ART. XXIV.—*The Geology of the Isthmus of Panama*; by
ERNEST HOWE.*Introduction.*

THE first serious effort to investigate the geology of the Isthmus of Panama was made by Robert T. Hill in 1895.* Although his stay on the isthmus was brief and the survey merely a hurried reconnoissance, the principal features of the geology and physiography were recognized. At the time of his visit little or no work was being done by the French company, few records of borings or soundings were available, and many exposures along recent cuts were already in the grasp of the jungle, so that certain details that escaped Hill remained to be worked out by MM. Bertrand and Zürcher† three years later when they made a report to the New Panama Canal Company. Working under more favorable conditions, these geologists were able to revise certain of Hill's views, and especially his conclusions concerning the igneous rocks.

In the following pages numerous references are made to the reports of Hill and of Bertrand and Zürcher, from which great assistance has been derived in the course of my own studies of the isthmian geology.

The field work upon which the present paper is based was carried on during a part of the summer of 1906, and in the following dry season from January to April, 1907, nearly five months in all. The work was undertaken for the Isthmian Canal Commission and had to do largely with economic matters; a brief outline of the geology, however, accompanied the report to the Canal Commission‡, a résumé of which has been published in "Economic Geology".§

The purpose of the present paper is to record in more detail certain observations on the geology, and more especially on the stratigraphy, that affect the conclusions reached by Hill and the French geologists. There were unusual opportunities for studying the section across the isthmus because of fresh exposures made by recent excavation along the canal line, and

* Robert T. Hill, *The Geological History of the Isthmus of Panama and Portions of Costa Rica*. Bull. Museum. Comp. Zool., vol. xxviii, No. 5, pp. 149-285. Cambridge, 1898.

† M. Bertrand and P. Zürcher, *Étude Géologique sur l'Isthme de Panamá*. Rapport de la Commission. Compagnie Nouvelle du Canal de Panamá, etc. Annexe I, pp. 85-120. Paris, 1899. The page references in the present paper are to a reprint of this report.

‡ Ernest Howe, *Report on the Geology of the Canal Zone*, Annual Rep. Isthmian Canal Commission, 1907. Appendix E, pp. 108-138.

§ ——— *Isthmian Geology and the Panama Canal*, *Economic Geology*, vol. ii, pp. 639-658. 1907.

at many places the information to be obtained from surface outcrops was augmented by a great number of boring records and samples.

Special thanks are due Mr. John F. Stevens, under whom as chief engineer the work was done, for many facilities placed at my disposal. I am also greatly indebted to Dr. William H. Dall for his kindness in looking over my collections and for many valuable suggestions.

Preliminary Statement.

The Isthmus of Panama, where it is to be crossed by the canal, consists of sediments and pyroclastics of Tertiary age that rest on an eroded surface of andesitic breccias and associated lava flows, all of which have been intruded at numerous places, probably in Miocene time, by dikes and large cross-cutting masses of andesite or basalt. During the period of intrusion, or immediately after it, the region was uplifted, and the cycle of erosion thus inaugurated continued to late maturity or old age. Before the completion of the cycle, however, another upward movement occurred accompanied by warping or a gentle medial doming. As a result of the continued erosion the basal igneous mass was exposed in the interior and a sub-mature topography developed in regions of harder rocks, while near both coasts less resistant sedimentary beds favored more active erosion and conditions of greater maturity prevailed. A third uplift caused the streams to entrench themselves in their old or mature valleys, but before this last cycle had advanced beyond its youth, a gradual subsidence began that continued until the young valleys were aggraded and the mature valleys of the second cycle drowned for short distances back from the coasts. A final slight upward movement has elevated the estuarine deposits, formed during the period of depression, a few feet above sea level.

Obispo Breccias.

The igneous complex that appears to underlie all of the other formations of the isthmian region consists largely of andesitic tuffs and breccias; it has been given the name Obispo on account of its characteristic exposures at Bas Obispo, the northern end of the Culebra cut. From Bas Obispo southward to a point between Empire and Culebra the breccias have been well exposed by excavation, but at the time of examination the zone of surface alteration had not been passed, so that although the rocks show their pyroclastic nature the petrographical character of the fragments and the matrix is not readily determinable. Fresher material was collected on the

Pacific side of the isthmus in the vicinity of Las Sabanas, and this has been compared with specimens from the other localities which seem to be equivalent.

The formation as a whole consists of moderately coarse breccias of andesite of a variety of textures but nearly uniform composition. Fine-grained tuffs have been observed, mostly on the northern side of the isthmus, while the Sabanas occurrences present an extremely coarse facies. As a rule the breccias of the interior are composed of angular fragments varying from a quarter of an inch to two inches in diameter. At a quarry near the Sabanas road one block more than six feet in diameter and many twelve or eighteen inches in diameter were observed in a cement as coarse as the average breccia of the interior. In a region where outcrops are few and continuous exposures unknown it is not possible to make generalizations, but from the observed occurrences it may be said that the usual appearance of the Obispo breccia lies between the extremes of coarseness and fineness that have been mentioned.

So far as observations have been carried, the rock fragments composing the breccias consist largely if not entirely of pyroxene-andesite. Some are highly vesicular and glassy, others markedly porphyritic, while the majority are dense, even-textured rocks in which individual crystals can be made out only with the aid of a lens. In one specimen there were doubtful indications of hornblende. The prevailing greenish gray color of the rock suggests what is found to be the case on microscopical examination, that the pyroxene, usually augite, has undergone extensive alteration; on the other hand, the plagioclase, which generally has a composition of about Ab_2An_3 , is comparatively fresh, a fact noted in the cases of most of the rocks of the isthmus where the final stage in the decomposition to the surface red clay has not set in.

Distribution of the Obispo breccia.—The most northerly occurrences of these breccias are shown by borings at the San Pablo dam site; from that point southward they appear occasionally at the surface, and are indicated in all the borings made at intervals of one kilometer along the center line of the canal as far as Empire. Decomposed but otherwise characteristic exposures are to be seen between Mamei and Gorgona along the Panama Railroad, and from Gorgona to Empire, where they disappear beneath a cover of later sediments, the Obispo breccias are the prevailing rocks. Composing the hills north, west, and east of Corozal, and particularly well exposed northeast of Panama in the vicinity of Las Sabanas, are rocks of the same petrographical character that are believed to be a part of the central mass.

Age of the Obispo breccias.—The only definite statement that can be made in regard to the age of the Obispo breccias is that they are older than the oldest sedimentary rocks of the region, which, as will be shown presently, carry a fauna considered by Prof. William H. Dall to correspond to the Claiborne Eocene. Although it is not improbable that the eruption of these andesitic breccias marked the beginning of Tertiary history in the isthmian region, there is no direct evidence that the rocks are not still older.

MM. Bertrand and Zürcher* included with the breccias that have been described as the Obispo, certain other fragmental igneous rocks exposed near Bohio, calling the whole "Roche de Gamboa." From fossil evidence found at Bohio they correlated the Gamboa rock with the Oligocene of southern Europe. Reasons are given in a later paragraph for believing that the breccias at Bohio are intimately associated with the oldest sedimentary rocks and separated from the Obispo breccias by an unconformity.

