AMERICAN JOURNAL OF SCIENCE

NOVEMBER 1926

THE LAVAS OF ETNA.

H. S. WASHINGTON, M. AUROUSSEAU, MARY G. KEYES.

INTRODUCTION.

Almost fifty years ago von Richthofen showed that, in the volcanic districts of Hungary and the western United States, there is a definite chronological sequence of different kinds of lava, which he thought to be of general application. The idea was developed by Iddings, who advanced the view that, at volcanoes, the sequence, similar to that of von Richthofen, begins with lavas of intermediate composition (andesite) and ends with those of extreme composition (rhyolite and basalt). The matter has been dealt with by many other petrologists and it would seem that, in general,[1] the sequence at eruptive centers differs from that at intrusive areas. At volcanoes it is most often one of "increasing divergence from the initial type" and at intrusive areas one of "decreasing basicity," to use Harker's phrases. There are, however, many exceptions and the sequence at any locality would seem to depend in great part on the general chemical character of the parent magma, as has been suggested by Daly.

In 1892 Geikie[2] concluded, from study of the British igneous rocks and ancient volcanoes, that igneous activity is usually cyclical and that each cycle yields the same general sequence of igneous rocks. The suggestion was made later by the senior author,[3] adopting Geikie's idea of recurrent cycles of volcanic activity, that at many volcanoes the close of a long cycle of activity is marked by a plinian, caldera-forming explosion, after which the volcano begins a new cycle of activity, in which there may be either, as suggested by Geikie, a recurrence of a lava sequence similar to that of the preceding cycle,

[1] See the summaries by Harker, Natural History of Igneous Rocks, 112-118, 1909; and Daly, Igneous Rocks and their Origin, 55 and 469, 1914.

[2] Geikie, A., Quart. Jour. Geol. Soc., **48**, 178, 1892: also Ancient Volcanoes of Great Britain, 2, 27, 92, 1907.

[3] Washington, Compt. Rend., XII Cong. Géol. Int., 229, 1914.

or a great change in the general character of the lavas. A number of strato-volcanoes of the Vesuvius type were cited as examples, Etna among them, but it was pointed out that "Few volcanoes have been studied with sufficient system, completeness, and detail, and also with sufficiently numerous and representative [chemical] analyses of the lavas of the different volcanic phases [cycles], to enable us to decide whether such a connection is general, and whether it is a real, causal one or only coincidental." The words of Geikie,[4] referring to recurrent cycles of igneous activity and rock sequence, may well be quoted: "In this difficult subject it is of the utmost importance to accumulate fact before proceeding to speculation." It is to the contribution of a few facts regarding Europe's greatest active volcano that the present paper is devoted.

In the course of several visits to Etna by the senior author, especially in June and July, 1914, in company with Dr. A. L. Day,[5] a fairly representative collection of its lavas was made, which was supplemented by a collection of the lavas of the Val di Noto, about 60 kilometers south by west of Etna.

The lavas of Etna have been much neglected by petrographers —a neglect that is the more singular because of the activity and ready accessibility of the volcano, and the abundant literature in which its eruptions have been described. Thus, Zirkel, in his Lehrbuch, gives one-half of a page to the Etna lavas; Rosenbusch, in his Mikroskopische Physiographie, dismisses them with one sentence, and does not mention them in his Elemente; other petrographical textbooks, those of Harker, Hatch, Iddings, Mennell, De Lapparent, Artini, and Jannetaz, either barely mention Etna lavas or say nothing of them. The greatest number of rock descriptions are those by von Lasaulx, which appear in the monumental, posthumous work by Sartorius, edited by von Lasaulx.[6] This is the classic book on Mount Etna, which will be often cited. Other descriptions of the lavas of Etna, most of them of recent flows, we owe to Italian petrographers and to Lacroix, references to which will be made on later pages.

The early analyses of Etna lavas by Silvestri, Ricciardi, and others are now of little more than historic interest. Fourteen analyses were published by von Lasaulx in "Der Aetna,"

[4] Geikie, Ancient Volcanoes, 1, 29, note 2, 1907.
[5] Washington and Day, Bull. Geol. Soc. Amer., 26, 380, 1915.
[6] Sartorius von Waltershausen and von Lasaulx, Der Aetna, Leipzig, 1880.

which, although incomplete and otherwise unsatisfactory by reason of their early date, yet serve to indicate some of the main chemical characters of the lavas of Etna at various stages of its history. A few good modern analyses, all of recent flows, have been made by Pisani, Ponte, Starabba, and Di Franco, which will be cited later.

THE VOLCANO.[7]

Volcanic activity in Sicily has been confined to the east coast of the island. It began with the pre-Cretaceous or Cretaceous basalts of Capo Passero, at the southern corner of the island. Of these rocks there are two analyses by Ricciardi.[8] These eruptions were followed by the Miocene basaltic volcanoes of the Val di Noto, about 60 kilometers to the northeast, of the lavas of which there are four modern[9] and a few older analyses.[10] To the Quaternary belong the pre-Etnean lavas around the volcano.[11] These are seen at the basaltic knobs at Motta Sant'Anastasia, Paternò, and San Marco, on the south; and the flows at Aci Castello, the Cyclopean Islands, and at the foot of the cliffs below Aci Reale and Aci Trezza, on the east. Sartorius thinks that these lavas are not connected with, or do not form part of, Mount Etna, although, as Platania says, "they are almost continuous with the actual mass of the volcano."

The earliest, definitely Etnean eruptions took place in the Quaternary Catanian gulf. Some of these were submarine and some were on the land-filled parts of the gulf. These earliest Etnean flows—the so-called "terrace" or "pedestal" lavas[12]—are very largely covered by later lavas, but they are exposed: on the south, at various localities along the Sirmeto River; on the east, at Aci Reale and the upper flows in the cliff below it; and on the north, in the valley of the Alcantara River. In the aggregate they form a broad, low pedestal, with slopes of from 2° to 5°.

[7] This brief description is based on the work of Sartorius and on the description by Prof. Gaetano Platania, Guida d'Italia, Touring Club Italiano, "Sicilia," 1919.

[8] Ricciardi, Gazz. Chim. Ital., 11, 385, 1881.

[9] Ponte, Atti Accad. Gioenia, 3, Mem. 10, 1910. Mariscalco, ditto, Mem. 9, 1914.

[10] Ricciardi, op. cit., 382.

[11] Sartorius, Der Aetna, 2, 48-62, 328, 423-431.

[12] Sartorius, Der Aetna, 2, 88-103, 390-392, 446, 450.

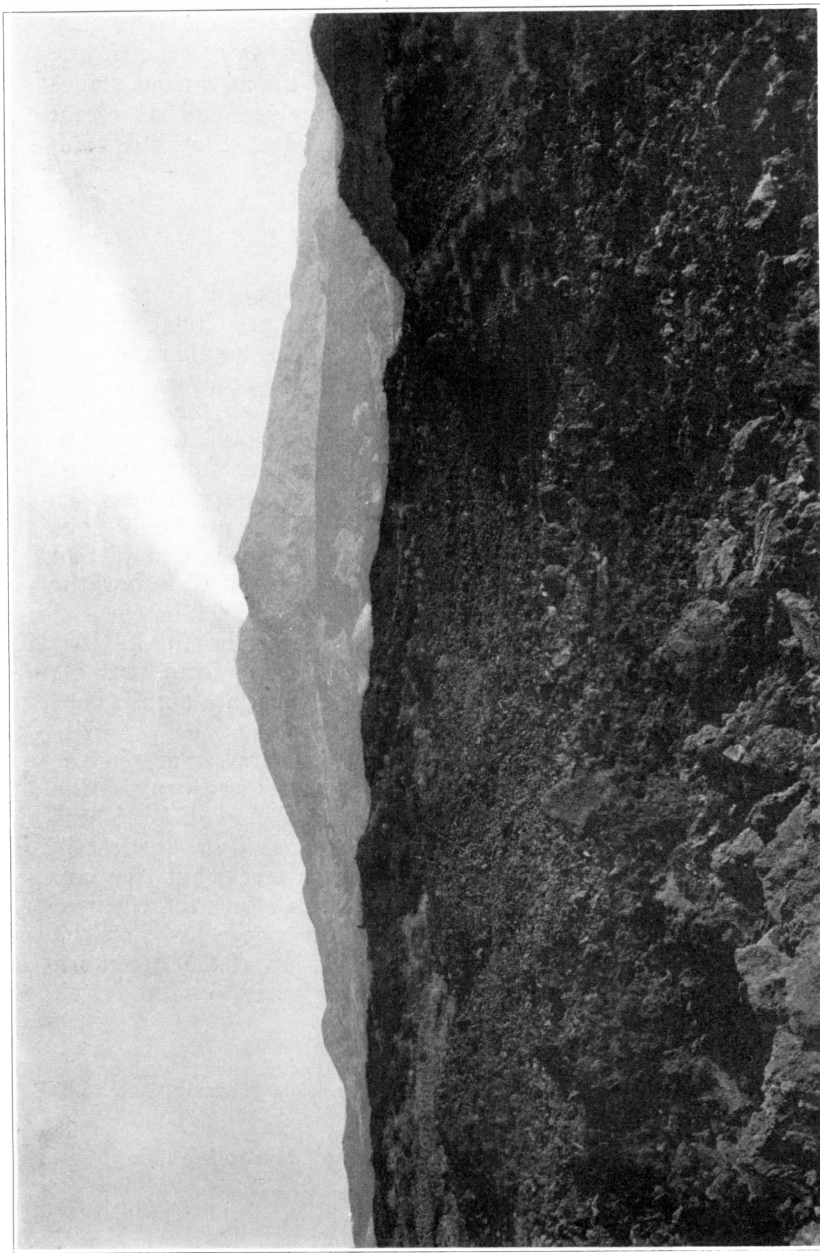

Fig. 1. Main cone of Etna, from the south (near Nicolosi). Terminal cone, with light vapors, on left: La Montagnola on right. Val del Bove behind highest ridge on right. Aa flow of 1910 in foreground. Photograph by Arthur L. Day, 1914.

From about the center of this platform rises the main cone of Etna, the "Centralkegel" of Sartorius[13]—the sides of which slope at from 20° to 30°. The boundary between this and the pedestal is in places quite sharp, but generally is obscured by recent flows and ash. According to Sartorius, the central cone began as a tuff cone, followed by lava flows and the intrusion of dikes. The early activity, according to Sartorius, took place at probably three centers, which lay on a straight fissure, running N. 36° 48′ W., the eruptions from which were probably mostly successive, but finally settled down to the present axis.

