a late Cretaceous (?) structural trough south of the main axis of the Cretaceous batholith. They probably are relatively minor eruptions belonging to the later stages of the Mesozoic cycle of activity.

CENTRAL REGION.

General Features and Distribution of Igneous Rocks.

In the central part of the Republic there were at least three periods of igneous eruptions—Cretaceous or Eocene, middle or upper Oligocene, and Miocene. Basaltic lavas and tuffs representing the earliest of these periods of eruption were definitely recognized at only two localities, one southwest of Las Cahobas and the other in the central part of the Chaîne des Mateux. Nephelite basalts of Oligocene age were found northeast of Thomazeau, and basalts of the same composition near Saut d'Eau may be of the same age or possibly younger. Miocene basaltic rocks were found in the Miocene sedimentary rocks just north of the Cul-de-Sac Plain and north of l'Arcahaie.

So far as known, all the igneous rocks are extrusive—lavas or tuffs—and no indications of intrusive activity were recognized in any part of the central region. Fragments of quartz and of yellowish iron-rich epidote in some of the Miocene sedimentary beds just south of St.-Marc probably were derived from the central parts of the Montagnes Noires, where these minerals are found in and associated with the intrusive rocks.

Pre-Tertiary or Lower Eocene Basaltic Rocks.

Basaltic lavas of pre-Tertiary or lower Eocene age are exposed about 4 kilometers southwest of Las Cahobas, where the road to Mirebalais crosses the gap in the Montagnes Noires. The mountains are anticlinal, and the basalts underlie the upper Eocene limestone near the center of the gap. (See Fig. 19.)

Basaltic volcanic rocks crop out in small areas south and east of Couyau, near the crest of the anticlinal arch of the Chaîne des Mateux. They probably lie at the base of the upper Eocene limestone or underlie it. Most of the outcrops are deeply weathered and have a reddish or yellowish iron-stained soil. At one exposure a basaltic tuff composed largely of altered basaltic glass and containing small Foraminifera is interbedded in the upper Eocene limestone. This material may represent reworked tuff in the basal parts of the upper Eocene limestones.

Exposures of the basal parts of the Eocene limestone and any underlying or interbedded volcanic rocks may be found in the unexplored deep valley north of Couyau that drains westward to Mont Rouis.

PETROGRAPHY.

Hypersthene basalts.—Two specimens collected southwest of Las Cahobas are hypersthene basalts.

