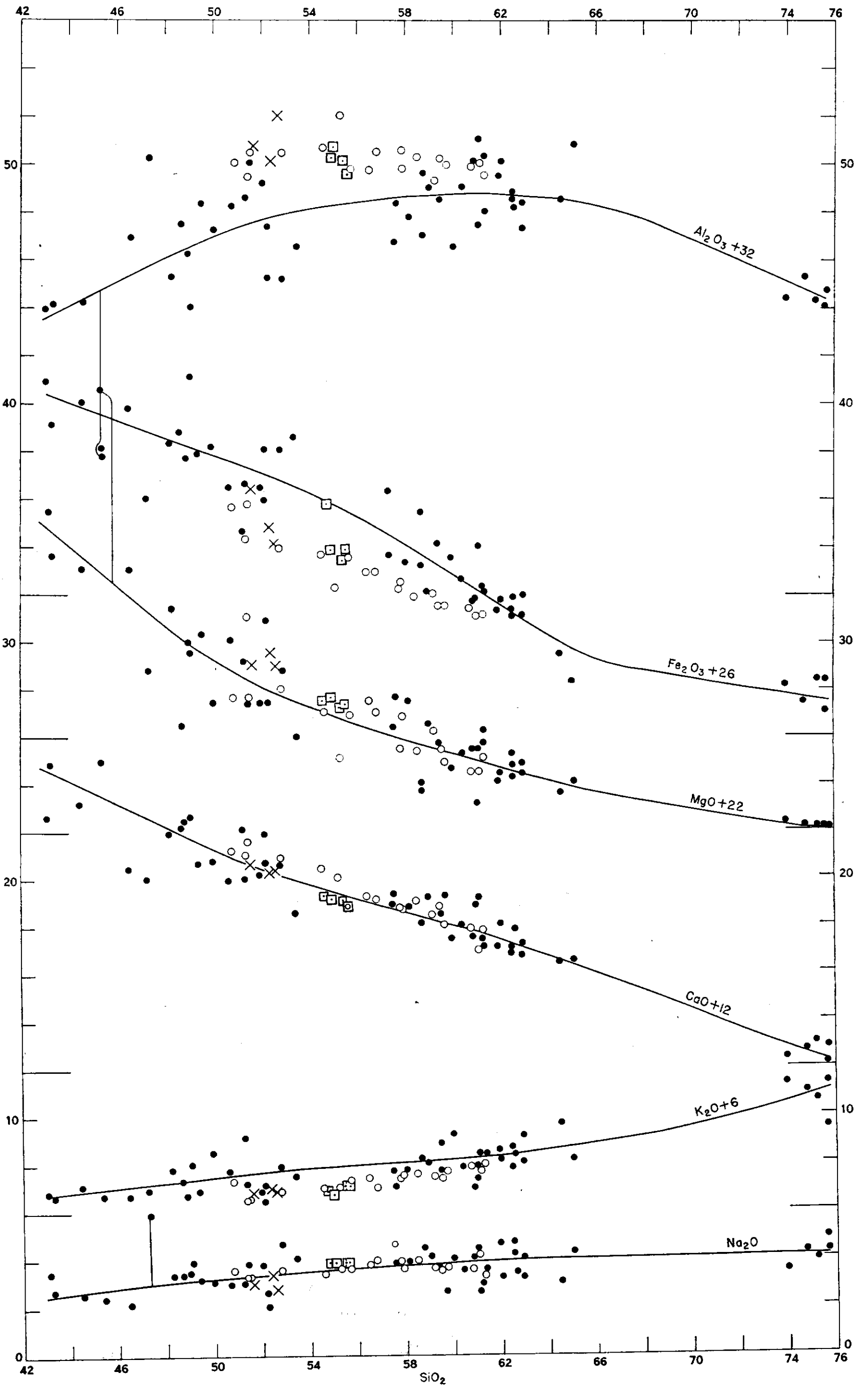

FIGURE 93.—Variation diagram of Mexican lavas. Black dots represent lavas of Neo-Volcanic Zone outside Michoacán; open circles, lavas of the Parícutin region; crosses, lavas and bombs of Jorullo volcano; squares, lavas of Parícutin volcano.

influence of the sesquioxides on the optical properties of the clinopyroxenes, it is unwise to speculate further.