The main cone (Fig. 1) is truncated, at the height of about 2,800 meters, by a roughly elliptical plateau, with diameters of about 4 and 3 kilometers. This is approximately horizontal, the ash-covered southern half, called the Piano del Lago, having an upward slope of 7° to 10° to the Observatory at the southern foot of the terminal cone. This plateau is the site of two ancient craters of the main cone, now almost wholly filled in by recent flows and ash. Of these the older, larger, and better known is the so-called "Elliptical Crater," which occupies the northern part of the plateau. Fragments of the walls of this remain: Monte Curiazzo, 1,266 meters long, west and northwest of the terminal cone; a curving ridge, largely covered by recent flows and ash, on the northeast; and a short stretch near the Torre del Filosofo, on the southeast. The eastern side of the elliptical crater has been broken down by the formation of the Val del Bove, proving that the crater antedated the formation of the caldera. The smaller, almost circular, Piano del Lago crater, about 1,300 meters in diameter, is less well defined. It occupies the southern half of the elliptical crater and extends outside of this to the southwest, the Observatory being on its southeast rim.

The present terminal, active cone rises from about the center of the Piano del Lago crater plateau, with a height of about 500 meters above this, so that the crater rim is about 3,300 meters above sea-level. The present active terminal crater, the form and size of which vary much from time to time, has a diameter of 400 or 500 meters: its depth in 1874 was about 1,000 meters, in 1914 about 450 meters, and is at present about 250 meters. An active mouth, now over 200 meters in diameter, opened on the northeast flank of the terminal cone in May, 1911. (Fig. 2.)

[13] Sartorius, Der Aetna, 2, 291, 332-340.

Fig. 2. Terminal cone, with bocca of 1911 on left. Note ash- and salt-covered slopes. Photograph by Arthur L. Day, 1914.

Very few lava flows have issued in recent times from the terminal cone, but a dozen or so eruptions have taken place within the area of the Elliptical and of the Piano del Lago Craters. The activity of Etna takes place almost wholly on its flanks, along radial fissures, some of which are of great length. In consequence, the slopes of the main cone of Etna are dotted with hundreds[14] of small, parasitic cones and crater pits (Fig. 3), which, according to the hypothesis of Ponte,[15] are mostly due to explosions from lava flows that make their way along buried strata of ash down the mountain slopes. Very few of these parasitic cones have broken through the outer pedestal.

On the eastern flank of the main cone is the great caldera called the Val del Bove, which permits study of the structure of the volcanic mass and of its earlier lavas. (Fig. 4.) This caldera is about 8 kilometers long and 5 kilometers wide, with an east-southeasterly trend. The steep, and in places precipitous, walls, 600 to 1,200 meters high, are made up of flows and beds of tuff and volcanic agglomerate, which are traversed by innumerable dikes. A former axis of volcanic activity is thought by Sartorius to have been in the southwestern part, the so-called Trifoglietto, and it is probable that the great paroxysmal explosion, which formed the caldera, took place at this center. The floor of the Val del Bove is, in general, rather flat, with a gentle southeasterly slope. Fragments of what Sartorius (2, 282) speaks of as an ancient "cross terrace," but which may be rather the remnants of the pre-caldera lower east slope of the main cone, form a series of hills and crags, surrounded by recent flows, between Monte Calanna on the southeast edge of the Val del Bove to Rocca Palombe on the north. These are made up of interbedded flows and ash beds, with dikes, as are the walls of the caldera.

Several eruptions, some of great violence, have taken place in recent times within the area of the Val del Bove, notably those of 1792, 1811, 1852, and 1908, the great flow of 1852 (Figs. 4, 6 and 7) being about 9 kilometers long, reaching nearly to Zafferana, its volume being about 420,000,000 $km.^3$ according to Sartorius. Other recent eruptions that took place on the terminal plateau (1811, 1819, 1838, 1842, 1869), have poured their lavas down into the caldera.

It is noteworthy that several of the vents on the plateau

[14] Sartorius (2, 384) enumerates 972, and the total is now about 1,000.
[15] Ponte, Zeitsch. Vulkan, 1, 9, 1913.

Fig. 3. Line of explosion craters and two driblet cones, "I Due Pizzi." These are recent, but of unknown date; on Elliptical Crater plain, north of Terminal Cone. Photograph by Arthur L. Day, 1914.

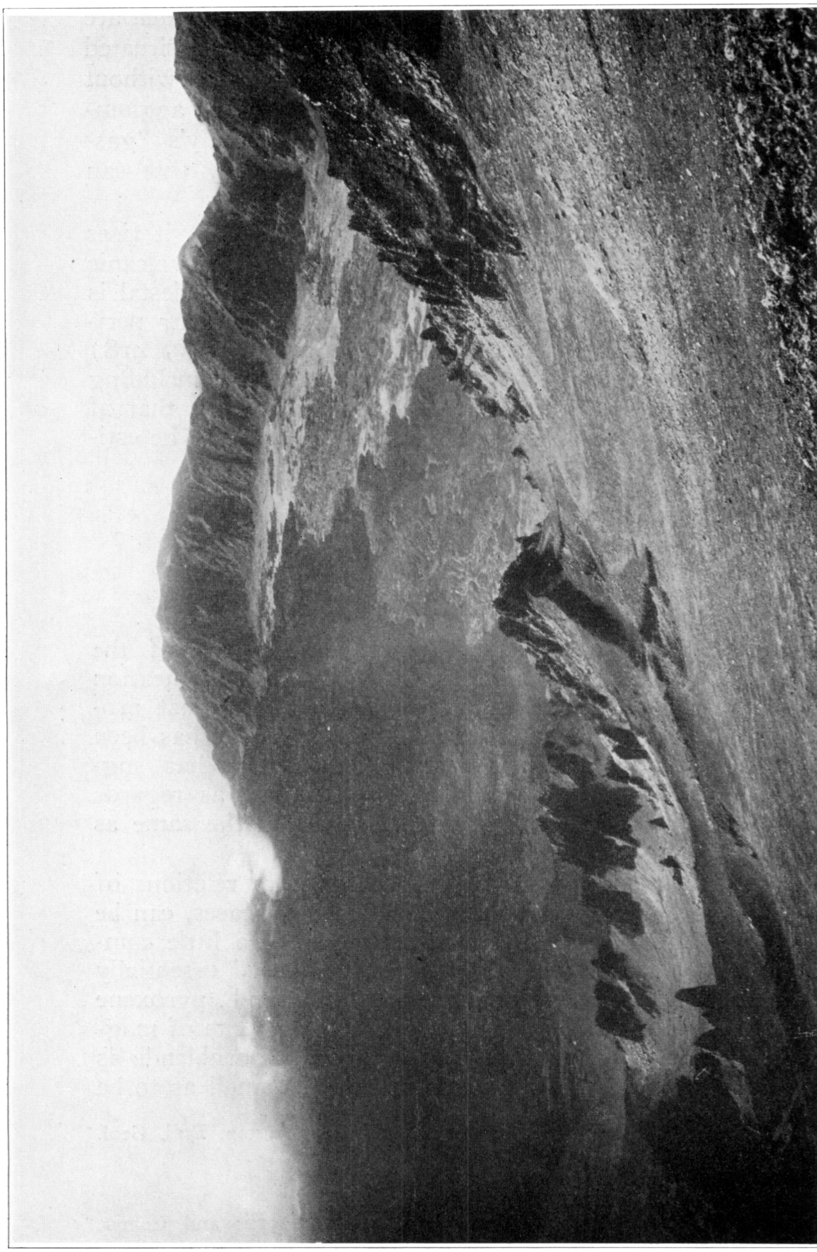

Fig. 4. Val del Bove from upper (west) rim. Serra di Gianicola in foreground; Trifoglietto center on floor to right; Monte Zoccolaro at left end of ridge, in background. Clouds gathering in bottom of valley hide Monte Calanna, to left of Zoccolaro. Poiareddu is small, isolated mass on right, at foot of cliff. Lava of 1852 (dark) covers central part of floor: lava of 1792 (light) to right. Photograph by Arthur L. Day, 1914.

area, such as those of 1763, 1792, 1811, and 1819, which are therefore later than the formation of the caldera, are situated very close to the edge of the upper precipitous scarp without the lava breaking through the loosely coherent ash and agglomerate beds that slope down into the caldera. Daly's "gas-fluxing" hypothesis[16] seems to be the only agency that can account for this.

The height of Etna is about 3,300 meters and, as it rises directly from the sea, it is thus one of the highest land volcanic masses on the globe. The diameter of its base or pedestal is about 40 kilometers, and its sinuous, roughly circular perimeter measures about 160 kilometers. Sartorius (2, 418) calculates the volume of the whole mass of Etna, including the Val del Bove caldera, to be 879 cubic kilometers, that of the terminal cone being 522 million cubic meters, and he estimates the age of the volcano at about 50,000 years.

The Lavas.

CLASSIFICATION.

Before beginning the petrographical descriptions of the lavas it will be well to state briefly the system of classification adopted for the Etna rocks. The system follows that proposed by Iddings[17] for andesites and basalts, and it has been used in describing Hawaiian lavas.[18] Lacroix[19] has suggested a classification along similar lines, which, as regards the andesites and basalts of Etna, is practically the same as that adopted here.

The classification is based on the quantitative relations of the normative mineral molecules, which, in most cases, can be closely judged for the unanalysed specimens, by a little comparative study. The lavas of Etna are composed essentially of plagioclase (of varying composition) and pyroxene (augite), with small and generally negligible amounts of magnetite and apatite, with or without olivine. Hornblende is present in a few Etna lavas, but in amount so small as to be

[16] Daly, Igneous Rocks, 251, et seq., 1914. Cf. Washington, Bull. Geol. Soc. Amer., **28**, 277, 1917.

[17] Iddings, Igneous Rocks, **2**, 21, 1913.

[18] Washington, this Journal, **5**, 467-474, 1923.

[19] Lacroix, Minéralogie de Madagascar, **2**, 219-225, 1922: and Compt. Rend. Cong. Géol. Int. XIII, 956-963, 1925.

negligible; in any case, the greater part of the modal hornblende would increase the normative pyroxene.