Bohio Formation.

The name Bohio is proposed for the oldest sedimentary formation recognized on the isthmus and includes certain beds occurring at Bohio, Vamos Vamos, and in the vicinity of Gatun. This name is suggested in order to avoid confusion in referring to the same rocks described by Hill and Bertrand, but not recognized by them as being parts of one formation.

What are believed to be the lowest beds of this formation are conglomerates exposed in the lock site partly excavated by the French near Bohio, and breccias in the quarries at the Bohio railway station. A mile and a half to the west, at a locality known as Vamos Vamos, rocks of the same age are exposed on the south bank of the French canal, and similar rocks, although no fossils have been found among them, occur along the Panama Railroad near Tiger Hill. On the west bank of the canal nearly opposite the mouth of the Gatuncillo the formation is again exposed and the beds carry abundant fossils. At intermediate points borings have shown the presence of rocks lithologically the same as those at Vamos Vamos or near Gatun, but their few fossils have been indeterminable. To the southeast of Bohio borings in the vicinity of Buena Vista and San Pablo have indicated the presence of beds like those at Bohio, while a few isolated patches of conglomerate that rest on the Obispo breccias in the neighborhood of Mamei, Gorgona, and Matachin, are in all probability a part of the Bohio formation.

* Étude Géologique sur L'Isthme de Panama, p. 5.

Lithologic character of the Bohio rocks.—Lack of continuous outcrops and sudden changes in the character of the beds within short distances have prevented an altogether satisfactory study of the Bohio formation. Boring records have assisted at a number of places, but even with their help the relations at Bohio are not easy to make out.

Directly south of the village of Bohio on the opposite side of the river is a hill about seventy-five feet in elevation, through the middle of which a cut was made by the French for the construction of a lock. The sides of the cut are now more or less covered by vegetation but still present excellent exposures of the rocks composing the hill. The section shown is about fifty feet in thickness and consists of beds of coarse conglomerates, gravels, and sands that strike N. 25° E. and dip about 14° to the northwest. Crossbedding is common and the beds of finer textured rocks are frequently lenticular. The conglomerates contain many bowlders a foot or more in diameter associated with coarse gravel or cobbles and held in a gritty matrix that is of the same character as the beds of finer sandstone. The bowlders are of a number of kinds of eruptive rock, the commonest being hornblende-andesites with less abundant hornblende augite-andesite, augite-andesite and latite porphyry; nearly all are coarse-grained and strongly porphyritic. It is noteworthy that of the bowlders examined few resembled rocks observed in other parts of the isthmus. The matrix in which these bowlders lie and the associated sandstones are composed of finer debris of the same rocks; quartz is so rarely present as to be negligible. It is worth noting in this connection that the bowlders of the conglomerate are of comparatively fresh rock while the matrix and intercalated sandstones are invariably decomposed, the alteration being to a complex aggregation of epidote, serpentine, kaolinite and sericite that causes the rocks to have a distinctly soapy feel. This is a feature common to most of the fragmental rocks not of direct volcanic origin, wherever alteration has not progressed so far as to result in the formation of the surface red clays.

Not more than a quarter of a mile north of the conglomerates exposed at the Bohio lock site, outcrops of a peculiar greenish brown rock are to be seen on the right bank of the Chagres beneath the village of Bohio. The hills to the north and east are composed of the same rock, and just back of the village, quarries are located from which building stone has been obtained for the Panama Railroad bridge piers and other purposes. The quarrying operations have exposed a vertical section of the rock about fifty feet thick. The rock is composed of fragmental materials of volcanic origin; the imbedded fragments are largely of pyroxene-andesite of a number of dif-

ferent textures, often fluidal and glassy, and varying from a tenth of an inch to one or two inches in diameter. Although many of the fragments are comparatively fresh, the matrix or cement is in an advanced state of decomposition, the secondary minerals being zoisite, epidote, serpentine, and some doubtful kaolinite. As a whole, however, the rock is so extremely altered that it is difficult to determine whether it is a simple volcanic breccia like the Obispo or a fine conglomerate of volcanic debris like that at the near-by lock site. So far as it is possible to make out, I am inclined to believe that it is a volcanic breccia, in the sense that it is more or less of eruptive origin, largely on account of the uniform character of the rock fragments composing it as contrasted with the varied petrographic character of the boulders in the conglomerate at the lock site. It is not impossible that the breccia represents a "volcanic mud-flow" as suggested by Bertrand.*

The particular interest attaching to this breccia is its intimate association with the conglomerates exposed at the lock site. This relation is not shown on the surface, but is brought out very clearly by borings made in exploring possible dam sites in the vicinity. One series of these borings, along what is known in the surveys as the "F" line, extended from the quarries at Bohío in a southerly direction across the river to the hill through which the French excavated the lock site, a distance of about one-half mile. At the northern and southern ends of this line respectively characteristic specimens of the breccia and of the conglomerate were obtained by the drill, while at intermediate points transitional facies were shown in nearly all the borings. Among other features is the association of the typical breccia of the quarry with water-laid sandstones or tuffs, many of which contain carbonaceous matter, while others, coarser grained, are composed of distinctly water-worn material and are held in a calcareous cement. Passing southward the breccias become less and less abundant while the water-worn material increases in coarseness and conglomeratic beds are to be noted in many of the holes. Layers of fine material interbedded with both the typical breccia and with the coarse conglomerates, as at the French lock site, are shown in practically all the borings.

The lowest point reached by the drills was about 194 feet below sea level near the middle of the line of borings. After passing through alluvium filling the Pleistocene valley of the Chagres, the deepest boring entered about thirty feet of coarse conglomerate; the matrix holding the boulders was ground up by the drill and none is shown in the samples collected, but

* *Op. cit.*, p. 5.

the presence of certain porphyritic rocks closely resembling those contained in the conglomerate of the lock site makes me believe that this is to be regarded as a conglomerate rather than as a breccia like that of the quarry where little or no variation in the character of the fragments of pyroxene-andesite was found. One hundred feet south of this point another boring passed through fine sandstones or tuffs before striking beds similar to those in the previous hole and at a corresponding elevation. About the same distance to the north from the first hole and at the same elevation, fine-grained beds like those of the second hole are also shown by the core, while still nearer the quarries and at an interval again of about one hundred feet fine material mixed with angular fragments of pyroxene and andesite is shown. In the opposite direction a corresponding change to the conglomerate facies is to be observed. Precisely the same transition is shown by a line of borings made from the hill in which the French lock site was excavated in a north-easterly direction across the valley of the Chagres to the hills east of Bohio.

This evidence would seem to indicate that the breccias, best shown at the quarries, were deposited contemporaneously with the conglomerates and sandstones of the lock site. The breccias were in large part, if not entirely, laid down in water, and probably running water, but it is impossible to decide whether the material composing the breccia was transported for some distance by streams before being deposited or if it fell into the water directly from the air. The angular character of the fragments, so far as it may be determined in the extremely decomposed rock, would seem to favor the direct deposition of the breccia in water as a result of volcanic eruption. Eruptions of fragmental material of uniform composition undoubtedly took place during this first period sedimentation, and evidence for this has been found at other points, especially in the vicinity of Culebra, as stated in a later paragraph.