As to the general trend of differentiation among the lavas of Parícutin and vicinity, there appears to be no reason to doubt that the principal control was crystal fractionation. In some andesites the wide range in composition and the reverse zoning among the feldspar phenocrysts may have resulted from mingling of magmas prior to extrusion, but there is no proof that differentiation was influenced by con-

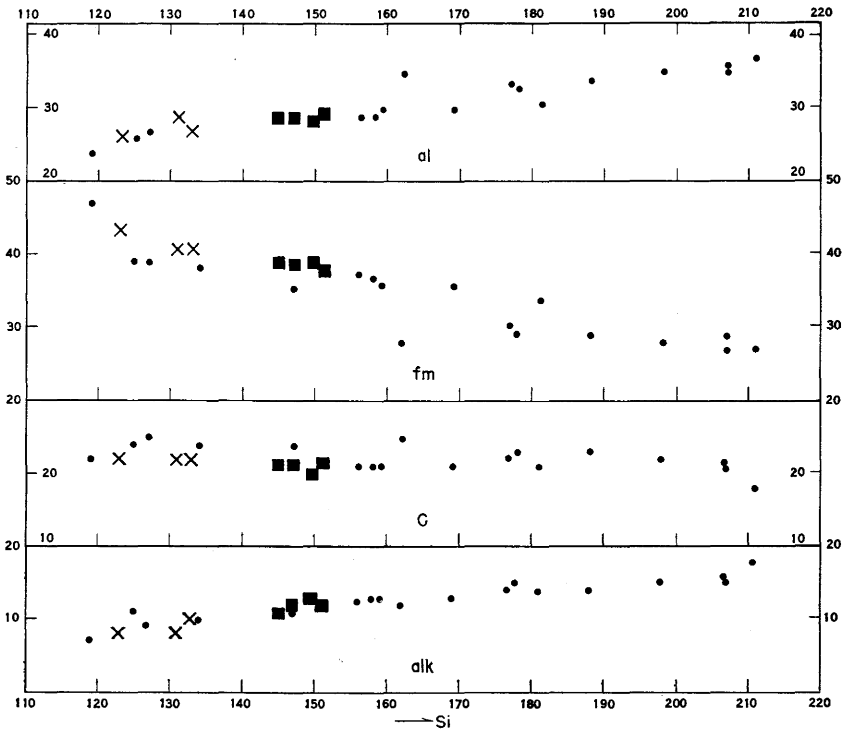

FIGURE 94.—Niggli diagram of Mexican lavas. Dots represent older lavas of the Parícutin region; crosses, lavas of Jorullo; squares, lavas of Parícutin volcano.

tamination of magma in consequence of selective solution of older rocks. At least under near-surface conditions there has been virtually no reaction between the magma of the Parícutin volcano and its inclusions of quartz monzonite.

No evidence has been found to suggest that differentiation took place in shallow feeding chambers; more likely the volcanoes of the Parícutin region were fed by narrow, vertical dikes tapping sources far below. Seismic studies may throw more light on this fundamental problem. At present pitifully little is known concerning the origin of volcanic magmas and the forces that impel them to the surface.

Finally, reference should be made to the products of the new volcano. The four most reliable analyses of lavas of Parícutin volcano are presented in table 3. Their similarity is striking. Less reliable analyses of lavas and ashes from Parícutin have been published elsewhere (Flores et al., 1945); these have been omitted in preparing the variation diagrams.

TABLE 3.—*Analyses of lavas from Parícutin volcano*

	1	2	3	4
Constituents				
SiO_2	54.88	55.04	55.51	55.59
Al_2O_3	18.38	18.82	18.19	17.72
Fe_2O_3	1.31	1.92	1.63	1.33
FeO	5.97	5.69	5.38	5.99
MgO	5.57	5.68	5.31	5.60
CaO	7.40	7.17	7.19	6.99
Ma_2O	3.88	3.88	3.92	4.00
K_2O	.86	.85	1.10	1.13
H_2O+	.13	.16	.08	.03
H_2O-	.05		.01	.04
TiO_2	.95	.94	.97	1.05
P_2O_5	.29	.21	.31	.36
MnO	.13	.07	.12	.13
Totals	99.80	100.53	99.72	99.96
Niggli values				
si	147	145	151	150
al	29	29	29	28.5
fm	38,5	39	38	39
c	21	21	21	20
alk	11.5	11	12	12.5
k	.125	.125	.16	.16
ng	.58	.57	.58	.59
qz	+1	+1	+3	0

1. The first flow. Erma Chadbourn, analyst.
2. Lava of Feb. 22, 1943. Includes 0.04 percent S and 0.06 percent BaO. Charles Milton, analyst.
3. Sapichu flow. Erma Chadbourn, analyst.
4. Ahuán flow. Erma Chadbourn, analyst.