The lavas, then, are divided primarily into groups based on the relative amounts of the salic and femic normative minerals, the salic minerals here being plagioclase and the femic being pyroxene, in some cases olivine also, and with a little magnetite, ilmenite, and apatite. The two groups to be considered here are those of andesite and basalt.

Andesite, as here defined, is a lava in which normative plagioclase dominates over the normative femic minerals; that is to say, plagioclase constitutes from 87.5 to 62.5 per cent of the norm.

Basalt is a lava in which the amounts of normative plagioclase and of femic minerals are about equal; that is to say, the percentage of feldspar is between 62.5 and 37.5, and conversely with the femic minerals.

In judging the classificatory position of unanalysed specimens it should be borne in mind that some of the normative anorthite, albite, and nephelite enters the modal augite, because, in calculating the norm of a rock, the Al_2O_3 of the augite is used in forming salic molecules. This is shown by the calculation of the norm of an augite,[20] as is done in the case of igneous rocks. If the norm of a typical Etna augite, that of Monti Rossi near Nicolosi,[21] be calculated, it is found to contain about 6.7 per cent of the anorthite molecule and 3 per cent of that of nephelite. Therefore, in judging whether an Etna lava is an andesite or a basalt, an allowance of about 10 per cent of the augite present must be made for the normative salic molecules present in it, and these are to be added to the amount of normative feldspar. In consequence, any andesite or basalt is slightly more andesitic (i. e. normatively feldspathic) than it appears to be, and the average modal feldspar is more albitic than is the average normative feldspar.

The presence or absence of olivine in these rocks is regarded as of less importance than the character of the feldspar, so that the two groups, andesite and basalt, are first subdivided according to the amount and character of the normative feldspar, the small amounts of normative orthoclase and nephe-

[20] Washington, The Roman Comagmatic Region, Carnegie Publ. No. 57, 134, 1906; Washington and Merwin, this Journal, 3, 122, 1922. Lacroix (Compt. Rend. XIII Cong. Géol. Int., 962, 1925) calls attention to the same point.

[21] Washington and Merwin, this Journal, 1, 29, 1921.

lite, when present, being reckoned in with the albite molecule. We may call oligoclase a feldspar more albitic than Ab_3An_1, andesine Ab_3An_1-Ab_1An_1, and labradorite Ab_1An_1-Ab_1An_3. We would thus have, for example, oligoclase andesite, andesine andesite, and labradorite andesite, and oligoclase basalt, andesine basalt, and labradorite basalt.

The terms andesite and basalt do not imply the presence of olivine; on the contrary, they are regarded as typically olivine-free. It has been noted that in these rocks, at Etna, Hawaii, Madagascar, and elsewhere, the amount of modal olivine is greater than that of the normative, and that olivine may be present in the rock although there is none in the norm, which may even show an excess of SiO_2. This is brought about by the tendency of hypersthene to split up at high temperatures, olivine crystallizing out and silica remaining in the liquid, this silica recombining with the olivine at lower temperatures to form hypersthene.[22] Whether olivine be present in the rock, and its amount, will, therefore, depend largely on the conditions of cooling and solidification.

For this reason the modal presence of small amounts of olivine is not regarded, either by us or by Lacroix, as of much classificatory importance. If there is none in the norm and but little in the rock the olivine is disregarded. If much olivine is present in the norm, and consequently more in the mode, the word olivine is prefixed (with a hyphen) to the name of the feldspar. Thus, we might have olivine-andesine andesite and olivine-labradorite basalt. It should be added that, in the case of the Etna and similar lavas, small amounts of both normative and modal nephelite are to be treated in much the same way as is olivine.

In this paper the terms *phyric* and *aphyric* will be used for porphyritic and non-porphyritic, as was done in the papers on the lavas of Hawaii cited above.

PRE-ETNEAN LAVAS.

Of the lavas that Sartorius regarded as pre-Etnean,[23] we have studied specimens from Aci Castello and the Cyclopean Islands, the Timpa Agnazio (near Aci Castello), the Grotta delle Palombe, and flows below Aci Reale.

Andesine andesite. The columnar lava of the lowest flow at the Grotta delle Palombe, below Aci Reale, is medium gray,

[22] Bowen and Andersen, this Journal, 37, 487, 1914.
[23] Sartorius, Der Aetna, 2, 48-62, 421-431.

fine-grained, with many small phenocrysts of glassy gray feldspar, but none of augite or olivine, in a dense, aphanitic groundmass. The thin section shows that the plagioclase phenocrysts are euhedral and much twinned, of about the composition Ab_3An_2: they contain some very small and irregular inclusions of brown glass, which are mostly clustered toward the center of the crystal. Some rare prismoidal phenocrysts of pale gray augite are seen, and fewer and smaller ones of fresh olivine. The groundmass is composed largely of small and thin laths of slightly twinned plagioclase, more albitic than the phenocrysts. There are many minute grains and prisms of colorless augite and fewer grains of magnetite, in a colorless glass base. Flow texture is not evident.

The analysis (No. 1 of Table I) is that of a rather acid "basalt," high in alkalies. Calculation of the norm shows that the rock is an andesine andesite.

The lava flow that forms the lower part of the picturesque rock of Aci Castello (Fig. 5) is of very different character. This is a pillow lava, made up of spheroidal masses, one-half to two meters in diameter, of radiating columnar structure, and with a thin glassy crust. The interstices are filled with baked mud, and the flow was evidently submarine. Most of the rock is weathered, but fairly fresh material was obtained from the interior of the large spheroids.

The rock is rather dark, dull gray, with a rough feel, very fine-grained and aphanitic, and without any phenocrysts. Small (up to 0.5 cm.) spherical vesicles of the pahoehoe form are present, but they are not as abundantly or as regularly distributed as in the typical Hawaiian pahoehoe. In the specimen analysed these vesicles contained no zeolites. Analcite, which is very abundant at the Cyclopean Islands, does not occur at Aci Castello, where (according to von Lasaulx) the zeolites are natrolite, chabazite, and phillipsite.

The thin sections reveal a texture that differs from that of all the other pre-Etnean or Etnean lavas which we have examined. Numerous slender laths, from 0.1 to 0.2 mm. long, of twinned plagioclase, about Ab_2An_1, and small prismoids and grains of colorless augite, but no magnetite, with rare small olivines, lie in an abundant glassy base. This glass is mostly dusty and rather dark brown; some patches have branched rows of minute magnetite octahedra. There is no flow texture.

The freshest specimen from the Isola di Aci, the largest of

Fig. 5. Spheroidal (pillow) lava, lowest flow of Aci Castello. Note radiate structure. Photograph by Arthur L. Day, 1914

the Cyclopean Islands, is similar megascopically to the lava of Aci Castello. But in thin section it shows a typically doleritic texture, made up of short, stout tables of labradorite, large anhedral crystals of pale brownish augite, magnetite grains, with no olivine. The rock is holocrystalline, and is probably andesite, possibly basalt. Some very interesting features are shown in the specimens from the contact of the basalt with the hardened mud, which need not be described here.

Olivine-labradorite basalt. A very femic lava is the phyric olivine basalt that forms a flow at the Sorgente Jusu, at the foot of the cliff below Aci Reale. This contains many phenocrysts of gray labradorite, black augite, and yellow olivine, all of them about 5 mm. in diameter, in a light gray, phaneric groundmass, which is evidently rather feldspathic. Under the microscope, the stout tables of much twinned labradorite, Ab_2An_3 to Ab_1An_2, show many small inclusions of brown glass and magnetite grains, which are often arranged in lines and are mostly clustered toward the center, leaving an inclusion-free border. Rounded phenocrysts of perfectly fresh olivine are more numerous than the larger prismoidal phenocrysts of pale gray augite, these latter inclosing some small feldspars. The groundmass is made up largely of andesine, about Ab_1An_1, in small laths and grains, with many granules of augite and of magnetite, but with scarcely any olivine. There is a little colorless glass. The chemical composition of this rock, shown in Table I, No. 3, is that of an olivine basalt, but rather higher in alkalies than usual. The average normative feldspar is almost on the border between andesine and labradorite. But, because of the prominence and abundance of the phenocrysts of labradorite and of olivine, the rock may be called olivine-labradorite basalt.

Another such femic lava is that which forms the Timpa Agnazio, near the Aci Castello railway station, notable for its huge spheroid of radiating columns. This is, megascopically, a compact, dark gray, basalt, with very small feldspar phenocrysts: the rock is not fresh. The thin section shows that it consists of short, thin laths of andesine or labradorite, with more abundant, pale gray augite, which in places is ophitic, elsewhere interstitial. There are some small irregular brownish magnetite grains, but olivine appears to be absent. Glass, altered to a yellowish aggregate, occurs in patches and interstitially. The rock is obviously a very femic basalt, but no analysis was made of it, because of its altered condition.

We have no specimens of the pre-Etnean lavas of Motta Sant'Anastasia and of Paternò. The descriptions by von Lasaulx indicate that they are not very fresh and that they are much alike. The Motta rock is aphyric, except for a few olivines, while that of Paternò has phenocrysts of labradorite, augite, and olivine, the last being especially abundant. The groundmass of both is similar, doleritic in texture, composed of laths of labradorite, with grains of augite, rather abundant olivine, and magnetite. These rocks apparently much resemble the lava of Sorgente Jusu and, like it, should probably be called olivine-labradorite basalt.

Val di Noto. It may be mentioned that all the lavas of the Val di Noto appear to be basalts. The specimens collected by Washington fall into three groups: holocrystalline basalt, with typical doleritic texture; glassy basalts with numerous, very small plagioclase laths, much like the rock of Aci Castello; and brown basaltic glass, with few phenocrysts, which seems to be some of the palagonite of Sartorius. That these basalts are very sodic, especially the glassy ones, is indicated by the analyses by Ponte[24] and by Mariscalco.[25] One of Ponte's analyses is given in Table I, No. 6. The specimens from the Val di Noto in our possession will be studied and published later.

PREHISTORIC LAVAS.

Of the lavas that make up the mass of Etna mostly covered by flows within historic times, those that form the pedestal will be described first, after which will be taken up those that constitute the main cone. With these latter will be considered the lowest flows in the Val del Bove. Von Lasaulx thinks that these form part of the pedestal, but Sartorius states definitely that they lie above and are later than the pedestal or "Terrace" lavas.

The Pedestal Lavas.

