# TECTONICS.

By WENDELL P. WOODRING.

## GENERAL FEATURES.

The relation of the West Indies to North America is somewhat similar to the relation of the Alps to Europe and of the Himalayas and East Indies to Asia. The West Indian region is a young mountainous complex, and its major tectonic features are due to crumpling of the earth's crust during the Alpine period of folding. It lies between the rigid mass of the Venezuelan highlands and the coastal plain of the southeastern United States, which, although covered in part by the Tertiary seas, was virtually rigid during the folding. During late Mesozoic and Tertiary time the West Indian region was part of the equatorial geosyncline that apparently almost completely encircled the globe. The track of this geosyncline is outlined by a zone of Alpine folds.

The tectonic trends of the Republic are shown in Plate XXIV. In the regions of broad folds these lines represent the crests of anticlines and the troughs of synclines, but in regions of closely spaced folds they merely represent the prevailing strike of the rocks. Some of the tectonic lines show the direction of major lines of rupture.

A striking feature of the tectonic lines, as shown by Plate XXIV, is their arrangement in arcs resembling the arcs of the geographic features, which the tectonic features have largely determined. No attempt has been made to discover the significance of the arrangement of these arcs, but they are like the arcs of folded mountains in other regions. Most of the arcs trend northwestward and are convex southward. In the Northwest Peninsula the west end of the arc representing the crest of the anticlinal arch formed at the end of Miocene time bends southwestward, thus paralleling the northeast end of the Bartlett Deep, which separates the islands of Haiti and Cuba and which at some places between them attains a depth of more than 1,000 fathoms. Some of the arcs in the Southern Peninsula are convex northward, and at the west end of the peninsula they seem to virgate, or branch out sheaf-like.

In this part as in other parts of the Tertiary equatorial geosyncline, beds that are no older than Pliocene, even Quaternary beds, are folded. Here also, as in other regions, the beds were folded at different times. There were apparently three principal periods of folding, one at the end of Cretaceous time, one at the end of Eocene time, and one during and at the end of Miocene time. Probably each of the periods of folding continued into the succeeding geologic period, and in parts of the Republic the folding that began in Miocene time still continues. A surprising result of the reconnaissance is the discovery that the tectonic features of

a large part of the Republic are due to folding and crumpling of the beds during the last period of folding—that is, during Miocene and Pliocene time.

## Tectonic History.

The pre-Mesozoic and early Mesozoic tectonic history of Haiti is so obscure that it can not be deciphered from the information now available. The schistose limestones of Tortue Island and the float of similar intensely metamorphosed rocks seen on the North Plain and the Léogane Plain indicate a record of Paleozoic or early Mesozoic folding that is too fragmentary to read.

The most extensive beds of known or supposed Cretaceous age are in the Massif du Nord. These beds are everywhere complexly folded. In the eastern part of the massif their strike is to the northwest, but in the western part it bends around toward the north, thus forming arcs that are convex to the south. Beds in the northwestern part of the Montagnes Noires and in the Southern Peninsula that are considered of the same age are similarly folded. This folding probably took place at the end of Cretaceous time, although its results can not easily be distinguished from those of later folding. For this reason no age can be fixed for some of the tectonic lines shown on Plate XXIV. The folding was accompanied or followed by intrusions of relatively large batholiths and stocks of quartz diorite, which reach the surface only in the northern part of the Republic and probably were confined to that part. The eastern part of the Massif du Nord contains the largest exposed batholith, and this same region was rigid after the intrusion. This rigidity presents a marked contrast to the mobility that prevails in the central part of the Republic, where thick deposits of younger marine sedimentary rocks have been considerably folded and crumpled.