Southeast of Bohio the character and distribution of the conglomerates and breccias are imperfectly known. Near San Pablo rocks similar to the Bohio breccias are indicated by borings beneath acid tuffs, while it is more than probable that the Bohio beds are represented in the neighborhood of Gorgona by conglomerates exposed along the line of the Panama Railroad. In most instances it is all but impossible to distinguish between the conglomerates and the volcanic breccias upon which they rest because of the extreme decomposition that both have suffered. The occurrences at Gorgona are fresher, however, and their conglomeratic character unmistakable. The andesitic breccias beneath these conglomerates belong to the Obispo formation and have been traced by borings practi-

cally all the way from near San Pablo to the type locality at Bas Obispo. Hill noted the presence of these conglomerates at the places named and correlated them with the beds at the Bohio lock site.*

Vamos Vamos and Gatun beds.—About two and a half miles west of Bohio, on the south bank of the French canal, at a locality known as Vamos Vamos, are exposures of sedimentary rock that have been described by Hill† and Bertrand.‡ The rocks are impure calcareous shales or marls of a dirty brown color, rich in fossils, and at certain horizons contain numerous large fossiliferous calcareous concretions that at first suggest boulders in a conglomerate.

Following the line of the French canal northwest for nearly six miles, no outcrops of any sort are to be seen until within a short distance of Gatun, where, on the left bank of the canal, are exposures of extremely fossiliferous marls and calcareous sandstones. Similar beds are exposed along the cuttings of the Panama Railroad through Tiger Hill between Bohio and Gatun. No other exposures in this region are known, but a great number of borings made at Gatun in exploration of dam and lock sites furnish much valuable information in regard to the character of the rocks. The samples of borings from the lowest sedimentary rocks at Gatun are all of extremely fine-grained, even-textured sandstones which in some places merge into sandy shales. The cementing material is usually calcareous, but considerable earthy impurity or clay is often present. The coarser components of the rock at Gatun and of that occurring along the canal between Gatun and Bohio consist of igneous material; in many specimens grains of nearly fresh feldspar and ferro-magnesian silicates may be recognized, but as a rule the material is in such a finely divided state that it is impossible to say whether it is of direct volcanic origin or has resulted from the degradation of older igneous rocks. At many points fossils are abundant in the core specimens and carbonaceous matter is very generally present.

Age of the Bohio formation.—From fossils collected by Hill and others and by myself and examined by Dr. William H. Dall, it appears that the beds described are of Eocene age and contain a number of species typical of the Claiborne and some common to the Upper Tejon of California.§ In the material that I collected at Vamos Vamos Dall has identified the following species:

* Op. cit., 188.

† Op. cit., p. 179.

‡ Op. cit., p. 6.

§ Hill, op. cit., Part VI, Report by Dr. William H. Dall upon the Paleontology of the collections, pp. 271-275.

<i>Lupia perovata</i> Conr.	<i>Cytherea</i>
<i>Glyptostyla panamensis</i> Dall.	<i>Mactra</i>
<i>Turritella gatunensis</i> Conr.	<i>Corbula</i>
<i>Marginella</i> sp.	<i>Tellina</i>
<i>Natica</i> (cf. <i>eminula</i> Conr.)	<i>Leda</i> sp.
<i>Pleurostoma</i> sp.	<i>Pyramidella</i> sp.
<i>Dentalium</i> sp.	

In addition to these there are fragments of *Ostrea* sp., *Liocardium*, and *Pecten*, and a small ribbed *Cardium* was noted.

From the locality on the left bank of the canal near Gatun practically the same fossils were collected as were found at Vamos Vamos with the addition of a *Cadulus*.

There can be no doubt that the rocks at Vamos Vamos, near Gatun, and at intermediate points as shown by borings, belong to the same formation, and they have been so regarded by Hill and Bertrand. The relation of these rocks, however, to the peculiar breccias and conglomerates at Bohio is not so clearly shown. Bertrand considers that the breccias at Bohio belong to the same series as those occurring in the central part of the isthmus which I have described as the Obispo formation, and he correlates them with the European Tongrian, that is, the base of the Oligocene in the Paris Basin section. This determination is based on fossils obtained from a boring at Kilometer 24-36. Here, according to Bertrand,* small nummulites of the Oligocene type are associated with *Orbitoides* that appear to be the same as those of the Peña Blanca marls (to be described later). The breccia, a part of the "Gamboa rock," is regarded, therefore, as certainly Oligocene and probably Aquitanian. In the geological profile accompanying Bertrand's report a special tint is given to the breccias, in order to accentuate the difference between these beds and the higher series, and they are referred tentatively to the Tongrian.

Hill appears to regard the breccia and perhaps the conglomerates at the French lock site as parts of an early igneous formation older than the Vamos Vamos beds. My own observations make me believe that the conglomerates at the lock site represent the lowest portion of the formation of which the Vamos Vamos beds and those in the vicinity of Gatun are the upper parts. This opinion is in accord with the local structure, the prevailing dip of the conglomerates, about 15 degrees to the northwest, being sufficient to carry them below the beds at Vamos Vamos. From a boring made by the Canal Commission at the Bohio lock site (Hole 24-b, K 24), fossils were obtained at elevations of from 20 to 40 feet below sea level that are believed by Doctor Dall to represent an Eocene horizon. They consist of fragments of *Lucina*, *Lima*, *Pecten*, *Cardium*,

* Op. cit., p. 5.

Protocardia, and *Ostrea*, a small *Fusus* (?), a specimen of *Orbulina*, and a *Melanian* (?) associated with abundant fragmentary plant remains. The abundance of carbonaceous material and the presence of the fresh-water *Melanian* within a few feet vertically of the salt or brackish water species suggest delta deposits, and with this the physical character of the beds agrees perfectly, the fossils being preserved in calcareous sandstones or shales between beds of conglomerate precisely as are those exposed at the cutting for the lock site. Before reaching these fossiliferous layers the drill passed through a fine breccia like that shown at the quarries at Bohio, interbedded with which are fine-grained sandy layers containing plant remains. Conglomerates like those of the lock site were found below this breccia, then at about twelve feet below sea level a fine carbonaceous sandstone layer was encountered, and below this the fossiliferous sandstones.

On the strength of this evidence I am inclined to regard the conglomerates and breccias at Bohio as members, probably occurring near the base, of the formation that I have called the Bohio, and that they were laid down as delta deposits at the mouth of a large river, while the Vamos Vamos beds and those near Gatun were deposited contemporaneously in deeper water. It is entirely possible, of course, that the conglomerates may belong to an earlier epoch than the Claiborne, but the evidence for or against this is so meagre that in the absence of anything to the contrary it seems entirely reasonable to place the conglomerates at the base of the Claibornian Bohio formation. No one can doubt the intimate relation between the conglomerates and the breccias nor that they are contemporaneous. It has been shown also that the conglomerate occurring in patches near Mamei and Gorgona rests unconformably upon the breccias of the Obispo formation. For this reason and as is also shown in the case of the Culebra beds, I believe that the Bohio rocks with their breccias are younger than the breccias of the Obispo formation instead of being a part of them as suggested by Bertrand.