Specimens, studied by us, from a flow at the railroad station of Paternò, south of the cone near the Sirmeto River, and one from Ponte Sospeso, in the Valley of the Alcantara, north of the cone, are almost identical. They are rather dark gray and phyric, with some large phenocrysts (0.5 to 1.0 cm.)

[24] Ponte, Atti Accad. Gioenia, **3**, Mem. 10, 5, 1910.
[25] Mariscalco, Atti Accad. Gioenia, **7**, Mem. 9, 1914.

and many small laths (1 to 3 mm. long) of white feldspar, some black augites, and fewer smaller crystals of yellow olivine, in a dense, dark gray groundmass. In thin section the large feldspar phenocrysts are seen to be labradorite, about Ab_2An_3. They are much twinned and contain small irregular inclusions of brown glass, which are mostly clustered toward the center. The few, pale yellow-brown augite phenocrysts and those of fresh olivine need no remark. The small, twinned feldspar laths, which belong to the groundmass, are about Ab_3An_2. The groundmass, otherwise, is composed of small grains of augite and magnetite, with a few microphenocrysts of fresh olivine, and possibly a little colorless glass. The texture is andesitic.

Di Franco[26] has described basalts from the Valley of the Alcantara which appear to be much like our specimen, and his analysis is also like ours of the Paternò specimen.

Analyses of two pedestal lavas are given in Table I, Nos. 4 and 5. The rather high percentage of alkalies for rocks that are so basaltic and so low in SiO_2 will be noted. The norms show that both lavas are labradorite-andesine andesite, that analysed by diFranco being almost a basalt.

Von Lasaulx[27] describes several of the "terrace" lavas from the valley of the Sirmeto, along the southern border of the volcanic area, which appear to resemble our specimens very closely. Sartorius and von Lasaulx assign to the "terrace" lavas the flows at Aci Reale and the upper ones in the cliff below it.

A specimen from a flow 80 meters above sea level, on the zigzag road down to the Scala of Aci Reale, studied by us, is dark gray, with many phenocrysts of black augite, fewer and smaller ones of yellow olivine, and very few of feldspar, in a dense groundmass. The thin section shows rather small, stout tables of labradorite and many phenocrysts of the usual augite and olivine, in a groundmass made up of small thick feldspar tables, many grains of augite and of magnetite, and scarcely any olivine. The rock was not analysed, but it appears to be much more femic than those of the Sirmeto and Alcantara Valleys, and is almost certainly an olivine basalt.

The general character of the pedestal lavas, to judge from the examination of our few specimens and from the descriptions by von Lasaulx, is decidedly femic. The lavas would

[26] S. di Franco, Atti Accad. Gioenia, 5, Mem. 21, 1912.
[27] Der Aetna, 2, 446, 448.

seem to be prevailingly labradorite andesite or basalt, some of them approaching andesine andesite. Olivine is often present, although usually not in great quantity.

TABLE I. Pre-Etnean and Pedestal Lavas.

	1	2	3	4	5	6
SiO_2	51.20	46.26	49.27	49.30	49.25	47.18
Al_2O_3	18.38	15.63	15.89	19.62	17.47	15.21
Fe_2O_3	2.71	3.80	2.46	2.53	3.33	4.07
FeO	5.95	5.21	6.09	6.67	6.77	7.26
MgO	3.51	8.44	7.56	3.82	3.75	6.64
CaO	8.34	9.77	10.51	9.95	11.09	8.86
Na_2O	5.22	3.17	3.51	4.37	4.45	7.61
K_2O	2.23	0.56	1.62	1.75	1.42	1.41
H_2O+	0.27	3.89	0.13	0.11	0.18	0.72
H_2O-	0.05	0.20	0.01	0.02	....	0.72
CO_2	none	1.11	none	none	n.d.	n.d.
TiO_2	1.21	1.24	1.63	0.95	1.74	1.09
ZrO_2	0.01	n.d.	0.07	n.d.	n.d.	n.d.
P_2O_5	0.89	0.51	0.52	0.80	0.81	0.08
SO_3	0.09	n.d.	0.12	n.d.	n.d.	n.d.
Cl	n.d.	n.d.	0.01	n.d.	n.d.	n.d.
Cr_2O_3	none	n.d.	none	n.d.	n.d.	n.d.
MnO	0.14	0.11	0.15	0.09	n.d.	0.02
BaO	0.10	n.d.	none	n.d.	n.d.	n.d.
	100.30	99.90	99.48	99.98	100.26	100.15

NORMS

	1	2	3	4	5	6
Or	12.79	3.34	9.45	10.56	8.34	8.34
Ab	32.49	27.25	23.58	25.68	26.72	12.31
An	20.29	26.41	23.07	28.36	23.35	3.06
Ne	6.25	....	3.12	6.25	5.96	28.26
Di	12.74	14.76	20.51	12.84	21.36	33.03
Hy	....	2.00	....	....	....	....
Ol	7.00	11.93	11.45	8.79	4.15	6.27
Mt	3.94	5.57	3.48	3.71	4.87	6.03
Il	2.28	2.28	3.04	1.82	3.34	2.13
Ap	2.02	1.34	1.34	2.02	2.02	....

1. Andesine andesite, II.5″.(2)3.4. Grotta delle Palombe, below Aci Reale. Aurousseau analyst.
2. Andesine basalt (II)III.5.3(4).(4)5. Pillow lava, Aci Castello. Keyes analyst.
3. Olivine-labradorite basalt (II)III.5.3.4. Sorgente Jusu, below Aci Reale. Keyes analyst.
4. Andesine andesite, II.5″.3.4. Railroad Station, Paterno. Keyes analyst.
5. Andesine andesite, II(III).5″.3.4″. Valle del Petrolo, Alcantara Valley. Di Franco analyst. Atti Accad. Gioenia, 5, Mem. 21, 5, 1912.
6. Basalt, III.7.1″.(4)5. Serravalle, Val di Noto. Ponte analyst. Ponte, Atti Accad. Gioenia (5), 3, Mem. 10, 1910.

Lavas of the Central Cone.

The prehistoric lavas that make up the main cone of Etna are best exposed in the walls of the Val del Bove. These consist of successive flows, most of which are separated, the one from the other, by beds of ash or of coarse volcanic agglomerate. The flows are cut by numerous dikes, most of which are vertical or nearly so. The dikes vary in width from a few decimeters to 20 meters, the greater number being from 1 to 2 meters thick. A few have a glassy border. Sartorius traced some of the dikes for distances of over one kilometer, but most of them are visible for very short distances or are seen only at the edge shown in the caldera wall.

The prehistoric lavas are also exposed at the remnants of the Elliptical Crater, especially at Monte Curiazzo. They are also to be seen in the Cava Secca and in the Val San Giacomo, between Zafferana and the Val del Bove, and at other localities, but the Val del Bove is, by far, the best locality for their collection and study.

These prehistoric lavas are all andesite, and are referable to two chief kinds, oligoclase andesite and andesine andesite, with some transitional varieties. Sartorius[28] regards the former as the earliest in the central cone, because they form some of the lowest flows in the walls of the Val del Bove, and because most of the blocks of igneous rock brought up from below and included in recent flows are of oligoclase andesite. It was impossible for the senior author, during five visits to the caldera, to study adequately this matter of succession, and a projected lengthy stay in the caldera was prevented by the outbreak of the war. Cursory examination of many flows and dikes, however, indicated that andesine andesite is much more abundant than oligoclase andesite, and that the latter occurs more frequently as dikes than as flows. But flows of either kind are cut by dikes of the other. We may, for the present, accept the judgment of Sartorius, based on many and prolonged visits to the volcano, that oligoclase andesite (which he calls "Aetnean trachyte") is, on the whole, earlier than andesine andesite.

Oligoclase andesite. Representative specimens, which we have studied, are from: the striking complex of dikes and flows that form the Serra Gianicola Grande, in the upper (west) wall; the upper part of the small side valley, where

[28] Sartorius, Der Aetna, 2, 432.

there is a spring of water, southeast of and near the Rocca Piccola del Corvo, unnamed on Sartorius' map, but which may be called the Val dell' Acqua; a dike about 1.5 meters thick west of the mouth of the Val del Monaco, having a glassy border 10 centimeters thick and with a small glassy apophysis; dikes in the Rocca Capra, and dikes and flows in Monte Cerase. Blocks of similar rock occur near the Montagnola and at the explosion crater south of the Due Pizzi. A thick, dark gray dike in Monte Calanna also belongs here and is, apparently, a representative of the "greenstones" of Sartorius.

The oligoclase andesite lavas are, in most cases, readily distinguishable in the field from the andesine andesites by their lighter color, their fine grain and rough feel, and by the presence, in many of them, of phenocrysts of white feldspar with few or none of augite or olivine. Some of the dikes of this rock, as one in the Val dell' Acqua and another in the Rocca Capra, show a marked platy parting parallel to the walls.

These lavas are divisible into two groups, those with and those without phenocrysts of feldspar. Inasmuch as the two varieties are much alike chemically and minerally, and as the aphyric variety is practically identical with the groundmass of the phyric lavas, they may be described together.

These rocks are light to medium gray, few of them dark gray, dense and without vesicles, and with a rough, trachytic feel. The feldspar phenocrysts, when present, are glassy white and conspicuous, up to about one-half a centimeter in diameter. Small phenocrysts of black augite are very rare, olivine is not seen, and hornblende is very rare in our specimens, although von Lasaulx states that it is rather common. In the groundmass there are usually visible small feldspar laths, shown by their sheen in reflected light.

The microscopic texture is eminently trachytic, which is best developed in the aphyric specimens. The highly euhedral feldspar phenocrysts are tabular, simply twinned according to the albite and Carlsbad laws, not zoned, and without inclusions. They are mostly oligoclase, about Ab_3An_1. The groundmass is composed in great part of very small, thin, simply twinned, laths of oligoclase, of the average composition Ab_4An_1. These and the larger feldspars show a marked flow texture in most of the specimens. Very small granules of colorless augite and of magnetite are not abundant, olivine is wanting, and small grains of brown hornblende are present in a few specimens. There is usually a little colorless glass but no nephelite. The thin apophysis of the dike near the Val del Monaco, both the dike and the apophysis being of the phyric variety, shows in this groundmass many thin laths of oligoclase, Ab_4An_1, in a slightly mottled, dark brown glass.