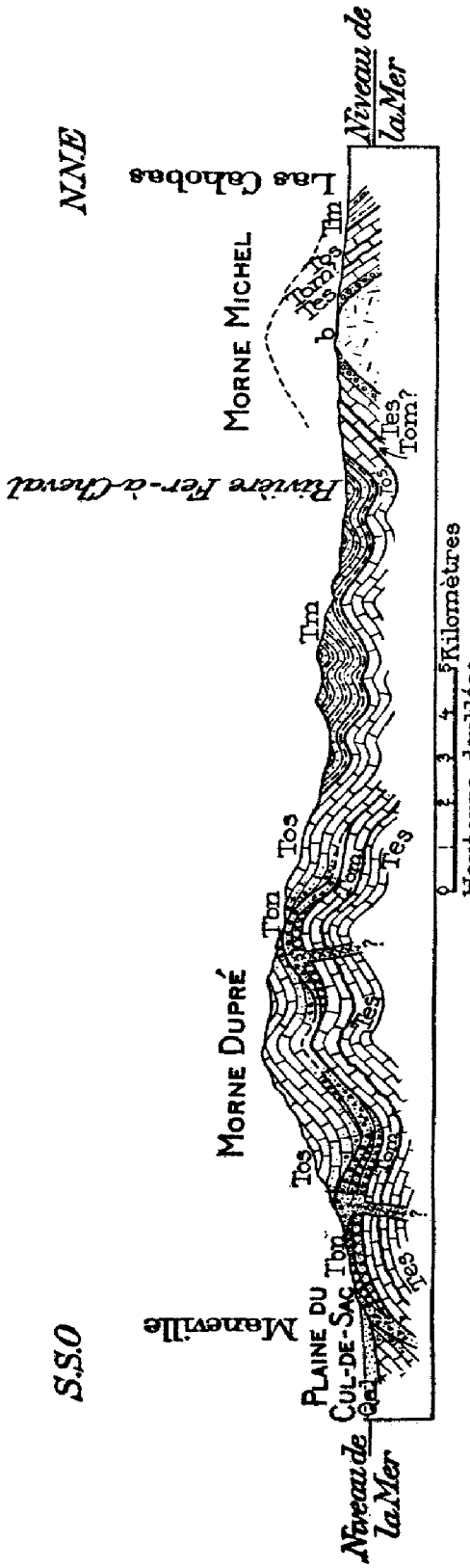


FIGURE 19.—Section across the Montagnes du Trou d'Eau and the Montagnes Noires from Maneville to Las Cahobas, showing the relations of the middle Eocene basalts in the Montagnes Noires and the supposed relations of the nephelite basalts to the middle and upper Oligocene limestones in the Montagnes du Trou d'Eau.

Qal, Quaternary alluvium; Tm, Miocene; Tos, upper Oligocene limestone; Tbn, bedded lavas, agglomerates and tuffs, principally nephelite basalts; Tom, middle Oligocene limestone; Tes, upper Eocene limestone; b, early Tertiary or Mesozoic basaltic lavas.

The rock has a sheet-like jointing. One of the specimens is a dark-gray to black highly vesicular lava, with vesicles 3 to 4 millimeters in diameter. Some of the vesicles are lined with altered glass or chloritic substances and opal. In thin section the lava is seen to contain prisms about 1 millimeter in length of a nearly colorless orthorhombic pyroxene. The fine groundmass shows a flow structure and consists of thin prisms of labradorite in a base of brown partly altered glass. The hypersthene phenocrysts may be in clusters of as many as six or seven crystals. Small hypersthene microlites are present in the glassy base. There are a few scattered prisms of plagioclase about 0.2 millimeter in length, and a few greenish to brownish grains of augite of about the same size. Fine specks of magnetite are scattered in the groundmass.

The second specimen is a greenish-gray rock of aphanitic texture. The hypersthene phenocrysts are altered to greenish serpentine and a mineral of low refraction ($n=1.47$), possibly some form of silica. There are a few grains of unaltered augite. The groundmass of this rock is similar in texture to the other lava except for a smaller proportion of glassy base.

Tuff.—No lavas suitable for petrographic study were collected in the Chaîne des Mateux. The tuffaceous rock east of Couyau interbedded in the upper Eocene limestone is a light-brownish rock resembling a much-weathered porphyry. It consists of fragments of a brown fine-vesicular altered glass or palagonite in a matrix of calcareous material. The original shapes of the glass fragments have been destroyed, either by alteration or transportation.

Nephelite Basalts.

Distribution and structural relations.

Near Saut d'Eau.—Southwest of Saut d'Eau (Ville Bonheur) the nephelite basalts rest on an eroded surface of limestone of middle Oligocene age. Along the trail from Mirebalais to Saut d'Eau, 3 kilometers southeast of Saut d'Eau, the basalts rest on soft, white marly beds that are considered a marly facies of Oligocene or Eocene limestone, which is also found on the hill west of Saut d'Eau. The relations of the basalts to the Miocene beds of the Artibonite Valley are not known. The basalt floors the open grass-covered savanna southwest of Saut d'Eau called Savane Madame Michel. Between this savanna and the Savane Madame Michaud, to the southwest, the trail to Fond-des-Orangers crosses low hills, where the underlying middle Oligocene limestone crops out. Northwest of the trail, just beyond the divide on Savane Madame Michaud, a more or less conical dissected hill rises about 200 meters above the savanna. The southeast slopes consist of bedded volcanic material and some vesicular flows. The bedded material is in thin, even beds, which in some places dip 20° to 30° southwestward. It consists of small fragments, some of which are partly rounded, and a few fragments of vesicular lava larger than a man's head. The general character of the material and

bedding indicate that it is partly reworked volcanic tuff and agglomerates, although their source was not discovered. (See Pl. XVIII, *B*, p. 280.) They probably overlie the flows to the east and south. The basaltic lavas extend southward into the valley called Fond-des-Orangers, where the underlying limestone is of upper Eocene age.