Beds of marine limestone of upper Eocene age are the most widespread surface rocks in the Republic, as is shown by the geologic map (Pl. I) and the descriptions on pages 106-138. These beds are folded and crumpled, in some areas more complexly folded than the younger rocks, so that there may have been a period of folding at the end of Eocene time and in early Oligocene time. It is difficult to distinguish the results of this period of folding from the results of the folding at the end of Miocene time. In the northwestern part of the Montagnes Noires, where there are no Miocene rocks, the trend of the folds is the same as in the southeastern part, where Miocene beds are involved in the folding. In several parts of the Southern Peninsula the Eocene beds have been folded since Miocene time. The large basalt area south of Port-au-Prince seems to be on the crest of a broad anticlinal arch, which probably dates back to the end of Eocene time. The thrust faulting along the north side of the area of basalt may be later. (See fig. 20, *C*.) The wide distribution of folded upper Eocene beds gives the impression that the results of the folding that

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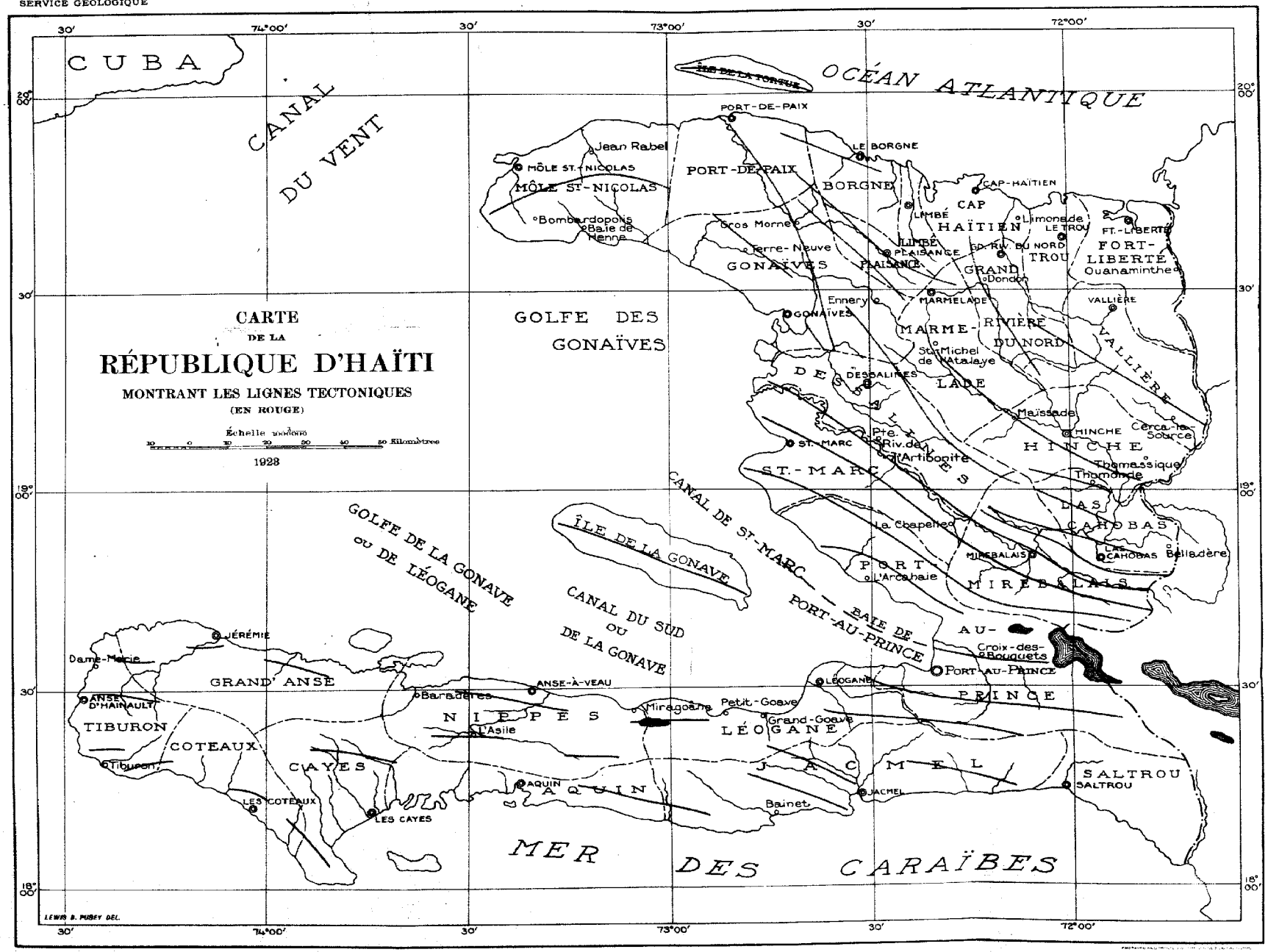
PLANCHE XXIV