Thickness of the Bohio Formation.—Of the thickness of the Bohio formation very little can be said. Borings on the "F" line at the Bohio dam site have brought up samples of the conglomerate, sandstone and breccia from nearly 200 feet below sea level, while at least 75 feet more may be added to this as exposed above sea level in the near-by hills. From Bohio to Gatun, where the Bohio formation is covered by younger beds, the distance is about seven miles in a straight line; assuming a uniform dip of only two degrees to the north-west, this would give at Gatun a thickness of nearly 1300 feet. At least 300 feet of the section has been shown in borings at Gatun.

Culebra Beds.

From near Empire to Pedro Miguel, a distance of about five miles along the line of the canal through the Culebra cut, are the best exposures of sedimentary rocks in the Canal Zone. The Obispo formation has been uncovered by excavation from Bas Obispo to a point about midway between Empire and Culebra, where it disappears beneath the sediments described by Hill and others as the Culebra beds. A considerable thickness of these beds has been exposed in the deepest part of the cut, beneath which borings have shown that they extend to at least 40 feet below sea level. A boring at Kilometer 55 passed through 207 feet of Culebra shales and sandstones without reaching the base of the formation. Nearly 175 feet should be added to this section as representing the part already removed from the canal prism at the point where the boring was made. This would give an observed thickness of nearly 400 feet. Hill estimated the thickness as at least 500 feet* and the total is probably greater rather than less.

So far as they have been exposed or explored by borings the rocks are found to be largely soft shales with abundant sandy, conglomeratic, and calcareous layers. At many horizons lenticular bodies of limestone occur. Although there are some thick beds of homogeneous pure clay shales, the majority of the rocks, whether sandstones, shales or conglomerates, are richly carbonaceous; lens-like seams of lignite have been found at many places in the cut and remains of trees and plants are abundant. The sandstones are impregnated with lime and in the coarser varieties of the rock films of the cementing calcite are readily visible. The conglomerates are composed of sub-angular rock fragments less than a quarter of an inch in diameter held in an impure calcareous matrix. The material of which all of the sedimentary Culebra beds are composed was derived from an older igneous land mass of which presumably the Obispo breccia was a part; quartz is notably absent and the colors range from bluish and greenish gray to nearly black in the richly carbonaceous beds.

In the upper part of the section at a number of places along the canal cut between Empire and Paraiso are extensive occurrences of andesitic breccias. Petrographically the fragments composing them closely resemble those of the Obispo breccia, but they are smaller and more uniform in size than those of the Obispo breccias of the same region. In the central area near Culebra summit these breccias are seen to rest upon the shales or fine sandstones of the Culebra beds. At the same locality there are numerous intrusive masses of basalt, and

*Op. cit., p. 193.

faulting and considerable folding have taken place so that the relations of the various rocks are not perfectly clear. There can be no question, however, that the breccias are a part of the upper Culebra beds, for in several places a simple sedimentary contact between the two kinds of rock was observed, and it was even possible to collect hand specimens showing the transition from fine shales to the breccia. The breccias are at many places cemented by calcite of secondary origin. Specimens collected at Gold Hill (Cerro Culebra) and Paraiso, although considerably decomposed, may be recognized as made up of fragments of pyroxene-andesite of different textures, some of which have an abundant glassy groundmass. A boring near Paraiso (Kilometer 58) showed similar rocks at several horizons, while interstratified with them were other beds of sediments exactly like those in the lower or main part of the Culebra section. It would appear, therefore, that toward the close of Culebra sedimentation volcanic eruptions took place and that the ejectamenta were laid down conformably on the sediments; a number of such eruptions evidently occurred with intervals of quiescence, during which the deposition of the sediments continued. The association of these breccias with the Culebra sedimentary beds corresponds closely with that of the Bohio breccias and conglomerates with the exception that the Culebra breccias appear in the upper part of the section while those at Bohio seem to be near the base. Unfortunately the state of decomposition of the Bohio rocks prevents satisfactory petrographical comparison between the two breccias. In neither case does it seem possible to separate the breccias from the sediments as distinct igneous formations.

The relation of the Culebra sediments to the Obispo formation is more definitely shown than the Bohio rocks to the Obispo on the Caribbean side of the isthmus. At the surface the relations are not always clear, but it is possible by means of borings made at frequent intervals to trace the Obispo breccias from Bas Obispo south to a point near Empire, where they suddenly pitch in a southeast direction beneath the rapidly thickening cover of the Culebra beds. There is a moderate amount of local folding and faulting in the region and the Culebra beds have a prevailing dip to the southeast, but their inclination is much less than that of the southeasterly pitching surface of the Obispo on which they rest. Near Corozal the Obispo again appears at the surface, while between Corozal and La Boca borings have shown that there are present, beneath the alluvium, sandy shales precisely like many found in the Culebra section. As mentioned later in discussing the age of the Culebra beds, certain limestones that are thought to belong to the upper part of the shale series rest on the

Obispo breccias near Empire. The evidence between Culebra and Empire, at Corozal, and in the vicinity of La Boca seems to indicate that an unconformity exists at the top of the Obispo separating it from the Culebra beds. As has been shown, similar unconformable relations appear to exist between the Obispo and Bohio formations on the Atlantic slope.

Empire limestone.—Hill noted an occurrence of massive, semi crystalline limestone near Empire and from its relations in the field referred it to the Culebra beds.* I am not certain that I identified Hill's exact locality, but I did succeed in finding limestone of precisely the same character in the vicinity of the railway station at Empire on both the east and west sides of the track. Fifty feet east of the new station there are exposures, about ten feet thick, of a very massive cream-colored limestone in which I was unable to discover fossils; the outcrop is a small one and its relation to other rocks in the vicinity is not shown. About 150 yards west of this locality on the opposite side of the railway a greenish, impure sandy limestone, hard and compact, occurs beneath thin-bedded calcareous shales and sandstones, the whole exposure being less than ten feet thick. Fragments of a *Pecten* were found in this limestone but no determinable fossils. There are no exposures between these outcrops and the canal cut about one quarter of a mile to the northeast, at which point the Obispo formation is found close to where it disappears beneath the Culebra beds.

Elsewhere in the Culebra section lenticular bodies of limestone, less thick than the massive rock at Empire but otherwise of the same character, are found associated with the calcareous shales and sandstones, and it seems reasonable, as Hill has suggested, to regard the Empire occurrences as of this nature and belonging to the Culebra beds. The field relations, such as they are, appear to indicate that rocks of the Obispo igneous formation must lie within a few feet of the surface in the neighborhood of Empire, and it is not impossible that the limestone may rest directly upon them.

About midway between Empire and Las Cascadas on the Panama Railroad other limestones occur. They are less massive than those at Empire, in places gnarly and crumbling, and being practically at the surface where exposed in the railway cut are considerably weathered. Their color is buff or yellowish pink. The few fossils from this locality are poorly preserved and indeterminate, according to Dr. Dall, but he recognized a nullipore and two species of *Pecten* and suggests that this may be a reef deposit.

* Op. cit., p. 195.

Nearer Las Cascadas boulder-like concretionary masses of hard crystalline limestone, one to four feet in length, are preserved in red clays of decomposition near the railway and canal. Fragments of a *Pecten* and a tube-like *Xylotrya* were collected from one of these limestones but their age could not be determined.