Near Thomazeau.—Nephelite basalts of the same character as those found at Saut d'Eau are exposed at the foot of the mountains northeast of Thomazeau and north of Maneville. On the trail from Thomazeau to Cormillon, at the foot of the mountains, conglomeratic beds near the base of the overlying upper Oligocene limestone contain pebbles of basalt and of a limestone, presumably of upper Eocene age. All the igneous pebbles in this conglomerate consist of altered nephelite basalt containing abundant crystals of olivine and generally are well rounded, as are the few pebbles of limestone. The igneous pebbles may be reworked tuffaceous and agglomeratic material. About 4 kilometers northeast of Thomazeau there are exposures of material that appears to consist of reworked agglomerates and tuffs, loosely cemented and dipping as much as 15° to 18°.

Along the trail from Cornillon to Marché Canard, on the north slope of the mountains, about 1 or 2 kilometers beyond their crest, weathered basalt underlies the upper Oligocene limestone. This basalt presumably is the same as that exposed farther southwest, near Thomazeau, although no specimens were examined petrographically. (See Fig. 19, p. 313.)

PETROGRAPHY AND CHEMICAL COMPOSITION.

The massive basalts of this series are dark-gray rocks when unaltered, although some are brownish. Extremely vesicular or scoriaceous lavas may be brown, coated with yellowish alteration products. The weathered surfaces of the gray rocks are bleached to a rusty brown, and vesicular lavas may be deeply pitted. The lavas from Saut d'Eau and Maneville are of exactly the same appearance and mineral composition, and in thin sections they are practically indistinguishable.

Nephelite basalt.—A typical unaltered rock from a locality about 2 kilometers northeast of Maneville is dark gray and not noticeably porphyritic but contains small phenocrysts, the largest about 1 millimeter in length, of glassy olivine and of augite in a dark-gray dense groundmass.

In thin section the texture is porphyritic with phenocrysts of olivine and augite in a fine-grained holocrystalline groundmass of augite, nephelite, and zeolites. (See Pl. XXIII, *B*.) The unaltered olivine phenocrysts are rounded to subhedral crystals of characteristic outline or are straight cross-fractured prisms, partly in clusters. A yellowish to brownish-yellow augite is less common as phenocrysts. It usually occurs in long, thin, cross-fractured prisms, which make up about 5 to 10 per cent of the rock. The augite is zonal, with extinction on 010 ($\perp \beta$), ranging from 42° to 52° on the outside, pleochroic ($\alpha = 1.70, \gamma = 1.72+$). The augite

in the groundmass is in small prisms and microlites. Titaniferous magnetite and probably ilmenite are the principal accessory minerals and form irregular grains and clustered aggregates. Both apatite in small prisms and some melilite are scattered in the groundmass in minor quantities. The nephelite forms irregular grains except near borders of the miarolitic cavities, where it forms stout hexagonal prisms that are sharply idiomorphic against the surrounding later crystallized zeolites. (See Pl. XXIII, *B*.) The nephelite is perfectly clear and unaltered. The zeolites scattered in the groundmass and filling the cavities in the rock could not be definitely identified.

As the nephelite is clear and unaltered in contact with the zeolites, some of the zeolites may be of primary origin. Small amounts of calcite and analcite, both probably of secondary origin, are present in the rock, generally in cavities with the zeolites.

The mineral composition of the rock could be only roughly estimated because of the texture of the groundmass and is about as follows: Olivine, 15 per cent; augite, 50 per cent; nephelite, 15 per cent; iron ores, melilite, and apatite, 10 to 12 per cent; zeolites, 8 to 10 per cent.