occurred at the end of Eocene time are extensive, but the impression is probably misleading. In the mobile central part of the Republic, where there are extensive areas of Miocene rocks, the Oligocene and Miocene beds have the same strike and dip as the Eocene beds. In the southwestern part of the Northwest Peninsula, however, beds apparently of upper Eocene age strike north-northwestward, whereas the crest of the main anticlinal arch formed at the end of Miocene time trends west-southwestward. Some of the folding in the Montagnes de Terre-Neuve and in the mountains in the central part of the peninsula (Montagnes du Nord-ouest) probably took place at the end of Eocene time. The folds in the upper Eocene beds along the northern and southern borders of the Massif du Nord are probably of the same age. The Eocene beds extending across the crest of the Massif du Nord near Dondon and Christophe's Citadelle were apparently deposited in a trough diagonal to the trend of the Cretaceous rocks. Meager evidence indicates that the beds in this trough were folded at the end of Eocene time along lines diagonal to the older trends. There is no evidence that Eocene deposits formerly extended across the crest of the massif east or west of this trough. The folds in the northwestern part of the Montagnes Noires, as well as those in part of the interior of the Southern Peninsula, may also date back to the close of Eocene time.

The evidence available indicates that there was no folding during Oligocene time or at its end, but the post-Eocene folding may have continued into lower Oligocene time. Upper Oligocene deposits are apparently conformable with middle Oligocene, and Miocene beds rest conformably on upper Oligocene.

Considered in relation to the present morphology, the most important occurrence in the tectonic history of the Republic was the folding and crumpling of the rocks during Miocene and Pliocene time. The tectonic features of the entire mobile central part of the Republic, as well as the outlines of the Northwest Peninsula and of parts of the Southern Peninsula are the results of this folding. The Central Plain, Artibonite Valley, and Cul-de-Sac Plain are deep synclinal troughs; the Northwest Peninsula, Montagnes Noires, Chaîne des Mateux, and Gonave Island are anticlinal arches. Miocene rocks are involved in all of these folds.

The Miocene beds of the Northwest Peninsula seem to be arched in a broad anticline trending west-southwest. Miocene marl crops out under the cover of Quaternary limestone near the crest of the arch along Rivière du Môle. Evidence presented on page 159 indicates that the Miocene beds in the reentrants near the head of Rivière de Jean Rabel and Rivière Cadet on the north side of the peninsula are in a shallow synclinal trough diagonal to the general trend of the arch but parallel to the strike of the upper Eocene rocks farther west. The syncline may be a survival from an older structural feature in the upper Eocene rocks flanking the trough. The reentrant of Oligocene and Miocene rocks on the south side of the

same gap and the similar reentrants heading into the gap separating the Montagnes du Nord-ouest from the Montagnes de Terre-Neuve may be similar structural features. Along the east side of the Arbre Plain the strike of the Miocene beds parallels the Montagnes de Terre Neuve. Some of the folding in the Montagnes de Terre Neuve and in the Montagnes du Nord-ouest probably took place at the close of Miocene time. In the Montagnes de Terre-Neuve the folding was accompanied or followed by intrusions of quartz diorite and granodiorite.

The upper Oligocene or Miocene limestone covering most of Tortue Island seems to be arched in a broad anticline.