Age of the Culebra beds.—Hill made a careful study of the Culebra beds, but only succeeded in finding fossils in the Empire limestone, mostly foraminifera that Bagg considered representative of the Eocene, and as quoted in Hill's report, he correlated this limestone with the Peña Blanca marl.* In material that I collected in the vicinity of Las Cascadas from rocks that I believed to belong to the same calcareous horizons as the Empire limestone, Dr. Dall failed to find any species from which the age of these beds could be determined. Bertrand and Zürcher, however, collected from the same localities and their material was determined by Douvillé as representing the Burdigalian Miocene, or the equivalent of the beds exposed at Kilometer 10 near Gatun.† The French geologists regarded the Empire limestone as belonging to the upper part of the Culebra beds and equivalent to the Vamos Vamos beds of the Caribbean slope. In the vicinity of Pedro Miguel Bertrand and Zürcher found fossils that were correlated with those from Las Cascadas. Fossils from my collection at the same locality were determined by Dr. Dall as probably representing an Oligocene reef deposit, while beneath them a typical Claiborne fauna was found in a compact impure limestone.

It is probable that the Claiborne horizon at Pedro Miguel is the one that Bertrand and Zürcher correlate with the beds at Las Cascadas, since the fauna of both is regarded by them as identical with that preserved at Kilometer 10 near Gatun. It is in collections from the Gatun locality made by Hill and myself that Dall finds his most typical Claiborne fossils. At both Pedro Miguel and Las Cascadas the position of the fossiliferous beds appears to be at or very near the top of the Culebra section, and in the absence of determinable fossils from lower horizons it seems reasonable to refer the Culebra beds as a whole to the same period as that in which the Bohio formation was deposited. The abundance of carbonaceous shales, seams of lignite and plant remains, together with fragments of a *melanian* found in the canal cut near Culebra, suggest that most of the beds below the limestone horizons were deposited in fresh water.

Limestones of the Upper Chagres.—Following the Chagres headward in a northeasterly direction from Matachin, where the river turns sharply to the northwest and flows toward the

* Op. cit., p. 272, 275.

† Op. cit., pp. 6-9.

Caribbean, calcareous rocks similar to those near Las Cascadas and Empire are exposed at many places between Cruces and Dos Bocas, a distance in a straight line of about twelve miles. Between Cruces and Palo Grande compact limestone similar to that at Empire rests on carbonaceous shales like many in the Culebra beds. The rock is partly crystalline and contains in places fragments of shells. About one mile above the mouth of the Chilibre is the lower end of a winding gorge through which the Chagres flows for nearly twelve miles, the entrance to the gorge being a mile below Dos Bocas. The river, entrenching itself in an old valley, encountered between the points mentioned limestones and calcareous sandstones which offered greater resistance to erosion than the rocks to the northeast and southwest, so that its former meandering course has been preserved very perfectly, and at the outside curves of the meanders are nearly vertical cliff exposures of massive calcareous sandstone and limestone, in places more than one hundred and fifty feet high. Although the length of the gorge following the river is approximately twelve miles, the belt of hard rocks traversed is only about four miles wide.

The rocks are all of a light cream or buff color and range from partly crystalline limestones to coarsely granular rocks composed of broken shells, sands, specks of magnetite and occasional pebbles of igneous rocks held in a calcareous cement. Certain layers are well bedded, others massive, while cross-bedding is not uncommon. Fossils, *Ostrea* and *Pecten*, are abundant, but I was unable to find any determinable species; at a locality about a mile below Alhajuela a bed composed of broken corals and fragments of molluscan shells was found.

The similarity of some of these rocks and their fossils with those observed near Las Cascadas is striking, and Bertrand and Zürcher regarded the two occurrences as of the same age.* I agree with this opinion in so far as the Chagres and Las Cascadas beds are correlated with the fossiliferous rocks exposed by the canal at Kilometer 10 near Gatun, whose fauna, as has been said, Dall considers Claiborne Eocene; the French geologists have compared the Chagres rocks with beds near Marseilles that grade from Upper Oligocene to Miocene. Bertrand states, on the authority of M. Boutan,† that the limestone near Dos Bocas resembles in part certain marls occurring at Peña Blanca, and that it contains foraminifera. I am not prepared to say that this is not the case, but the structure of these beds as noted both by Bertrand and myself would carry them beneath the limestones of the gorge, and they should correspond closely in position to the limestones observed near Cruces and therefore be comparable to the Empire limestone.

* Op. cit., p. 10.

† Op. cit., p. 10.

MARLS OF PEÑA BLANCA.

(*Lower Oligocene.*)

Less than a quarter of a mile west of the railway station and quarries at Bohio at the base of a low hill are outcrops of a hard, light yellowish marl. A quarter of a mile still farther west the same rock has been exposed in excavations for a diversion channel made by the French. The rock as a whole may be described as a thick-bedded marl, buff to cream-colored, and containing foraminifera in greater or less abundance, the most typical being *Orbitoides fortisi*. Sparsely disseminated through the rock are minute specks of a dark silicate and fragments of feldspar. So far as is known, the only occurrences of this rock are at the localities mentioned between Bohio and Peña Blanca.

Nowhere in the vicinity of Bohio was I able to discover the relation of the Peña Blanca rock to the Bohio conglomerate or breccia, nor is any direct evidence found in the borings, but from the general field relations it would seem that the marls are younger than the breccias, since less than half a mile east of the marls borings have indicated the presence of the breccias and conglomerates many feet below the observed elevation of the marls, while as shown at the lock site exposures, the Bohio rocks dip about fifteen degrees in the the direction of the marls. Unless a fault of considerable magnitude occurs between the two localities, of which there is no evidence, the marls cannot be older than the Bohio beds, nor is there any indication that they were contemporaneous deposits, borings between Peña Blanca and Vamos Vamos having passed through rocks of the Vamos Vamos facies of the Bohio alone. Hill states* that he found the foraminiferal marls in unconformable contact with the conglomerates at a locality known as Peña Negra, one mile below Bohio. I was unable to identify this point, but Hill's observation is in entire accord with my opinion that the foraminiferal beds of Peña Blanca rest unconformably on the rocks of the Bohio formation.

Hill regarded the Peña Blanca beds as older than the Vamos Vamos, basing his opinion on the northwest dip of the Vamos Vamos beds and the position of the foraminiferal marls southeast of them. I have shown, however, that in all probability the Vamos Vamos beds and the Bohio conglomerates belong to the same formation, and the discordance between the Peña Blanca and Vamos Vamos beds is to be considered as another manifestation of the same unconformity observed by Hill at Peña Negra. This view agrees with Dr. Dall's opinion that the Peña Blanca marls, on account of the presence of the charac-

* Op. cit., pp. 178-179.

teristic species *Orbitoides fortisi*, are of Lower Oligocene age corresponding to the Vicksburg.

MONKEY HILL FORMATION.