A chemical analysis of this rock, an analysis of a similar rock from Grenada, British West Indies, and average analyses of nephelite and melilite-nephelite basalts for comparison are given in the following table:

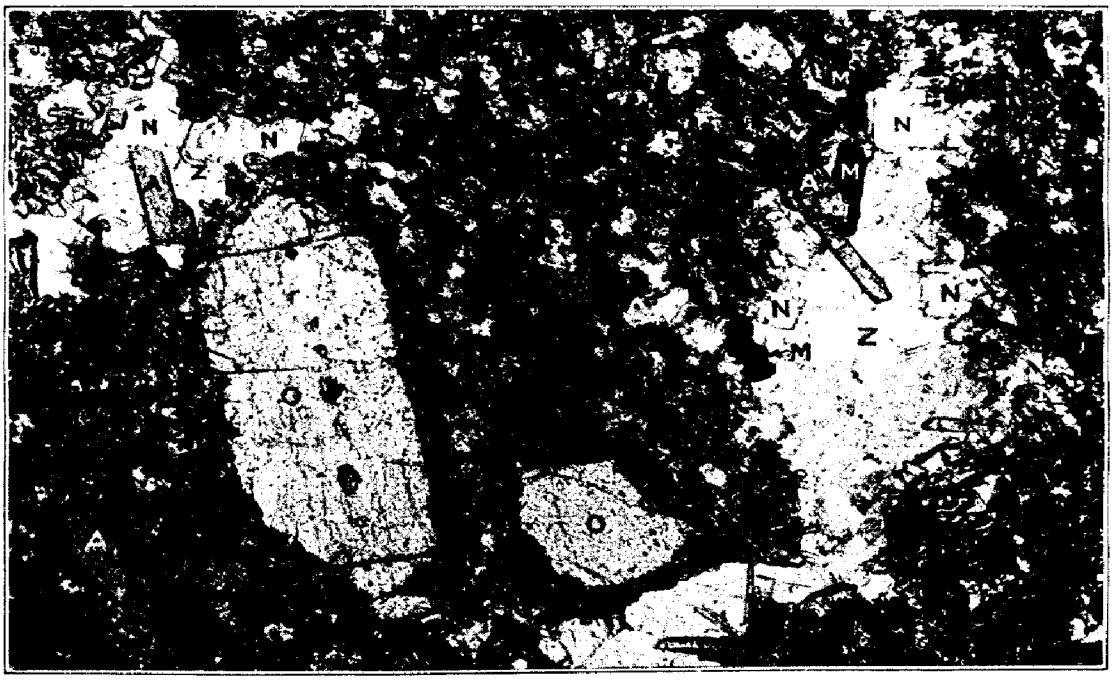
Analysis of nephelite basalt from Maneville, an analysis of a similar rock from Grenada, and average analyses of nephelite basalts.

	1	2	3	4
SiO_2	38.64	42.83	39.87	37.56
Al_2O_3	11.14	10.92	13.58	10.08
Fe_2O_3	5.35	4.33	6.71	6.82
FeO	5.31	8.82	6.43	5.94
MgO	13.04	14.02	10.46	15.32
CaO	14.40	13.20	12.36	13.82
Na_2O	3.43	3.24	3.85	3.11
K_2O	1.90	.64	1.87	1.53
H_2O+	3.01	1.80	2.22	2.52
H_2O-	.29	....		
TiO_2	2.85	.05	1.50	2.66
P_2O_5	.71	.39	.94	....
MnO	.14	.12	.21	.06
	100.21	100.36		

1. Nephelite basalt, near Maneville, Republic of Haiti. H. S. Washington, analyst.
2. "Olivine basalt," Grenada, British West Indies. J. B. Harrison, analyst. Rocks of Grenada, p. 10, 1896. Given by H. S. Washington in Chemical analyses of igneous rocks, U. S. Geol. Survey Prof. Paper 99, p. 709, 1917.
3. Average of 26 analyses of nephelite basalt. Daly, R. A., Igneous rocks and their origin, p. 33, 1914.
4. Average of 5 analyses of melilite-nephelite basalt. Daly, R. A., op. cit., p. 33.