Three analyses of the feldspar phyric variety, and one of the aphyric, are given in Table IIa. The first three are much alike and indicate the general uniformity of this type of lava. They are clearly analyses of very feldspathic andesite, so high in potash that they might well be called trachyandesite. The small glassy apophysis has a composition much like that of the parent dike, except that it is slightly more femic and shows a higher ratio of Fe_2O_3 to FeO than does the dike, which also contains considerable glass. The aphyric variety, the analysed specimen of which is rather dark gray, is distinctly lower in SiO_2 and is otherwise more femic, as is to be expected from the absence of oligoclase phenocrysts and the consequently greater relative amount of pyroxene and of magnetite.

A variety transitional to the andesine andesites is represented by a specimen from a massive flow at the base of Monte Zoccolaro, inside the Val del Bove, which may be the same as that described by von Lasaulx (2, 449).

This basal Zoccolaro lava is light reddish gray, fine-grained, with some very small and inconspicuous phenocrysts of feldspar and fewer of augite, in a dense aphanitic groundmass. The microscopic appearance is much like that of the andesine andesites, the texture being basaltic instead of trachytic. The tabular feldspar phenocrysts are of andesine, about Ab_2An_1, while the groundmass laths are somewhat more sodic. There is a little glass. The analysis (No. 5 of Table IIa) resembles that of the aphyric oligoclase andesite, the chief differences being the lower SiO_2 and the higher Al_2O_3 in the Zoccolaro rock. The small amount of normative hematite is connected with the reddish color of the rock. This lava may be called oligoclase-andesine andesite.

Andesine andesite. As has been said above, the greater number of the flows and dikes of the central cone are referred to andesine andesite. These differ from the oligoclase andesite lavas by their generally darker color and by the more frequent and more abundant presence of augite phenocrysts. They are of typically andesitic habit, and lack the trachytic feel of the more sodic lavas, produced by the small parallel feldspar laths in the groundmass. Many of the dikes of andesine andesite show columnar structure, few or none being platy. Their micro-texture is decidedly andesitic, trachytic flow texture being seen in few specimens. In megascopic habit the andesine andesites are much more varied than are the oligoclase andesites, but only a few of the various types will be described here. The analyses will be discussed together.

In a frequently occurring type there are very many feldspar phenocrysts, which are usually small laths and not very prominent; with which are fewer, but often larger, phenocrysts of black augite. This type is represented by a specimen from a thick dike, with marked columnar structure, at the northwest foot of Zoccolaro, and by one from a dike in the south wall of Val del Bove, east of the small lava cataract at Poiareddu; both of these rocks have been analysed. Other specimens are from the lava flow that is quarried behind the church of Zafferana; from some of the flows at Monte Curiazzo, part of the "Elliptical Crater," near the terminal cone; and from a flow at the summit of Monte Calanna. Others come from now indeterminable flows and dikes.

These rocks are mostly medium gray, the small (2-3 mm.) inconspicuous feldspar tables and laths glimmering in an aphanitic groundmass. Black augite phenocrysts are not abundant, and none of olivine are visible. In thin section the sharp, highly euhedral and much twinned feldspar phenocrysts are seen to be of andesine, varying in composition from about Ab_2An_1 to Ab_3An_2, in some cases more calcic. They are not zoned and many contain inclusions of brown glass, which are mostly rod-like and arranged parallel to the side pinacoid. These inclusions are generally grouped toward the center, leaving a narrow clear border. The nearly colorless, fresh augite crystals call for no special remark. There are often some smaller, subhedral micro-phenocrysts of fresh olivine, but crystals of hornblende were seldom seen, although von Lasaulx speaks of this mineral as abundant. The groundmass is made up for the most part of very small laths of feldspar, more sodic than the phenocrysts, and usually diversely arranged. There are also many very small grains of colorless augite and of magnetite, with very few small grains of olivine. A little glass, usually colorless, is often present.

A specimen from a dike in the south wall of the caldera, east of Poiareddu, may be taken as typical of this variety with small and inconspicuous feldspar phenocrysts; an analysis of this is given in No. 8 of Table IIb. A specimen of almost identical chemical composition (No. 9 of Table IIb) is from a narrow dike in the Val dell' Acqua. This differs, however, from the general type in the abundance and size of the feldspar phenocrysts, which are very conspicuous, white, equant, and from 2 to 5 mm. in diameter. In the micro-groundmass there are many small tables of oligoclase-andesine, with hardly any augite or magnetite, but there is much dusty, slightly brownish glass.

A specimen from a thick columnar dike on the inner northwest foot of Zoccolaro, a short distance inside the Val del Bove, is of the general type, but it contains a few phenocrysts of black hornblende, some of them one or two centimeters long. This is the only specimen that we have in which phenocrysts of this mineral are seen. An analysis of it, but including no hornblende phenocrysts, is given in No. 7 of Table IIb. It is notably higher in SiO_2 than the general type, and its analysis much resembles that of the aphyric oligoclase andesite of Serra Gianicola (No. 4, Table IIa).

A somewhat different variety is found at a thick dike at the east foot of Zoccolaro, between it and the flow of 1852, on the property (in 1914) of Alfio Brischetto. In this, many black augites, only about one millimeter in diameter, with few feldspar phenocrysts, are scattered through a very light gray, aphanitic groundmass. The micro-texture is like that of the others, but some small olivines are present, and there is a tendency to trachytic texture. The analysis (No. 6 of Table IIb) greatly resembles those of the columnar dike inside Zoccolaro and that of the flow at its base, as well as that of the aphyric oligoclase andesite.

A variety that seems to be abundant shows many rather prominent phenocrysts of augite and feldspar in a medium to dark gray, aphanitic groundmass. The micro-texture is like that of the preceding. This variety is represented by specimens from the south end of Monte Curiazzo (the largest remnant of the Elliptical Crater), from Monte Cerase (on the north wall of the caldera) and from other localities. No analysis was made of this type, but it would appear to be rather more femic than any of the preceding.

A final variety, apparently not very abundant, is represented by a specimen from the Punta Lucia, at the north end of Monte Curiazzo, apparently a flow. This is very dark gray and basaltic-looking, wholly aphyric and of very fine grain. The thin section shows that the rock is composed very largely of small, thick-tabular micro-phenocrysts of andesine, about Ab_2An_1, with very few of augite and none of olivine. The micro-groundmass is feldspar-free, made up of minute granules of colorless augite and of magnetite, with some colorless glass. The thin section and the analysis (No. 10 of Table IIb) show that this lava is lower in SiO_2 and otherwise more femic

TABLE IIa. Prehistoric Lavas of Etna.

	1	2	3	4	5
SiO_2	58.12	58.36	58.22	54.34	54.81
Al_2O_3	18.54	18.39	17.94	17.94	19.91
Fe_2O_3	1.90	1.81	3.39	2.69	3.63
FeO	4.21	3.64	2.82	5.60	3.11
MgO	1.87	0.79	1.05	2.76	2.75
CaO	4.92	5.02	5.03	6.08	6.71
Na_2O	5.82	5.88	5.57	5.52	5.43
K_2O	2.81	2.78	2.81	2.80	2.29
H_2O+	0.11	0.84	1.00	0.10	0.21
H_2O-	0.07	0.09	0.16	0.02	0.06
TiO_2	1.25	1.24	1.42	1.90	1.40
ZrO_2	n.d.	n.d.	n.d.	0.05	n.d.
P_2O_5	0.67	0.83	0.58	0.47	0.17
S	n.d.	n.d.	n.d.	0.07	n.d.
Cr_2O_3	n.d.	n.d.	n.d.	none	n.d.
MnO	0.16	0.16	0.15	0.15	0.10
BaO	n.d.	n.d.	n.d.	0.16	n.d.
	100.45	99.83	100.14	100.65	100.58

NORMS

	1	2	3	4	5
Q	1.08	3.12	6.06	....	....
Or	16.68	16.68	16.68	16.68	13.34
Ab	49.25	49.78	47.16	41.92	44.54
An	15.85	15.29	15.29	15.57	23.07
Ne	....	....	....	2.56	0.85
Di	3.22	3.25	2.41	9.77	7.37
Hy	7.33	3.91	1.73	....	....
Ol	....	....	....	5.32	2.72
Mt	2.78	2.55	4.87	3.94	5.34
Il	2.43	2.28	2.74	3.65	2.74
Ap	1.68	2.02	1.34	1.01	0.34

1. Oligoclase andesite, "II.5.2".4, (phyric). Flow above spring, Val dell' Acqua. Aurousseau analyst.
2. Oligoclase andesite (I) II.5.2.4, (phyric). Dike, Val del Monaco, Val del Bove. Aurousseau analyst.
3. Oligoclase andesite (I)II."5.2".4, (vitrophyric). Apophysis from No. 2. Aurousseau analyst.
4. Oligoclase andesite, II.5.2".4, (aphyric). Serra Gianicola, Val del Bove. Keyes analyst.
5. Oligoclase-andesine andesite, II.5."3.4. Flow, Base of Zoccolaro, Val del Bove. Keyes analyst.

than any of the others, so that it is almost a basalt rather than an andesite. In the norm, there is a very marked diminution in the amount of anorthite, and a similar increase in diopside and magnetite, these, and the low figure for olivine, being consonant with the mode as shown in thin section.

In the prehistoric lavas of Etna as a whole there is evident a rather remarkable progression, chemically and normatively,

TABLE IIb. Prehistoric Lavas of Etna.