(*Upper Oligocene.*)

Between Gatun and the coast at Colon is a more or less hilly region in which numerous exposures may be found along the lines of the Panama Railroad and the French canal. Fossils collected from the rocks at these points indicate that all of the beds are of the same age. The rocks are well stratified, often thin bedded, calcareous sandstones, argillaceous sandstones, marls and shales, usually fine grained and even-textured, and when fresh of a neutral bluish or greenish gray color. They belong to what Hill called the Monkey Hill beds,* the best exposures at the time of his visit being near the Panama Railroad where it passes through the hills. At the time of my examination by far the best exposures were at Gatun, where extensive excavation had been made for the locks. At this point also it is believed that the base of the formation is shown. In order to avoid ambiguity these beds will be referred to as the Monkey Hill formation, as they were so described by Hill, although in my report to the Canal Commission they were spoken of as the Gatun beds, since they made up a large part of the rocks through which the locks at Gatun were to be constructed.

From fossils collected both by Hill and myself at Monkey Hill and Gatun, Dr. Dall considers that the Monkey Hill formation is equivalent to the Chipola Oligocene, that is, younger than the Vicksburg or the *Orbitoides* marls of Peña Blanca. Among the species recognized are :

<i>Cardium</i> sp.	<i>Turritella</i>
<i>Liocardium serratum</i> Linn.	<i>Oliva</i> sp.
<i>Psammobia</i>	<i>Cadulus</i>
<i>Cytherea</i>	<i>Cerithiopsis</i>
<i>Abra</i>	<i>Agriopoma</i>
<i>Tellina</i>	<i>Cyclinella</i> .
<i>Chione</i>	

Directly below and within a foot or two of the point where these fossils were collected at Gatun is a coarse conglomerate also containing numerous fossils that are pronounced by Dall as of the same age as those found near Gatun in the Bohio beds. The conglomerate appears to grade upward into the fine calcareous sandstone or marl that contains the younger fossils, and were it not for the definite indication of greater

*Op. cit., 176-177, 208.

age from the fossil evidence, I should be inclined to consider this conglomerate a basal member of the Monkey Hill formation; it is, of course, not impossible that this may be the case and that the fossils were derived from the erosion of the older Bohio terrane. Less than half a mile in a straight line from this locality is the point where the Bohio (Claibornian) fossils were collected at the edge of the French canal near Gatun (Kilometer 10), and the general dip of the beds at this locality is in the direction of the conglomerates exposed at Gatun. In any event the base of the Monkey Hill formation must be very near the conglomerate, whether actually at the top or including the conglomerate. Unfortunately there are no other exposures in the vicinity to throw light on this matter and little can be learned from the drill records. The conglomerate is clearly shown by a number of borings, below which are beds of a white pumiceous tuff associated with other conglomerates similar to the uppermost one, and calcareous sandstones and marls. Beneath these beds are fine calcareous or argillaceous sandstones of uniform composition that undoubtedly belong to the Bohio formation.

At Gatun about eighty feet of the Monkey Hill formation is shown, but, as in the case of the other sediments, it is only possible to give an approximate estimate of the thickness of the whole formation. From rough calculations, assuming low dips of from one to five degrees from Gatun northward, there should be a thickness of at least five hundred feet in the vicinity of the Monkey Hills near Colon, while perhaps from two to three times this thickness may exist. To the west, where the Chagres leaves its main valley and passes through a younger valley to the sea, a thickness of from one hundred and fifty to two hundred feet is actually shown in the hills, while as much more must exist beneath the present floodplain of the river if the dips observed in the region are at all regular.

No rocks corresponding in age to those of the Monkey Hill formation have been observed on the Pacific side of the isthmus.

The lithologic character of these rocks is essentially the same as that of the finer-grained Bohio rocks. They are composed almost entirely of the debris of igneous rocks, in some cases the particles being exceedingly fresh, but commonly decomposition and fineness of texture make it impossible to say whether the material was derived directly from volcanic eruption or from the degradation of an older land surface. I am in favor of the latter hypothesis, inasmuch as no evidence has been found elsewhere of contemporaneous eruptions.

IGNEOUS ROCKS.

Acid Porphyries and Tuffs.

The oldest igneous rocks, the breccias of the Obispo formation, have already been described, and it has been shown that eruptions of much the same character continued intermittently for some time during the period of early Tertiary sedimentation. After an interval of quiet, eruptions of an entirely different sort of rock took place either at the close of the Bohio epoch or at the beginning of the Monkey Hill. These later eruptives are largely fragmental and are found on both the Atlantic and Pacific sides of the isthmus. The massive rocks of this period are best shown at Ancon Hill, which is composed entirely of rhyolite porphyry. Almost completely surrounding Ancon Hill, the continuity being broken only on the west by a later intrusion of pyroxene-andesite, are tuffs and fine breccias of the same composition as the rhyolite porphyry of the hill. The tuffs are well bedded and in some places quite massive, individual beds varying from six inches to five or six feet in thickness; they are fine-grained and, where exposed near the surface, usually altered to a white clay.

Beds similar to those in the vicinity of Panama are exposed between San Pablo and Tabernilla on the Atlantic slope, the best outcrops being along the Chagres River near the point where the Panama Railroad crosses northwest of San Pablo.

These comparatively siliceous rocks are the ones that Hill placed in his Panama formation; he referred to them as rhyolitic tuffs,* while Bertrand considered them as trachytic.† Specimens that I collected from various points showed greater or less decomposition in most cases and none was sufficiently fresh for chemical analysis. A microscopical study shows that they are all closely related and that in addition to the occurrences mentioned, certain intrusives in the Culebra beds probably belong to the same series. It is impossible to group all these rocks under one descriptive head such as rhyolite tuff or trachyte tuff; certain facies are distinctly rhyolitic, others trachytic, while forms near quartz-bearing latite are not uncommon.

The rock of which Ancon Hill is composed is a creamy-white porphyry with phenocrysts of feldspar in a fine felsitic groundmass; occasional specks of an altered dark mineral are present. Microscopically the rock is seen to be a porphyry with phenocrysts (mentioned in order of relative abundance) of albite, quartz, and orthoclase in a groundmass containing abundant orthoclase, some quartz and a little albite. Slight kaolinization of the feldspars has taken place, and the ferro-

* Hill, op. cit., 199-202.

† Bertrand, op. cit., 9, 23.

magnesian mineral, altered beyond recognition, has stained the rock slightly with iron oxide; there is no indication that the dark silicate was an important constituent. Another specimen of the same rock from a near-by locality showed little or no porphyritic texture; a few fragments of orthoclase and laths of oligoclase are present, with many large irregular patches of quartz; there is some magnetite and limonite but apparently no ferro-magnesian mineral.

The islands of Naos and Culebra in Panama Bay, between three and four miles from Ancon Hill, are composed of a similar porphyry containing a moderate number of phenocrysts of plagioclase ranging from andesine to a labradorite (Ab, An_2), and hornblende. The groundmass is holocrystalline and consists of orthoclase and plagioclase in about equal amount with traces of hornblende, usually altered to chlorite, some magnetite, and quartz.