A. PHOTOMICROGRAPH OF BASALT FROM THE MASSIF DE LA SELLE, NORTH OF RIVIÈRE GOSSELINE.

P, plagioclase; D, diopside; O, olivine; S, serpentine; I, ilmenite. Ordinary light. ×90.



B. PHOTOMICROGRAPH OF NEPHELITE BASALT FROM THE VICINITY OF MANEVILLE.

O, olivine; A, titaniferous augite; N, nephelite; M, titaniferous magnetite; Z, zeolites. Ordinary light. ×90.

The norm of the Maneville nephelite basalt, calculated according to the quantitative classification, is as follows:

Norm of Maneville nephelite basalt.

Anorthite	9.48	Calcium orthosilicate	7.75
Leucite	8.72	Magnetite	7.78
Nephelite	15.70	Ilmenite	5.40
Diopside	25.10	Apatite	1.71
Olivine	15.80	The rock is uvaldose ((III) IV. 2.3.2".2.)	

In chemical composition the rock falls between Daly's nephelite and melilite-nephelite basalts, except that it is higher in calcium and slightly higher in titanium. The iron oxides are somewhat lower. The gradation toward melilite-nephelite basalt is also indicated by the presence of some calcium orthosilicate in the norm.

Some of the basalts at this locality are notably higher in augite and iron ores than the rock analyzed. In a specimen collected about half a kilometer northeast of Maneville the groundmass is composed largely of augite prisms and microlites together with a smaller percentage of interstitial nephelite and zeolites. Besides the accessory minerals it contains small brownish cloudy grains of an isotropic feldspathoid, probably haüynite or some member of the sodalite group, and flakes of reddish-brown biotite. The olivine in this rock is partly altered to serpentine and iron ores. Calcite accompanies the zeolites, both in the groundmass and in the cavities, and these minerals are probably to some extent secondary, although probably of late magmatic or deuteric origin. The augite probably comprises about 60–65 per cent.

Haüynite-nephelite basalt.—A specimen collected about 2 kilometers northeast of Thomazeau contains 3 to 5 per cent of haüynite as an accessory mineral. In thin section it shows hexagonal cross sections about 0.2 millimeter in diameter, generally clouded with brown or gray dusty inclusions, some of them in sectors or symmetrically arranged. Some sections are elongated, forming hexagonal prisms, which are probably due to dodecahedral twinning. Reddish-brown biotite is also present in small flakes.

Zeolitized nephelite basalt.—A brownish-gray rock, collected about 4 kilometers southeast of Saut d'Eau, is a nephelite basalt containing zeolites. It contains scattered vesicles and amygdules and is speckled with brownish-yellow grains of olivine altering to serpentine and iron oxides. In thin section the olivine is seen to occur in euhedral to subhedral crystals, some of which are marked by embayments of the groundmass. The augite phenocrysts are brownish green and have the characteristic zonal and "hourglass" structure. The augite is partly in very long prisms whose ratio of length to width is more than 10 to 1. This rock differs from some of the basalts in the development of the nephelite, which may be in relatively large crystals that poikilitically inclose the augite and accessories of the groundmass, and in the presence of considerable analcite,

which forms part of the base and replaces the nephelite. The mineral composition of the rock is approximately as follows: Olivine, 10 per cent; augite, 60 per cent; nephelite, 7 (?) per cent; iron ores, 5 per cent; analcite, 10 (?) per cent; zeolites, 8 (?) per cent. Apatite is an accessory mineral.

Melilite-nephelite basalt.—A large vesicular bomb or fragment from the bedded volcanic débris northwest of Savane Madame Michaud is a melilite-nephelite basalt. It differs from the other nephelite basalts only in the presence of a few small yellowish crystals of melilite, some of which have characteristic biconcave sections.

RELATIONS AND ORIGIN OF THE LAVAS.