	6	7	8	9	10
SiO_2	54.37	53.29	51.05	50.97	48.90
Al_2O_3	18.35	19.14	20.97	20.96	16.20
Fe_2O_3	2.62	5.63	1.66	1.17	7.01
FeO	4.56	2.43	5.69	4.50	4.98
MgO	3.22	3.32	2.70	3.07	5.13
CaO	7.15	7.41	8.70	8.70	9.37
Na_2O	5.23	4.74	4.44	4.42	4.60
K_2O	1.98	2.41	2.06	1.91	1.65
H_2O+	0.13	0.18	0.28	0.30	0.32
H_2O-	0.08	0.16	0.14	0.10	0.06
TiO_2	2.06	1.13	1.44	2.22	1.40
ZrO_2	n.d.	n.d.	n.d.	n.d.	0.04
P_2O_5	0.12	0.59	0.61	1.06	0.85
S	n.d.	n.d.	n.d.	n.d.	0.09
Cr_2O_3	n.d.	n.d.	n.d.	n.d.	trace
MnO	0.09	0.12	0.11	0.11	0.13
BaO	n.d.	n.d.	n.d.	n.d.	0 07
	99.96	100.55	99.85	99.49.	100.80

NORMS

	6	7	8	9	10
Or	11.68	14.46	12.23	11.12	10.01
Ab	44.01	39.82	31.96	37.20	30.92
An	20.85	23.62	28.36	31.97	18.63
Ne	....	....	2.53	....	4.26
Di	11.15	7.34	9.15	3.80	17.63
Hy	....	2.53	....	....	....
Ol	4.09	1.85	7.85	6.28	3.88
Mt	3.71	4.41	2.32	1.62	10.21
Il	3.95	2.13	2.74	4.26	2.74
Hm	....	2.56	....	....	....
Ap	0.34	1.34	1.34	2.35	2.02

6. Andesine andesite, II.5."3.4. Dike, East of Zoccolaro, Val del Bove, Keyes analyst.
7. Andesine andesite, II.5.3.4. Dike, Inside Zoccolaro, Val del Bove. Aurousseau analyst.
8. Andesine andesite, II.5.3.4. Dike, East of Poiareddu, Val del Bove. Aurousseau analyst.
9. Andesine andesite, II.5.3.4. Dike, Val del Acqua, Val del Bove. Keyes analyst.
10. Andesine basalt-andesite, II(III).5"."3.4. Flow, Punta Lucia, Elliptical Crater. Aurousseau analyst.

Fig. 6. Upper (west) end of Val del Bove. Edge of Elliptical Crater plain above; double flow (dark) of 1869 on right of slope; lava of 1852 on right of valley floor; dark flow of 1910, with two dagalas, on extreme left; Serra di Gianicola to right of this. Photograph by Arthur L. Day, 1914.

as shown by Tables IIa and IIb, and also modally. There are also indications of grouping; at one end the well-marked variety of the phyric and aphyric oligoclase andesites, these being connected by some transitional forms with the feldspar-phyric andesine andesites, which are also fairly well marked. The more femic end seems to be less well characterized, and the most femic basalt-andesites do not seem to be abundant.

RECENT LAVAS.

The recent lava flows of Etna are very numerous. Sartorius[29] enumerates 3 that are prehistoric, 6 of Greek, Roman, and Norman times, 21 of uncertain dates in the 10th to the 18th centuries, and 53 of eruptions of definitely known dates from 693 B. C. to 1879, besides "hundreds" of remnants of flows of entirely unknown date.

Von Lasaulx[30] describes them under two main groups: plagioclase-rich lavas, with little augite, and those with much of both plagioclase and augite, a few being very rich in augite and magnetite and others being glassy. Some of the modern lavas, from 1883 to 1911, have been described, with analyses, by Lacroix,[31] Ponte,[32] and Starrabba.[33]

According to Sartorius the pahoehoe form of flow prevails among the lavas of Etna, although the aa form is also seen. It appeared, however, to Doctor Day and to the senior author, that the aa form was, by far, the more prevalent among the recent flows, though there were patches of pahoehoe here and there. All our specimens show the irregular, aa form of vesicle; none of them the more spherical and smaller form of pahoehoe.

In connection with the description of the recent lava flows the occasion may be taken to revive and introduce into modern volcanological literature a term much used by Sartorius. This is "dagala," the local term for an area surrounded, but not covered, by a lava flow—a sort of island in the stream. (Fig. 6.) The corresponding Hawaiian term is "kipuka." "Dagala" has priority over "kipuka," as it was used by Gem-

[29] Sartorius, Der Aetna, **2**, 398.
[30] Von Lasaulx, Der Aetna, **2**, 452-460.
[31] Lacroix, Compt. Rend. Acad. Sci., **147**, 99, 1908.
[32] Ponte, Mem. Accad. Lincei, **8**, 663, 1911; Rend. Accad. Lincei, **21**, 209, 1912.
[33] Starrabba, Atti Accad. Gioenia, **88**, Mem. 22, 1911.

mellaro[34] and Sartorius[35] years before the Hawaiian term was introduced into the literature.[36]

Most of the recent Etnean lavas are very uniform in character, but they may be referred to two main groups: oligoclase andesite, which is very feldspathic, and andesine basalt, with considerable augite. Flows of the latter are much the more numerous of the two. This division corresponds, in general, to that adopted for the prehistoric lavas of the central cone, both as to mineral composition and as to relative abundance. As being the more abundant the andesine basalts will be described first.

Andesine basalt. As typical of the recent basaltic lavas of Etna there may be considered those of the eruptions of 1669, 1787, 1792, 1811, 1838, 1852, 1886, 1892, 1910, and 1911, specimens of which we have studied.[37] These are supplemented by the descriptions of other flows by von Lasaulx and others.

These basalts are, on the whole, fairly uniform, though several varieties may be distinguished. Different parts of the same flow, such as that of 1910, may, however, exhibit different varieties. The descriptions that follow apply, in almost all cases, to specimens from the non-vesicular interior of the flow.

A variety with many conspicuous augite phenocrysts, with very few of feldspar, is that of the lava of 1669, the specimen studied coming from the large quarry behind the electric light plant in Catania. The greenish black augites, from 2 to 5 mm. long, are scattered through a light gray, densely aphanitic groundmass. A few small, yellow olivines and small feldspar laths are visible. In thin section the fresh euhedral augite phenocrysts are pale yellowish gray, nonpleochroic, and contain some inclusions of magnetite but none of feldspar. The tabular feldspar phenocrysts, about Ab_1An_1, are twinned mostly according to the Carlsbad law, and contain many very small glass inclusions, which are for the most part clustered toward the center, with a clear border. The few,

[34] Gemmellaro, La Vulcanologia dell'Etna, Catania, 146, 1858.

[35] Sartorius, Der Aetna, 2, 162, 217, 284, 285, 288, etc. The term was used by the senior author in editing Perret's "Vesuvius eruption of 1906," Carnegie Publ. No. 339, 75, 1924.

[36] "Kipuka" has been used by Jaggar in recent volumes of the Bull. Hawaiian Volc. Observatory, e. g. 8, 74, 1920, although elsewhere (e. g. 7, 133, 1919) he uses "island." I do not find the word used in the writings of Green, Dutton, Dana, Brigham, Hitchcock, or Bryan.

[37] A specimen of the 1908 flow is lost.

small, rounded, olivine phenocrysts are perfectly fresh. The groundmass is composed of very small feldspar laths, about Ab_3An_2, with grains of augite and magnetite, but no olivine. There is no flow texture, and nothing approaching ophitic or intersertal texture. A little colorless glass may be present. An analysis of this lava is given in No. 1 of Table III. The lava of 1911, collected where the flow crosses the main road in the Contrada Solecchiata, is much like that of 1669. This variety appears to be not very abundant, although von Lasaulx speaks of it as being the most usual variety. To it he assigns the flows of 1852, 1863, and 1865, although our specimens of that of 1852 belong rather to another variety.

The variety which appears to us to be that most often met with is represented by specimens of the flows of 1787, from the quarry near the observatory; of 1811, from near Rocca Capra; of 1838, from west of the terminal cone; of 1886, from near Nicolosi; and much of the 1910 flow. This variety corresponds apparently with most of the examples of the plagioclase-rich variety of von Lasaulx, others belonging to the oligoclase andesites.

This variety is dark gray, with many small (1-2 mm.), glistening but inconspicuous tables of feldspar, but no or very few crystals of augite or olivine, in a dense aphanitic groundmass. The specimen of the 1811 flow contains some small olivines. In thin section the abundant feldspar (Ab_1An_1) phenocrysts are as in the preceding variety, but there are few of augite and practically none of olivine, except in the 1811 flow. The groundmass is very fine-grained and in most specimens appears almost opaque, with very many small laths of andesine (Ab_3An_2) scattered through it. High powers resolve the darker groundmass into an aggregate of minute augite and magnetite grains, as is the composition of the more crystalline, with a little dark glass in some cases. There is seldom olivine in the groundmass. An analysis of the lava of 1910 is given in No. 3 of Table III.

A third variety is represented by specimens of the flow of 1792, from near the Rocca Piccola del Corvo, and from the small lava cascade of this flow between Poiareddu and the caldera wall. These resemble the preceding as regards the abundance, size, and appearance of the feldspar phenocrysts, and the virtual absence of those of augite and olivine; but the groundmass, megascopically, is much darker, almost black, and much denser. The thin sections show the usual feldspar

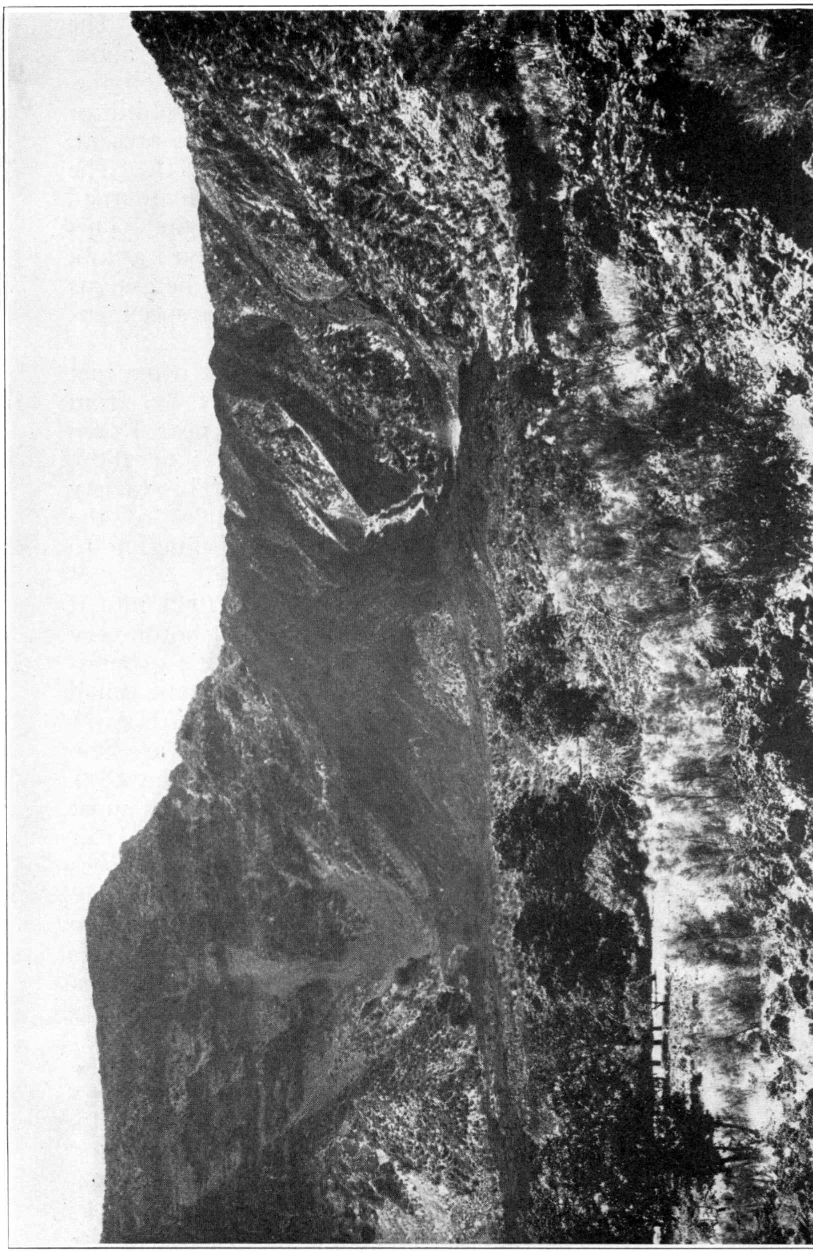

Fig. 7. Cascade of lava of 1852, over the Salto della Giumenta, between Monte Zoccolaro (left) and Monte Calanna (right), into the Valle di Calanna. Dagala at foot of main cascade. Photograph by Arthur L. Day, 1914.