The sections on Plate XXXVI show that the Miocene rocks of the Central Plain are folded in a deep syncline and that they are upturned against the mountains along the borders of the plain. Near the foot of the Montagnes Noires in the northwestern part of the plain the lower part of the Thomonde formation is thrust northeastward over the Maïssade tongue (see Pl. XXXVI, section *B-B'*), and there is probably another high angle thrust fault of greater displacement at the mountain front. The northeast limbs of the Thomonde and Chamouscadille anticlines are very steeply tilted near the mountains, and in depth these folds probably pass into thrust faults. The great scarp south of Cerca-la-Source, near the southern border of the Massif du Nord (see Pl. XXV, *A*), seems to be a fault scarp between upper Oligocene limestone and Cretaceous (?) argillite, but the evidence available to prove the existence of this fault is stratigraphic only.

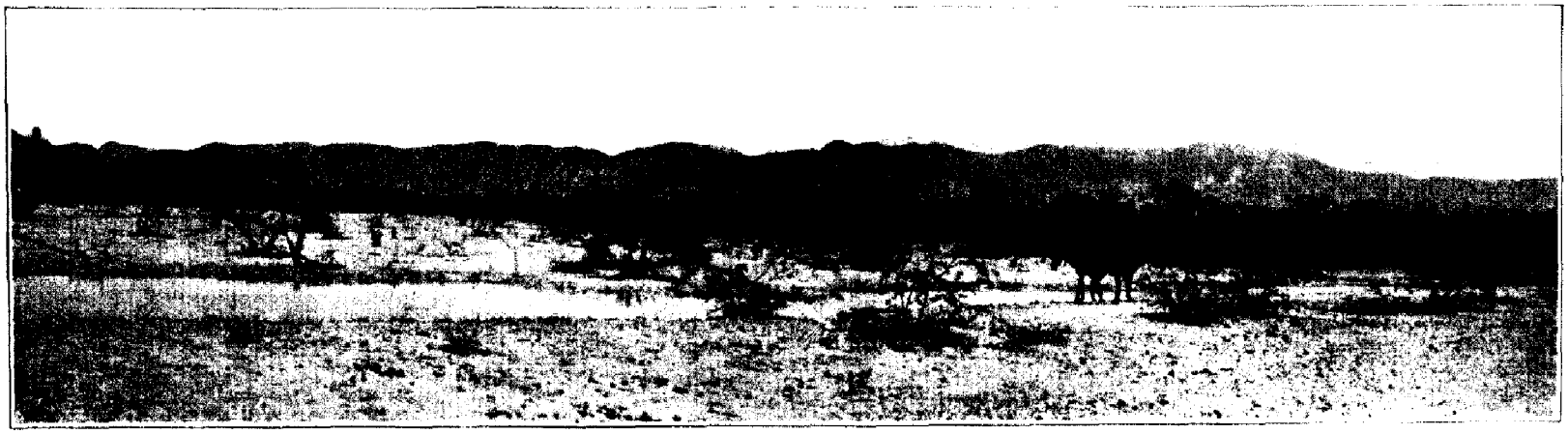
Northwest of the gorge of Rivière Artibonite the Montagnes Noires constitute a compound anticline, but southeast of the gorge they constitute a single anticlinal arch separated from the compound anticline by a syncline.

Figure 12, page 207, and Figure 13, page 208, show that the Artibonite Valley is a deep synclinal trough resembling the Central Plain and containing secondary anticlines. Exposures along the road from Mirebalais to Las Cahobas show that the Miocene rocks are crumpled near the foot of the Montagnes Noires. Plate XXVI, *A*, is a view of a small, peculiar asymmetrical anticline that extends across the narrow valley of Rivière Fer-à-Cheval at Savanette and, on the south side of the stream, bends eastward up the valley. West of Savannette a low arch almost at right angles to the trend of the trough of the syncline brings upper Oligocene limestone to the surface.

The Chaîne des Mateux is perhaps the most perfect example of a large anticline in the Republic. Figure 5, page 128, a section across the range, shows that on the southwest flank Oligocene rocks are thrust southwestward over Miocene rocks and that there probably is another thrust fault at the edge of the Arcahaie Plain. The secondary anticline on the northeast flank of the mountains near St.-Marc is shown in Figure 12, page 207.