Closely related to the rock of Naos Island is an intrusive sill found in the beds at Culebra north of Gold Hill (Cerro Culebra). This rock is a fine-grained porphyry with a fluidal base, largely glassy, but containing a few microlites of plagioclase and minute grains of orthoclase. The phenocrysts are mostly andesine although labradorite is present. A dark mineral, perhaps hornblende, was observed in several specimens, but in all cases it has been considerably altered. In one specimen it was impossible to decide whether the altered mineral had been hornblende or biotite, the ragged form suggesting the latter. Near Las Cascadas, and associated with the Obispo breccia, a dense rock with a marked fluidal texture is exposed at several places. Under the microscope it is found to consist of a partly glassy groundmass, laths of plagioclase, a little orthoclase and an abundance of fine grains of magnetite. The few plagioclase phenocrysts are considerably decomposed and ferro-magnesian minerals are notably absent.

All of these rocks, with the exception of the Ancon porphyry, appear to be intermediate between true rhyolites and latites, with perhaps a stronger tendency toward the latitic form; the impossibility, however, of determining the exact character of the groundmass in most cases prevents a definite classification by microscopical methods, and none of the specimens, as has been said, was sufficiently fresh to warrant chemical analysis. The tuff exposed by the Chagres River in the vicinity of San Pablo consists of small fragments of fibrous or vesicular glass or pumice of low specific gravity; there are occasional particles of plagioclase and orthoclase crystals but no quartz. A greater textural variation is found in the tuffs in the vicinity of Panama; they are less pumiceous and consist of fragments of rock essentially the same as that of Ancon Hill.

The relation of the tuffs and fine breccias in the vicinity of Panama to Ancon Hill suggests that the pyroclastics were derived from a volcanic center now marked by the massive porphyry of Ancon. The tuffs, as has been said, are well stratified and surround Ancon Hill except in the vicinity of Sosa; they dip away from Ancon Hill at all points and in a few instances have been found to be cut by dikes that appear to radiate from the hill as a center. No local source or center of eruption for the tuffs on the Atlantic slope has been found, and it is possible that they may have been derived from the Ancon eruptions, the distance between the points being only twenty miles. The extremely light pumiceous character of the San Pablo deposits would favor this view.

The age of the acid eruptives is fairly well shown at several places. Near Panama evidence from borings quoted by Bertrand* indicates that the acid tuffs are younger than the Culebra beds and rest upon them. I was unable to find boring records at the localities mentioned by Bertrand, but the field relations fully justify Bertrand's view. The Culebra beds disappear beneath the surface of the lower Rio Grande Valley near Pedro Miguel, and at Miraflores the acid tuffs are well exposed at a number of points. Borings made in exploring for dam sites between Sosa Hill and Corazal and also across the mouth of the Rio Grande indicate the presence of sediments similar to those of the Culebra beds at approximately seventy or eighty feet below sea level, and one boring near La Boca showed a dike of rock similar to that of Ancon Hill cutting these sediments. On the Atlantic side between San Pablo and Tabernilla there is no surface evidence bearing on the age of the acid tuffs. Borings for a dam site near San Pablo indicate rocks similar to those of the Bohio breccias, beneath what I believe to be tuffs of the acid series, but the advanced decomposition of the rocks makes it difficult to distinguish one from another, and the supposed tuffs may be sandstones of the Bohio formation. It was mentioned, in describing the Gatun occurrence of the Monkey Hill beds, that beneath the uppermost conglomerate borings revealed the presence of one or more beds of extremely fine white pumiceous tuff, and recent excavation for a road from the old Gatun railway station to the encampment at the top of the hill has exposed the tuffs. They are clearly interstratified with the sediments, but as previously stated, it is difficult to determine the base of the Monkey Hill beds, so that the tuffs may be regarded as lying either at the top of the Bohio or at the base of the Monkey Hill formation. In either case there can be no doubt that they are younger than the Eocene sediments and not Cretaceous, as supposed by Hill.

* *Op. cit.*, 8-9.

Basic Intrusives.

The last phase of eruptive activity of which there is evidence in the Canal Zone is represented by numerous basic intrusives that occur in great abundance in the central and southern parts of the isthmus. To the north, on the Atlantic coast, they are exposed in the vicinity of Porto Bello, and about eighteen miles east of Colon. Between Gorgona and Pedro Miguel most of the hills are composed of the basic rocks. In all observed occurrences the rocks are intrusive in the older formations and most commonly occur as large stock-like masses; dikes are numerous but no surface flows have been found. The rocks that have been collectively referred to as basic intrusives are pyroxene-andesites or basalts. All are notable for the calcic character of the feldspar, which is frequently bytownite or anorthite. Augite and magnetite are abundant and many of the rocks contain considerable orthorhombic pyroxene. The majority of the rocks are pyroxene-andesites, but basalts are common and in one or two instances were found to contain much olivine; practically all have more or less glass in the groundmass and some are vesicular. Although undoubtedly related to the andesites from which the Obispo breccias were derived, none of the Obispo rocks shows the extremely basic character of many of the later intrusives.

At many places in the interior the basic intrusives may be seen cutting the older sedimentary rocks, while the relations near Panama seem to indicate that the andesite of Sosa Hill has been intruded into the rhyolitic tuffs of Ancon. So far no basic rocks have been observed to cut the Monkey Hill formation, but the large masses of pyroxene-andesite at Porto Bello are probably intrusive in these sediments although no contacts have been observed. The very uniform lithologic character of the Monkey Hill beds, and the lack of any observed unconformity indicating decided crustal movements such as must have accompanied the intrusion of the andesites, would seem to show, in the absence of any more direct evidence, that the period of basic intrusions followed the Monkey Hill epoch and may have been the immediate cause of the termination of that long period of quiet sedimentation.

Distribution of the Rocks.

Unfortunately little is known of the areal distribution of the various formations that have been described. The section exposed along the canal line is fairly complete and in places it has been possible to trace certain of the formations a few miles beyond the boundaries of the Canal Zone, but even if greater areas had been examined it is doubtful if any more

definite information in regard to the limits of the different formations could have been obtained. To a moderate degree the character of the topography may be taken as a guide and the known distribution of the different sorts of rocks thus slightly extended. This applies more especially to areas of sedimentary rocks as contrasted with those of igneous formations.

Obispo breccias.—In the vicinity of Matachin Obispo breccias form the hills north of the Chagres, but the surface extension of the formation in this direction can not be great, for, not more than four miles northwest of Matachin, younger sediments are exposed in the neighborhood of Tabernilla and Frijoles. From Matachin southeasterly the breccias occur on both sides of the canal, in places covered by the Culebra beds, beneath which they eventually disappear between Empire and Culebra; they again make their appearance in the vicinity of Corozal and they have been noted at several places in the hills traversed by the old Cruces trail northeast of Miraflores and Pedro Miguel. The breccias are particularly well shown in the rolling country northeast of the city of Panama near Las Sabanas. From borings, the Obispo is known to occur as far north as San Pablo, but beyond that point there is no evidence of its existence.

Basic intrusives.—Although the basic intrusives are not limited to any particular part of the isthmus, they are most abundant in the areas characterized by the Obispo breccias. In the Culebra region they are especially numerous, and are believed to make up a large part of the mountainous region southwest of the city of Panama along the Pacific coast; near the shore are many exposures of columnar basalt that have been observed beyond the mouth of the Chorrera River, 18 miles southwest of La Boca. No basic intrusives have been found northwest of San Pablo in the Canal Zone, but at Porto Bello, about 18 miles northeast of Colon, pyroxene-andesites are exposed at the water's edge and occur in many of the near-by hills.