On the basis of their *qz* values and the presence of normative quartz, the lavas of Parícutin are here classed as olivine-bearing basaltic andesites. Figure 94 shows that their composition falls on the general curves for the Parícutin region as a whole. Among adjacent lavas they resemble most closely the basaltic andesites of Cerro del Aire and Cerro de Cutzato, but they do not differ greatly from the recent flows of Cerro Prieto and the final outflow, less than a century ago, of the Cerros del Jabalí cone cluster. Their resemblance to the olivine-free hornblende andesite of Mesa de Zirimóndiro also deserves to be noted. The products of Jorullo are less siliceous and, having negative *qz* values of 1 to 9, are to be classed as olivine basalts.

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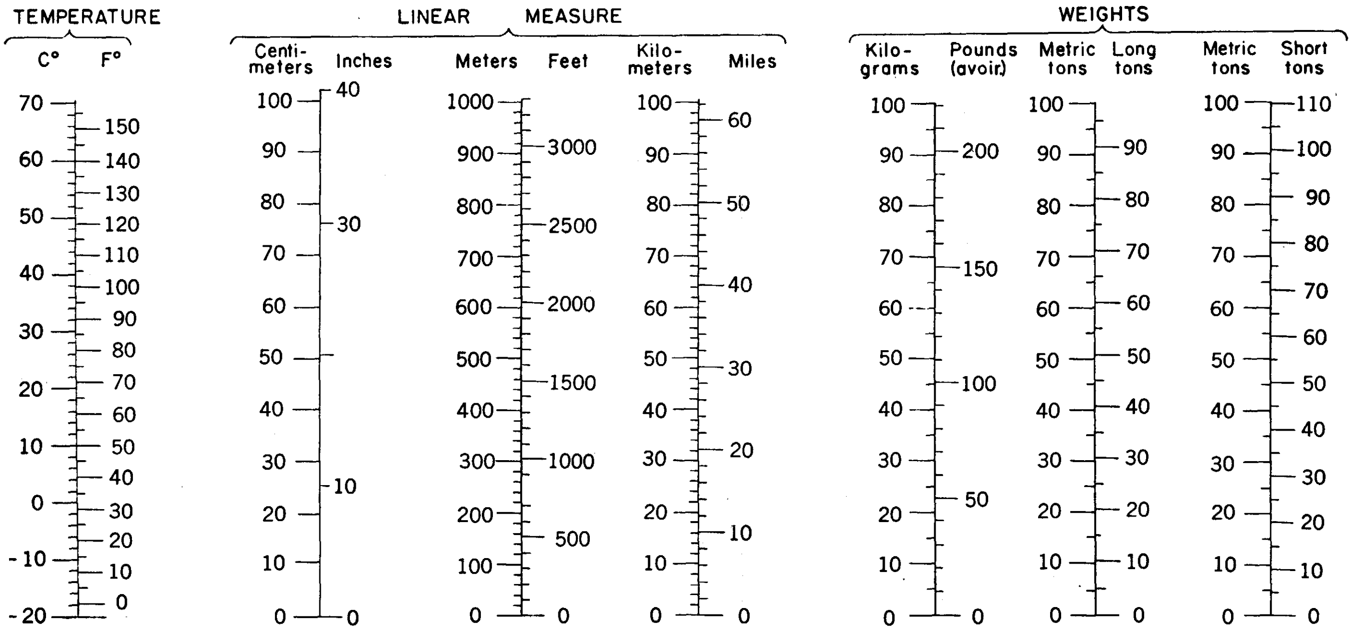
METRIC EQUIVALENTS



1 cm. = 0.3937 in.
1 in. = 2.5400 cm.

1 m. = 3.2808 ft.
1 ft. = 0.3048 m.

1 km. = 0.6214 mile
1 mile = 1.6093 km.

1 sq. m. (m2) = 1.20 sq. yd.
1 hectare (100x100 m.) = 2.47 acres
1 cu. m. (m3) = 1.31 cu. yd.

1 kg. = 2.2046 lb.
1 lb. = 0.4536 kg.

1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2,205 lb.
1 long ton = 1.0161 metric ton
1 short ton = 0.9072 metric ton

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