*A.* SUPPOSED FAULT SCARP SOUTHWEST OF CERCA LA SOURCE.

The ridge is composed of limestone forming steep cliffy slopes. Part of the village of Cerca-la-Source is shown in the foreground.



*B.* FAULT SCARP ON THE EAST SIDE OF THE GONAÏVES PLAIN.

The trough of the Cul-de-Sac Plain is perhaps the most remarkable surface feature of the Republic. It has been interpreted as a downfaulted block bounded by normal faults and has been cited as a subaerial form of trough of the sort that is generally submerged in the West Indies, such as the Bartlett Deep, Brownson Deep, and Anegada trough. The Cul-de-Sac trough is clearly a syncline, as Miocene beds are upturned on the flanks of the mountains bordering it and similar beds have been penetrated by wells in the plain. Moreover, the trough is bounded on the south side by a zone of high-angle thrust faults that dip toward the mountains, and there is evidence on the north side of similar high-angle thrust faults. Figure 21 is a section drawn across the trough and part of the bordering mountains. (See also Fig. 15, p. 219.) The Eocene and Miocene rocks are more intricately crumpled than is shown in the figure. The main fault on the south side of the trough is well exposed on the Grande Rivière du Cul-de-Sac a short distance above Bassin Général. Steep southward dips

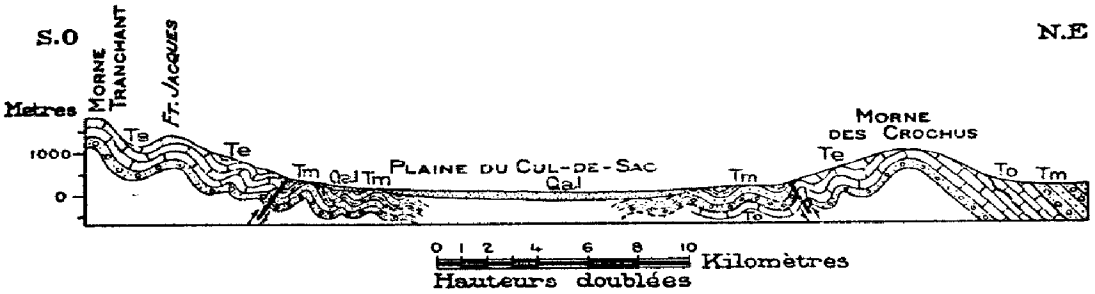



FIGURE 21.—Section across the Cul-de-Sac trough and adjoining mountains. Qal, Quaternary alluvium; Tm, Miocene; To, Oligocene limestone; Te, upper Eocene limestone.

were found on the north limb of the overturned arch south of the main fault. Plate XXVI, *B*, shows minor imbricated high-angle thrust faults exposed on the Grande Rivière du Cul-de-Sac in a zone of crumpled upper Eocene rocks south of the main fault. Port-au-Prince Bay and the St.-Marc Canal are apparently the submerged prolongation of this trough, which thus trends northwestward in an arc convex southward, parallel to the arcs of the Chaîne des Mateux, the Artibonite Valley, the Montagnes Noires, and the Central Plain.

The tectonic features of several parts of the Southern Peninsula clearly show that the widespread upper Eocene limestones were folded during Miocene time. Marine Miocene beds in the interior lowland on the Grande Rivière de Jérémie are now separated from the sea by a range composed of upper Eocene limestone. As shown on page 227 and in Figure 7 (p. 137), these Miocene rocks are not folded to form a synclinal trough but dip persistently northward toward the mountains, indicating that the upper Eocene limestone has been thrust southward over the Miocene beds. Lignite-bearing Miocene rocks at Camp Perrin are thrust northward over coarse conglomerates deposited as deltas and alluvial fans near the lakes

and swamps where the lignite-bearing beds were laid down. (See pp. 235-236, and Fig. 17, p. 234.) These nonmarine beds were probably at one time continuous with the marine Miocene beds that crop out on the Cayes Plain. The range of upper Eocene limestone now separating them may also have been thrust northward. Although the tectonic features of the largest interior lowland, the Asile Valley, are not fully known, it seems probable that a fault bounds the lowland on the south. Most of the nonmarine Miocene beds in this lowland are but slightly folded.