Acid eruptives.—The rhyolitic rocks and others related to them occur in two general areas. One of these is at Panama, where the well-bedded tuffs surround the central mass of rhyolite porphyry of Ancon Hill. The fragmental rocks underlie the city and extend as far north as Miraflores. Similar rocks are also found on the southwest side of the Rio Grande opposite La Boca, while massive rock like that of Ancon Hill composes the islands of Naos and Culebra in Panama Bay. Hershey has reported similar rocks more than one hundred miles to the southwest near Santiago.* The

*The Geology of the Central Portion of the Isthmus of Panama, Oscar H. Hershey, Bull. Dept. of Geol., Univ. of Cal., vol. ii, p. 244, 1901.

second area, in the vicinity of San Pablo and Tabernilla, is probably more restricted than that of the Pacific side. The rocks are best exposed along the Chagres River near San Pablo, but the hills extending northward from Barbacoas, where the Panama Railroad crosses the Chagres, are composed entirely of these acid pyroclastics. Their exact northwestern limit is unknown but probably lies at some point between Buena Vista and Tabernilla. Similar rocks are found in the vicinity of Gatun interbedded with the sediments at that locality.

Sedimentary rocks.—A little more is known in regard to the distribution of the sedimentary formations. So far as my observations go, the Culebra beds are restricted to the occurrences in the Culebra district with a probable extension as far south as La Boca suggested by borings. On the northern side the sediments from the Bohio formation up to the Monkey Hill have a much wider distribution. The sediments extend from Limon Bay along the line of the canal to Bohio at least, and remnants of the Bohio formation have been found as far south as Matachin. The subdued topography characteristic of areas of these young sedimentary rocks extends in a northeasterly direction from Colon almost to Porto Bello and throughout this distance I believe that sedimentary rocks are the only ones represented at the surface. Between this coast belt and the interior, where the limestones of the upper Chagres are exposed, is a region of some elevation concerning which there is no information whatever except quite near the canal line, at Tabernilla and Frijoles, where poorly exposed sediments containing lignite are known to occur. Southwest of the canal line and along the Atlantic slope sediments have been traced for nearly twenty miles up the valley of the Trinidad River. The rocks of this region are of the same character as the Bohio or Monkey Hill formations; they are exposed at a few places along the water's edge, but the rock at these outcrops is in an extremely decomposed condition and no fossils were discovered. On the Pacific coast southwest of the city of Panama and beyond the range of hills composed of basic intrusives is the broad low valley of the Chorrera, that, on account of its very subdued topography, looks as if it had been eroded in sedimentary rocks. The Chorrera River rises near the head waters of the Trinidad and it is not improbable that the sedimentary rocks extend across the divide and down the Chorrera to the Pacific. According to Lull,* coal, probably a lignite, occurs in the drainage of the Rio Indio,

* Reports of Explorations and Surveys for the location of Inter-oceanic Ship Canals through the Isthmus of Panama, E. P. Lull, U. S. N., Washington, 1879. Pp. 30-32.

and the deposits may be reached from the Pacific side by ascending the Chorrera River. The locality is indefinite, but cannot be far from the head waters of the Trinidad, where similar lignites have been reported.

Structure.

The broader features of the geological structure of the isthmus are simple. In the Canal Zone the sedimentary rocks of the Atlantic side dip toward the coast at moderate angles while on the southern side of the isthmus the inclination of the Culebra beds is in the direction of the Pacific. It has not been possible to discover any marked characteristic structure in the Obispo breccias; in the central region the few contemporaneous flows appear to be nearly horizontal, while no evidence of stratification can be made out in the occurrences near Panama and Las Sabanas.

When examined in greater detail it is found that the inclination of the older sediments on the Atlantic side of the isthmus is greater than that of the Monkey Hill beds. The strikes also are different; that of the Bohio formation, best shown at Bohio and Vamos Vamos, being about northeast-southwest, while the Monkey Hill beds at Gatun strike more nearly east and west. This agrees with the evidence of unconformity between the Bohio formation and the *Orbitoides* beds of Peña Blanca. No indication of marked faulting has been discovered in the region north of Empire, although local fracturing and minor dislocation have occurred at places where the folding appears to have been pronounced as at Vamos Vamos, according to Hill, and to a minor degree at Gatun.

The acid tuffs at San Pablo are inclined to the northwest at angles of from five to ten degrees; with the exception of isolated patches of Bohio conglomerate near Matachin these are the last beds encountered, following the canal southward, in which any structure can be made out until the Culebra beds are reached near Empire.

South of Empire greater structural complexity exists. The Culebra beds are locally folded, but have a general southeasterly dip of from ten to fifteen degrees. At several points the Culebra cut is crossed by small faults, the downthrows of from ten to fifty feet being to the southeast. At the deepest part of the cut, where the canal passes between Gold Hill and Contractor's Hill, the Culebra shales with the breccias in the upper part of the section have been intruded by basalt and since intrusion have suffered faulting. The mass of Gold Hill has dropped as a block or wedge between the beds on either side, being bounded on the north and south by faults; during

the process of faulting, the sediments, previously deformed by the intrusions of basalt, were still further twisted and now dip at angles of sixty degrees or more to the northeast into Gold Hill.

Between Culebra and the Pacific the structure is simple. The Culebra beds, frequently intruded by broad dikes of basalt, are gradually carried by their prevailing southeast dip beneath the level of the Rio Grande valley not far from Pedro Miguel. From Miraflores to the outskirts of the city of Panama the acid tuffs have been locally folded, but in the neighborhood of Ancon Hill and under the town their structure, as already mentioned, appears to be due to initial dips of the beds deposited on the flanks of the old Ancon volcano. That is, in tracing the beds from north of Ancon around the hill to a point on the shore close to Sosa Hill the strike is found to swing through an angle of nearly one hundred and eighty degrees; the dips range from five to fifteen degrees, the steeper inclination being found near the base of Ancon Hill.

Reviewing these facts, the structure of the isthmus appears to be characterized by a dominant arch or broad anticline with its axial trend between east-west and northeast-southwest, the crest of the arch being in the south-central part of the isthmus near Bas Obispo. The northern limb of the anticline is of moderate inclination, while the southern limb, near the crest of the arch at least, is steeper. The limestones and calcareous sandstones of the upper Chagres are nearly at the crest of the fold and their prevailing southwest to west dip suggests that the anticline pitches to the southwest. Whether this is a broad structure or comparatively local is not known, no evidence having been found in the country southwest of the Canal Zone. It is probable that the westward pitch is more than a mere local cross fold and due to the same uplift that formed the San Blas Range to the east. Unfortunately there is little or no trustworthy information as to the geology of these mountains other than that they are believed to have a core of granular rock* intruded in late Tertiary time. It must be borne in mind, however, that there is evidence of a decided orogenic movement in this region in late Eocene time that caused the unconformity at the base of the Peña Blanca *Orbitoides* beds; it is not impossible that the supposed southwest pitch of the anticline may be due to the earlier deformation.

Washington, D. C.

* Hill, op. cit., pp. 211-213.