phenocrysts, with small glass inclusions, but few phenocrysts of augite or olivine. The groundmass is formed of opaque, dark brown glass, irresolvable under high powers, which contains many very small laths of andesine or oligoclase-andesine. It is evident that nearly all the augite and magnetite is uncrystallized and exists in the dark glass. This variety is a highly vitreous form of the second variety, and is the "glasreich" variety of von Lasaulx, who also cites the lava of 1792 as an example. The lava of 1892, from the lowest Monte Silvestri, belongs here, though it contains more phenocrysts of augite. Specimens of the 1852 flow (Fig. 7) are also similar, but the very vitreous base is somewhat more easily resolvable. An analysis of the lava of 1792 is given in No. 2, Table III.

What may be a distinct variety is found in the vesicular, upper parts of the flow of 1910. This shows rather many and fairly large, up to 5 mm. long, phenocrysts of andesine and some of black augite in a medium gray aphanitic groundmass. The thin sections closely resemble those of other specimens from the same flow. The vesicles are large and irregular—of the aa form. This variety may indicate a different set of conditions of crystallization in the upper part of the flow, or else the rising of the larger feldspar crystals through the liquid. Study of this variety in the field would be of interest.

In their general characters these andesitic and basaltic lavas are very uniform, much more so than the corresponding prehistoric flows. According to the classification adopted by us, some of them are andesite and some basalt, but in either case the one is transitional toward the other group, as is shown by the symbols given with the analyses. The nephelite molecule is present in the norm of all the analyses of these lavas, although none of this mineral could be detected in the thin sections, nor was it observed in crevices. Although a small amount of the olivine molecule is likewise present in all the norms, and a little of this mineral is seen in many of the specimens, yet none of these lavas contains enough to entitle it to be called olivine basalt or olivine andesite.

A word as to the earlier analyses of these lavas, such as those by Pisani, Ponte, and Starabba, two of which are given in Table III. With about the same general amounts of SiO_2 Fe_2O_3, FeO, CaO, Na_2O, K_2O, and TiO_2, they are all consistently higher than ours in Al_2O_3, and lower in MgO and especially in P_2O_5. The low P_2O_5 is unquestionably erroneous, as the abundance of apatite in these lavas, as well as in the prehistoric ones, is noted by von Lasaulx, and is indicated by our analyses. As to the other two constituents, it would appear that, in general, the magnesia has not been entirely separated from the alumina by a sufficient number of reprecipitations and in the presence of sufficient ammonium chloride, a point to which attention has frequently been called.

Nephelite-oligoclase andesite. Very few of the recent lavas of Etna are of oligoclase andesite. We have only one specimen that belongs here, which is remarkable among the lavas of this volcano in containing a notable quantity of nephelite. This is a specimen of the flow of 1329, or possibly 1333,[38] from Monte Rosso, near Fleri, on the road from Catania to Zafferana. Some of the recent lavas described by von Lasaulx, especially a flow of 122 B. C. and a lava of unknown, but early, date, at Linguaglossa, are apparently oligoclase andesite, as they have a trachytic flow texture, are of a very light gray color, and are said to resemble the oligoclase trachytes of the Val del Bove. It cannot be told, from the descriptions by von Lasaulx, whether these lavas contain nephelite. When he studied them it was too early in the use of the microscope to permit of the easy or certain determination of this mineral as a constituent of the base of the groundmass.

The specimen of the 1329 lava is compact and shows many small (1-3 mm.) tables of glistening white feldspar, with very few of augite and rare and small grains of olivine, in a densely aphanitic, very light gray groundmass. Under the microscope the feldspar phenocrysts are seen to be of oligoclase, about Ab_4An_1, simply twinned and with few glass inclusions. Microphenocrysts of augite are very few, and there are none of olivine. The fine-grained groundmass is composed mostly of small laths of oligoclase, with some grains of augite and magnetite, in a colorless base, which resembles glass, but which staining shows to be nephelite, at least in great part. A trachytic flow texture prevails in much of the section.

An analysis of this lava is given in Table III, No. 4. This agrees well with the appearance of the rock in thin section, as far as the feldspar, augite, olivine, and ores go, but the amount of normative nephelite appears to be rather higher than the modal. Small quantities of nephelite, however, appear in the norm of many Etna lavas, among them in all the analysed recent flows, although it is not visible in thin section. Also,

[38] Sartorius, Der Aetna, 1, 217; 2, 162.

it is difficult to estimate the actual percentage of such residual nephelite in the rock.

The name "nephelite-oligoclase andesite" is given to this Etna type because of its highly feldspathic and salic character, and because of the subordinate role of the nephelite. According to all the text-books, a lava composed of lime-soda feldspar and nephelite, with augite, etc., is a nephelite tephrite. In the case of these rocks, no special attention has been paid, even by Iddings,[39] to the quantitative relations between the modal felsic and mafic minerals, or the normative salic and femic molecules. Nor has any place been provided for rocks that contain oligoclase as the only lime-soda feldspar. The occurrence of oligoclase in these rocks has occasionally been vaguely recognized by such names as "trachyte tephrite" or "tephritic trachyte." But the usual concept of a "nephelite tephrite" is of a rock that falls in salfemane or, if in dosalane, in which the feldspar is andesine or, most often, labradorite. It would seem to be a logical following out of the principles of the classification of the plagioclase-augite lavas—andesites and basalts—suggested by Iddings and adopted in this and in other papers, to apply the same principle to such lavas which contain nephelite as well. This is not the place for an adequate discussion of the topic, but it was for such reasons that these Etna lavas have been called by us "nephelite-oligoclase andesite," rather than "nephelite tephrite."

General characters. The general characters of the recent lavas of Etna are fairly evident from the descriptions and analyses given in the preceding pages and from those given by other petrographers.

An overwhelming proportion of the lavas of the last few hundred years are andesine andesite or andesine basalt, probably most of them the latter. Some of them contain labradorite as phenocrysts and in some the average normative feldspar may be labradorite, but our specimens indicate that the average normative feldspar is, in general, andesine. Also, inasmuch as some of the normative anorthite molecule enters modal augite, the average modal feldspar will be more albitic than the normative. Although small amounts of olivine are present in the norms and often some modal olivine, yet none of these lavas, so far as is known, is so high in olivine as to be called olivine basalt. These lavas are very uniform in character, the varieties noted above being due chiefly or wholly

[39] Iddings, Igneous Rocks, 2, 267, 1913.

to differing conditions in cooling and in solidification. Indeed, so uniform are they chemically and modally, that only a few analyses were deemed to be necessary to represent them.

A very much smaller number of the flows are of oligoclase andesite, which resemble the lavas of this kind in the Val del Bove. Nephelite is present in some of these recent lavas, but

TABLE III. Recent lavas of Etna.

	1	2	3	4	5	6
SiO_2	49.62	48.53	48.46	50.10	49.75	49.22
Al_2O_3	16.00	17.94	15.92	18.83	18.30	18.49
Fe_2O_3	2.81	2.82	3.42	2.70	2.85	2.91
FeO	7.61	6.89	8.00	5.52	6.28	6.87
MgO	5.20	4.23	5.05	2.79	3.45	3.85
CaO	10.25	9.99	10.09	8.09	9.76	10.21
Na_2O	4.12	4.45	4.13	6.97	4.96	4.91
K_2O	1.46	1.62	1.61	2.24	1.89	1.39
H_2O+	0.22	0.04	0.01	0.02	0.40	0.09
H_2O-	0.07	0.08	0.03	none	....	....
TiO_2	1.64	2.27	2.03	1.97	2.45	2.00
ZrO_2	none	n.d.	none	n.d.	n.d.	n.d.
P_2O_5	0.62	0.56	0.65	0.67	0.03	0.03
SO_3	0.05	n.d.	0.14	n.d.	n.d.	n.d.
Cr_2O_3	none	n.d.	none	n.d.	n.d.	n.d.
MnO	0.13	0.11	0.18	0.13	n.d.	n.d.
BaO	0.09	n.d.	0.09	n.d.	n.d.	n.d.
SrO	0.03	n.d.	n.d.	n.d.	n.d.	n.d.
	99.92	99.53	99.81	100.03	100.12	99.97

NORMS

	1	2	3	4	5	6
Or	8.90	9.45	9.45	12.79	11.12	8.34
Ab	27.25	25.68	25.68	33.01	23.58	23.58
An	20.85	23.91	20.29	13.62	21.96	24.19
Ne	3.98	6.53	4.83	14.20	9.94	9.66
Di	21.54	18.11	20.24	17.87	22.37	21.61
Ol	8.46	6.09	8.50	2.21	2.08	4.39
Mt	4.18	4.18	4.87	3.94	4.18	4.18
Il	3.19	4.41	3.80	3.80	4.71	3.80
Ap	1.34	1.34	1.68	1.68	....	....