Gonave Island is a broad anticlinal arch. The trend of its crest parallels the Chaîne des Mateux and the folds in the northern part of the Massif de la Selle. Tilted Miocene beds cover the lower part of the flanks of the arch, and in the northwestern part of the island these beds extend across the crest.

All the Miocene rocks involved in the folding seem to be of lower and middle Miocene age. The folding probably began in late Miocene time. The evidence already given (see p. 241) shows that the marine conglomerates and marls in the valley of Rivière Gauche near Jacmel are of Pliocene age. These rocks are as strongly folded as any of the Miocene beds, so the folding must have continued into Pliocene time. The Pliocene beds strike northwestward and at all the localities where they were examined dip southwestward. The southern margin of the lowland was not examined, but if the southwestward dip continues it may be inferred that the upper Eocene limestone in the range bordering the lowland has been thrust northward. The same relation is suggested by the discovery that there are middle Oligocene rocks at sea level on the west side of Jacmel Bay and upper Eocene rocks at a higher altitude not far to the west.

Many high-angle thrust faults are associated with the folds, particularly those that were formed during the last period of folding. No extensive overthrust sheets such as characterize Alpine folds in many other parts of the Tertiary equatorial geosyncline were discovered. Detailed work among the upper Eocene limestones, which consist of many different types of rock, may reveal overthrust sheets.

The remarkable normal faults along the Trois Rivières trough are probably later than Miocene. The rocks in the trough are of middle and upper Oligocene age. Details of the fault along the west side of the trough south of Gros-Morne are given on pages 120-121, and the fault is shown in the section forming Figure 27, *A-A'* (p. 442), and Figure 30 (p. 471). The fault plane seems to dip steeply eastward, and the throw is several hundred meters. Normal faults of this magnitude are unusual in the Republic. The fault along the east side of the trough was not closely examined. The scarp that along its southward prolongation rises abruptly above the Gonaïves Plain is shown in Plate XXV, *B*. Morne Grammont, an outlier of the Montagnes Noires in this region, resembles the main mountain front, as it seems to be a block tilted northeastward and bounded on the west by a normal fault.

*A.* ASYMMETRICAL ANTICLINE OF MIOCENE MARL AND LIMESTONE AT SAVANETTE, ON RIVIÈRE FER-À-CHEVAL.

*B.* MINOR HIGH-ANGLE THRUST FAULT IN LIMESTONE OF SUPPOSED UPPER EOCENE AGE ON GRANDE RIVIÈRE DU CUL-DE-SAC.

In the mobile central part of the Republic and in the Northwest Peninsula the distribution of the Quaternary reef caps [1] is intimately related to the major folds produced during the Miocene folding. In these parts of the Republic the reef caps are confined almost entirely to the flanks and plunging crests of anticlines. This relation is shown by the reef caps on the crests and flanks of the northwestward-plunging anticlines north and south of St.-Marc but is most strikingly shown in the Northwest Peninsula, where the Quaternary reef caps have an altitude of 400 to 450 meters above sea level on the crest of the anticline formed during the Miocene folding. The reef caps are most numerous at the crest of the arch but decrease in number and altitude down on the flanks, away from the end of the peninsula. Gonave Island is the only major anticline striking into the sea on which reef caps were not found, but the extremities of the island were not examined and the caps may be there. So far as known all the reef caps are symmetrically arched over the anticlines. This arching of the reef caps shows that the folding in places continued through Quaternary time. In the Northwest Peninsula, at least, it is probably still going on. The significance of the distribution of the reef caps in the southern Peninsula is not known.