In six sections studied from both localities and in specimens of conglomeratic volcanic débris that included fragments of lava, none of the basalts contained feldspar. The lavas from Thomazeau, from near Maneville, and from Saut d'Eau are remarkably similar in petrographic character. Accordingly, the lavas at these different localities must either have been derived from the same parent source of magma or the magmas must have had a similar genetic history.

As the lavas overlie the middle Oligocene and Eocene limestones the magmas in reaching the surface must have passed through at least a thousand meters of limestone. The uniformity of the lavas and the failure to find more siliceous types of igneous rocks associated with them indicates that the magmas were fully formed before they reached the chambers or conduits of the volcanoes from which they were erupted. A more extended study might, however, reveal the presence of other types of lavas.

AGE OF THE ERUPTIONS.

As the basaltic rocks at Saut d' Eau and northeast of Thomazeau are of exactly the same petrographic character and contain similar associated beds of reworked volcanic débris the eruptions in the two localities probably occurred at the same time, although this has not been proved by studies of the structure. The basalts at Saut d'Eau are of post-middle Oligocene age, and those near Thomazeau are overlain by upper Oligocene limestone. If the rocks at the two localities are of the same age the eruptions occurred in late middle or early upper Oligocene time. No evidence was found during the field work to indicate that the eruptive rocks were ever continuous between the two regions.

In the San Juan Valley and the valley of Rio Yaque del Sur, in the Dominican Republic, nearly flat-lying beds of limburgite capping mesas and upland areas of gravel are considered Pleistocene.[1] The fact that these limburgites are probably of similar composition to the nephelite basalts of the Republic of Haiti indicates that eruptions of lava of

[1] A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, p. 203, 1921.

ultrabasic composition may have occurred intermittently over a considerable part of later Tertiary time. The lavas at Saut d'Eau may therefore be younger than those near Maneville, but their relation to the Miocene beds of the Artibonite Valley is not known.

Miocene (?) Basaltic Rocks.

GENERAL FEATURES AND STRUCTURAL RELATIONS.

Basaltic lavas and waterworn débris derived from them are interbedded in Miocene sediments on the south slope of the Chaîne des Mateux. About 4 or 5 kilometers north of l'Arcahaie, on the trail to Couyau, basalt is exposed in a ridge 50 to 60 meters in width and appears to be interbedded in the Miocene series. (See Fig. 5 and pp. 213-214.) Another exposure, which probably represents the same bed, was seen along the same trail, about 2 or 3 kilometers farther north.

Along the trail between Saut d'Eau and the Cul-de-Sac Plain, about 3 kilometers southeast of Source Morissel, conglomerate that consists probably of reworked basaltic agglomerates and tuffs is interbedded in the Miocene series.

PETROGRAPHY.

A fragment or cobble of dark-gray amygdaloidal lava in the Miocene sediments south of Saut d'Eau contains amygdules lined with chlorite and calcite.

In thin section this rock consists of abundant needles of labradorite and thin prisms and grains of augite in a somewhat altered base that contains chlorite. Greenish augite also forms phenocrysts from 0.2 to about 1 millimeter in diameter, partly in clusters of several grains. The thin prisms of augite, especially in the groundmass, have a brownish color and are zonal, giving an extinction $Z \wedge c$ ranging from 46° to 52°. Magnetite is an accessory mineral in small grains. Some aggregates of a serpentinous or chloritic mineral may be secondary after olivine, although their shapes are not distinctive. Chlorite occurs interstitially in the altered base and also lines some amygdules. Zeolites and calcite are also present in the amygdules. The augite, which forms 40 to 50 per cent of the base, is somewhat similar in character and development to the augite found in the nephelite basalts near Saut d'Eau and Maneville. This basalt is furthermore similar in many respects to the amygdaloidal basalts of the later basaltic eruptions of the northern region. (See p. 284.)

AGE AND RELATIONS OF THE LAVAS.

Conclusive evidence that the volcanic débris in the Miocene beds near Source Morissel was derived from lavas of Miocene age was not obtained. Some of the eruptions, however, probably occurred in Miocene time, as is indicated by the bed of solid basalt in the Miocene north of l'Arcahaie. (See Fig. 5, p. 128.)