1. Andesine basalt (II)III.5″.3.4. Lava of 1669, Catania, Washington analyst.
2. Andesine andesite, II″.5(6).3.4. Lava of 1792, Val del Bove. Keyes analyst.
3. Andesine basalt (II)III.5″.3.4. Lava of 1910, above Nicolosi. Washington analyst.
4. Nephelite-oligoclase andesite, II.6.2.4″. Lava of 1329, Monte Rosso, near Fleri. Keyes analyst.
5. Andesine basalt, II.5(6).3.4. Lava of 1908, Pisani analyst. Lacroix, C. R. Acad. Sci., **147**, 102, 1908.
6. Andesine basalt, II″.5(6).3.4″. Lava of 1910, Monte Recupero. Ponte analyst. Ponte, Mem. Accad. Lincei, **8**, 679, 1911.

does not seem to occur in the corresponding prehistoric flows. Few specimens of this variety have been studied, but here also there appears to be general uniformity. There is slight indication that the oligoclase lavas are more frequent among the earlier flows, as they may be (according to Sartorius) in the case of the prehistoric lavas. But much more study of all the datable flows is needed to decide this point.

Summary and Conclusions.

The lavas of Etna, including the pre-Etnean volcanoes, are remarkably uniform, especially for such a huge volcano. The pre-Etnean lavas are mostly olivine-labradorite basalt, with some olivine-free andesine andesite. The earliest, "pedestal" lavas greatly resemble the pre-Etnean, but they contain less olivine and seem to be, on the whole, more andesitic. Among the prehistoric lavas that make up the main bulk of the cone there is more diversity. The greater number of the flows and dikes are of olivine-free andesine andesite, which is somewhat variable, the SiO_2, for instance, running from 54.4 to 48.9, that is, from the silicity of a typical andesite down to that of a basalt. A smaller number are of oligoclase andesite, also olivine-free, with trachytic texture, and with about 58 per cent of SiO_2. There are transition forms between these two main types. The recent lavas, poured out since the formation of the Val del Bove caldera and the axial shift from the Trifoglietto to the present site, appear to be overwhelmingly andesine basalt, either with very little olivine or quite free from this mineral. They are of very uniform characters, some slight modal and textural differences being brought about by local variations in the conditions of cooling of the flows. A small proportion of the recent flows is of oligoclase andesite, one of which contains nephelite.

The general character of the Etnean lavas, including the pre-Etnean, is shown in the average composition (Table IV, No. 1), which is based on the 18 analyses made by us. With it are given for comparison the averages of the lavas of Hawaii Island,[40] of the Deccan traps (representing the plateau basalts),[41] and of Daly's "average basalt."[42] These are all calculated to a water-free basis.

[40] Washington, this Journal, 6, 361, 1923.
[41] Washington, Bull. Geol. Soc. Amer., 33, 797, 1922.
[42] Daly, Igneous Rocks and their Origin, 27, 1914. For a criticism of this average see: this Journal, 12, 352, 1926.

TABLE IV. Averages of the lavas of Etna, etc.

	1	2	3	4
SiO_2	51.91	49.73	51.68	49.65
Al_2O_3	18.16	13.71	13.83	16.13
Fe_2O_3	3.09	2.92	3.25	5.47
FeO	5.37	8.64	10.13	6.45
MgO	3.90	8.27	5.57	6.14
CaO	8.36	9.10	9.65	9.07
Na_2O	4.85	3.16	2.65	3.24
K_2O	2.00	1.02	0.73	1.66
TiO_2	1.61	2.84	1.95	1.41
P_2O_5	0.62	0.48	0.40	0.48
MnO	0.13	0.13	0.16	0.30
	100.00	100.00	100.00	100.00

1. Average of the lavas of Etna: 18 analyses.
2. Average of the lavas of Hawaii Island: 56 analyses.
3. Average of the Deccan traps: 11 analyses.
4. Average of "basalt" (Daly): 161 analyses.

The average Etna lava, whose symbol is II.5.3.4, is clearly andesitic, as is shown by the high Al_2O_3, Na_2O, and K_2O, the rather high SiO_2, and by the calculated norm (not given here). It is much more salic and alkalic than the Hawaiian and Deccan averages, and also more so than the "average basalt" of Daly. TiO_2 is much lower than at Hawaii, while P_2O_5 is much higher. Indeed, so alkalic are the lavas of Etna that Rosenbusch refers them to the trachydolerites.

The occurrence of nephelite-oligoclase andesite as an early flow (1329) is of interest because it indicates the prevailingly sodic tendency of the Etna lavas. In line with this is the presence of the nephelite molecule in the norm of nearly all the Etna lavas, except the oligoclase andesites, in which the high silica forbids its presence, even the recent flows of basalt showing from 4 to 6.5 per cent in the norm, although none was detected in the rock.

Leucite was reported by Johnston-Lavis[43] as present in an Etna lava, but Platania,[44] in a recent paper shows that this is most probably an error, due to interchange of labels with a Vesuvius lava. Platania[44] and Ponte[45] also point out that Dittler's[46] reported discovery of leucite in the ash of the 1911 eruption is also an error. Ponte found none in his study of this ash.

Augite, and less olivine, are the most abundant mafic

[43] Johnston-Lavis, Boll. Soc. Ital. Microsc., Acireale, 1, 26, 1888.
[44] Platania, Pubb. Ist. Geog. Fis. Catania, No. 21, 1922.
[45] Ponte, Rend. Accad. Lincei, 21, 209, 1912.
[46] Dittler, Centralbl. Min. Geol., 691, 1911.

minerals. An analysis of the augite, found as loose crystals at Monti Rossi, near Nicolosi, from the eruption of 1669, has been published elsewhere, with a statement of its optical characters.[47] The analysis, and its norm, calculated as if the mineral were a rock, are given here for more ready reference. The analysis, calculated to 100 per cent as free from 4 per cent of magnetite, is as follows: SiO_2 50.09, TiO_2 2.11, Al_2O_3 3.71, Fe_2O_3 1.47, FeO 4.96, MnO 0.21, MgO 14.01, CaO 22.48, Na_2O 0.73, K_2O 0.01, H_2O+ 0.22. The norm of this is: Ab 0.52, An 6.67, Ne 3.12, Di 82.55, Ol 0.76, Mt 2.09, Il 3.95. It will be noted that about ten per cent consists of salic molecules, chiefly anorthite and nephelite.

It has been noted in preceding pages that von Lasaulx found hornblende to be present in many of the prehistoric lavas of Etna, although in small quantity, whereas it was seen in few of our specimens. The occurrence of hornblende at Etna has been studied by di Franco,[48] who describes it in seven lavas, pre-Etnean, prehistoric, and recent. His analysis of a large crystal of hornblende in a prehistoric andesite (?) at Milo, on the east slope, is as follows: SiO_2 40.10, TiO_2 2.05, Al_2O_3 14.71, Fe_2O_3 9.60, FeO 4.83, MgO 11.64, CaO 12.13, Na_2O 4.07, K_2O 0.78, H_2O 0.58, Sum 100.49. Specific gravity = 2.97. These hornblendes are pleochroic in brown and yellow, and in this respect and in their high soda content they are intermediate between barkevikite and basaltic hornblende. In the paper cited above Platania reports the occurrence of the sodic amphibole, riebeckite, in an Etna lava. Biotite seems never to have been certainly observed as a constituent of Etnean lavas.

The markedly andesitic, or rather trachyandesitic to trachybasaltic,[49] character of the lavas of Etna, as shown by the work of von Lasaulx and by the preceding descriptions and analyses, is in great contrast with the view generally held that they are chiefly basaltic.[50] This idea is prevalent because the recent lavas, which are mostly basalt, have been most often described and are better known than the earlier and more abundant andesitic ones.

[47] Washington and Merwin, this Journal, 1, 27, 1921.

[48] Di Franco, Atti Accad. Gioenia, 6, Mem. 3, 1911.

[49] The term "trachybasalt" is used by us, rather than "trachydolerite," in accordance with the recommendation of the Committee on British Petrographic Nomenclature (Min. Mag., 19, 144, 1920), although no modal orthoclase is visible.

[50] Iddings, Igneous Rocks, 2, 556, 1913; Mennell, Manual of Petrology, 159, 1913; von Wolff, Der Vulkanismus, 1, 149, 1914; Daly, Igneous Rocks and their Origin, 423, 1914; Artini, Le Rocce, 370, 1919.

A progressive change in general chemical characters has been noted along certain comagmatic volcanic lines, such as that of the leucitic volcanoes of western Italy[51] and that of the Hawaiian Islands.[52] The andesitic and subalkalic character of the Etna lavas lends a probability to comagmatic connection of them with what may be called the Tyrrhenian Region. The line suggested begins with the basaltic lavas of Capo Passero and the Val di Noto, in southern Sicily, passes through andesitic Etna, thence to the Aeolian Islands, where basalts, andesites, and rhyolites occur, and is presumably extended to the Ponza Islands, with andesite and rhyolite, and thence northward to the more silicic islands of Giglio, Monte Cristo, Elba, Capraia, and Gorgona. It is hoped to take up the study of the petrologic and comagmatic relations of the islands along the Tyrrhenian subsidence in a later paper.

Finally, does this study of the lavas of the whole mass of Etna indicate a progression of types, such as was suggested by von Richthofen and Iddings, or a cyclical activity with concomitant change in the character of the lavas, as has been suggested by Geikie and Washington? On the whole, it cannot be said that Etna answers either of these questions definitely in the affirmative: on the contrary, the answer to both questions seems to be rather in the negative.

The pre-Etnean and "pedestal" flows are dominantly andesitic and basaltic, and there is a change to more salic and more sodic lavas in the main mass, before the formation of the caldera of the Val del Bove, after which the general character of the lavas changed slightly toward a more femic composition. The latest "recent" lavas are more uniform and more femic than those that preceded the caldera formation. There seems to have been a reversal, during the latest, present phase to the characters of the earliest lavas, with an intermediate, long-continued, aberration to a more salic and more sodic magma, without the extrusion of complementary, more femic, and more ferrous, magnesic, and calcic, products. The Etna magma seems to have been but little differentiated, and the succession of flows from the beginning to the present time is certainly not that of "increasing divergence from an initial type."

Geophysical Laboratory,
Carnegie Institution of Washington.

[51] Washington, The Roman Comagmatic Region, Carnegie Inst. Wash. Pub. No. 57, 1906.

[52] Washington and Keyes, this Journal, 12, 336, 1926.