### Bearing of Tectonics on Geologic History of West Indies.

The folding at the close of Miocene time determined the location of such geographic features as the Central Plain, Artibonite Valley, and Cul-de-Sac Plain, which if submerged would be similar on a small scale to the great submerged troughs of the West Indies. The Cul-de-Sac Plain would be a particularly striking trough if submerged, comparable to the Anegada trough and having about the same curvature. Accumulating evidence indicates that the submerged troughs were at least deepened if not entirely formed at the close of Miocene and during Pliocene time.[2] The Northwest Peninsula, which was the most mobile part of the Republic during Quaternary time, is adjacent to the northeast end of the Bartlett Deep, perhaps the most remarkable of the submerged troughs. The submerged troughs, which have been recently described by Taber,[3] have been interpreted by Vaughan and Taber as downfaulted blocks bounded by normal faults. The subaerial troughs are deep synclines bounded in part by a zone of imbricated high-angle thrust faults. It has recently been suggested that it is more reasonable to believe that the submerged troughs are similar deep synclines [4] probably limited by high-angle

[1] The Quaternary limestones at many localities resemble material in the near-by living fringing reefs; at other localities they are merely coralliferous limestones. For convenience all these deposits are called reef caps.

[2] See Vaughan, T. W., Geol. Soc. America Bull., vol. 29, pp. 625-627, 1918; U. S. Nat. Mus. Bull. 103, pp. 609-610, 1919.

[3] Taber, S., The great fault troughs of the Antilles: Jour. Geology, vol. 30, pp. 89-114, Pl. 1, text fig. 1, 1922.

[4] See Woodring, W. P., Tectonic features of the Republic of Haiti and their bearing on the geologic history of the West Indies (abstract): Washington Acad. Sci. Jour. (Awaiting publication.)

thrust faults. Possibly both the subaerial and the submerged troughs were deepened by vertical movements later than the folding, probably of the same age as the movements that produced the high-angle normal faults at the edge of the Trois Rivières Valley trough. This narrow trough would be a striking feature if submerged, but such troughs bounded by normal faults are unusual in the Republic.

## EARTHQUAKES.

By Wendell P. Woodring.

### Records Available.

Earthquakes are frequent in the Republic, as in other parts of the Tertiary equatorial geosyncline. During the history of the colony and of the Republic disastrous earthquakes have at times almost or completely destroyed Port-au-Prince, Cap-Haïtien, and other cities. Different parts of the Republic have had distinct seismic histories, and an attempt is here made to correlate the seismic phenomena with the known tectonic features. The information on which this attempt is based was obtained from records and accounts published by Rev. J. Scherer, Directeur de l'Observatoire Météorologique du Séminaire-Collège St.-Martial, Port-au-Prince. M. Scherer deserves the highest praise for his patience in collecting records and for his striking accounts of the disastrous shocks and of their relation to the surface and to the geologic features. His publications are as follows:

Les grands tremblements de terre dans l'île d'Haïti: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1911, pp. 153-162, 1912. An English translation of this article was published in the Bulletin of the Seismological Society of America, vol. 2, pp. 161-180, map, 1912.

Les tremblements de Terre de l'île d'Haïti dans leurs rapports avec le relief du sol et les fosses maritimes qui l'entourent: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1912, pp. 132-139, 1913.

Catalogue chronologique des tremblements de terre ressentis dans l'île d'Haïti de 1551 à 1900: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1913, pp. 147-151, 1914. This catalogue is based principally on the following two catalogues: Poey y Aguirre, Andrès, Catalogue chronologique des tremblements de terre ressentis dans les Indies Occidentals de 1530 a 1858; suivi d'une bibliographie séismique concernant les travaux relatifs au tremblements de terre des Antilles: (Extrait de l'annuaire de la Société Météorologique de France, tome 5, p. 75, séance du 12 Mai, 1857) 76 pp., Versailles, 1858; and Tippenhauer, L. Gentil, Liste der Erdbeben auf Haiti: Die Insel Haiti, pp. 170-175, Leipzig, 1893.

Tremblements de terre observés en Haïti de l'année 1901-1910: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. ann., année 1920, pp. 100-104, 1921.

In addition to these accounts and catalogues, M. Scherer has published records of shocks in the Bulletins of the Observatoire. The Bulletins appeared semiannually from the last half of 1909 to the end of 1916, and