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THE GEOLOGY

OF THE

CENTRAL PORTION OF THE ISTHMUS OF PANAMA.

BY

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CONTENTS.

INTRODUCTION.

Because of the richness of its undeveloped mineral resources, the complexity of the problems presented by its geologic phenomena, its comparatively easy accessibility, and its forming a connecting link between the two great divisions of the American continent, the Isthmus of Panama seems destined to be of exceptional interest to students of geology. During about three months in the early part of the year 1898, the writer was engaged (incidental to prospecting for the precious metals) in a somewhat desultory investigation of the geologic history of the central portion of the Isthmian country, traveling about 1,000 miles by schooner, canoe, horseback, and afoot, and although the time was hardly sufficient to gain a very comprehensive knowledge of the subject, it resulted in the discovery and partial exploration of several formations earlier in age than any yet reported from the Isthmus.

Great obstacles to the pursuit of geological study in such a tropical land as the Isthmus of Panama are presented by the density or jungle-like character of the vegetation in large portions of the low plains and in certain high mountainous areas where rain falls at least once during every day in the year; by the enervating effect of the warm moist atmosphere, which dulls the intellect and decreases the power of observation, destroying the zest for knowledge, which is the real incentive to scientific progress; by the scarcity and in portions of the country total absence of roads or even a path or trail; and by the long delays consequent on life among a people characterized by a lack of energy. In illustration of the first statement, I will mention that one morning I climbed a high tree and from its branches learned more of the geology of the vicinity in ten minutes than I had in the preceding several days of travel in the forest.

In January, 1895, Mr. Robert T. Hill examined a section across the Isthmus on the line of the Panama railway and canal, and another across Costa Rica between Punta Arenas and Port Limon. The results are given in his admirable paper entitled "The Geological History of the Isthmus of Panama and Portions of Costa Rica." * My study was made independently and without a knowledge of his, and to a certain extent covered the same ground, but in the following pages I shall endeavor to avoid traversing matter already treated at length by him, and add only new material to the literature of Isthmian geology.

The oldest formation observed by Mr. Hill on the Isthmus of Panama is a water-laid rhyolitic and trachytic tuff, by him named the Panama formation. I was fortunate in accidentally discovering a series of formations under and consequently older than the Panama formation. Part of this series represents an old land which once existed mainly to the southward of the present Isthmus. Mr. Hill had suggested that such an ancient land occupied the position indicated, and my happening upon a remnant of it was a remarkable confirmation of his hypothesis.

It is unfortunate that the strenuous conditions of my journey prevented the collection and submission to paleontological specialists of sets of fossils from the pre-Panama formations encountered. Marine fossils were observed in a number of places, although generally imperfect. My failure to secure specimens leaves this open as a splendid field for some enthusiastic collector. Some of the localities will be mentioned in the following pages.

The absolute determination of the age of the earlier formations must be left for future students, but I will ask the indulgence of the reader to remarks showing what correlations are indicated by the lithology, structure, and sequence of the strata. There is a remarkable similarity between several formations on the Isthmus of Panama and a series of probably late Jurassic and Cretaceous age in California. I submit that it is not a mere coincidence, but that they have been formed under like conditions, at about the same time, and subsequently subjected to about the same amount of metamorphism.

AREA STUDIED.

The Isthmus of Panama, generally considered as coextensive with that political division of the Republic of Columbia, officially

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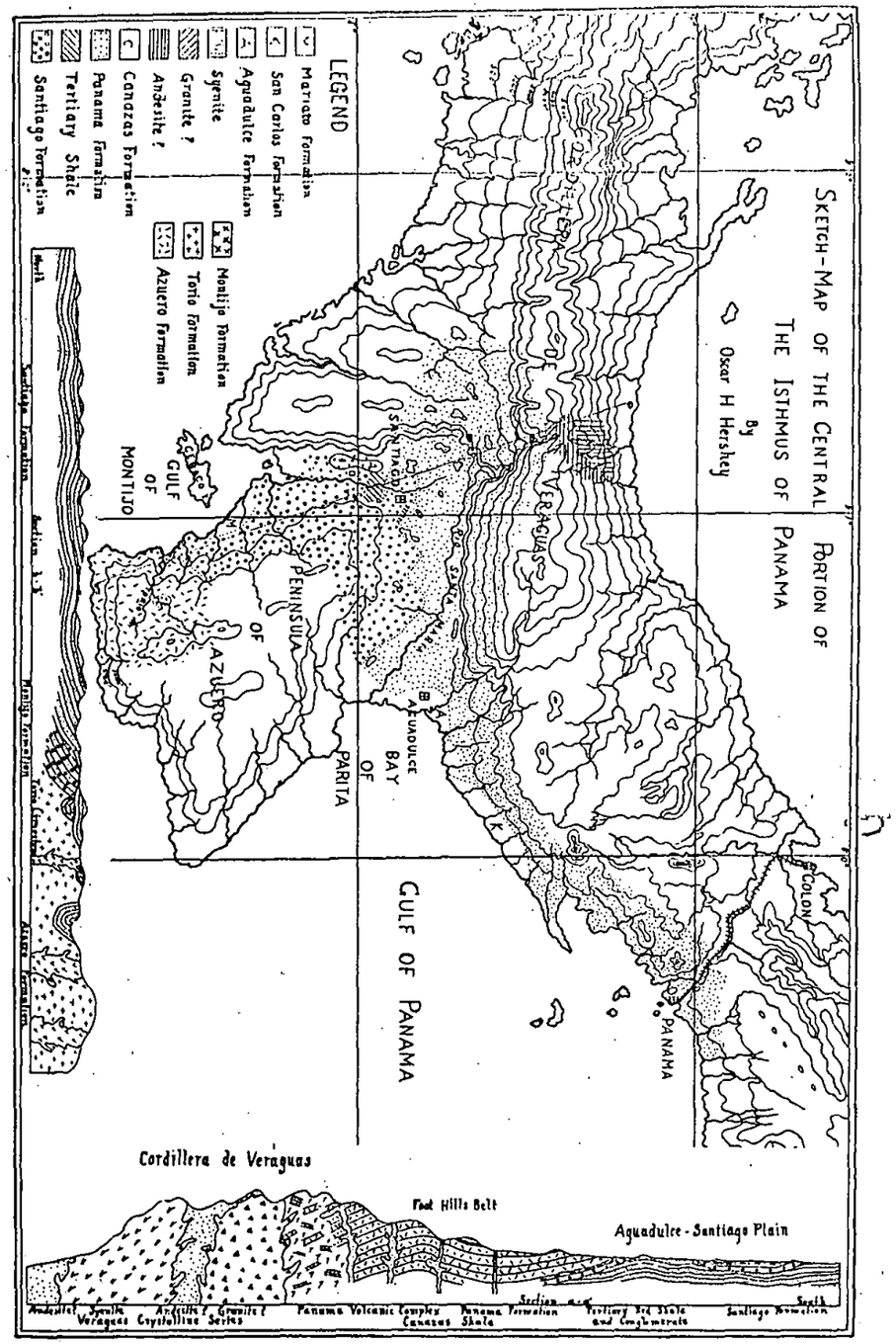
styled the Department of Panama, a strip of land about 400 miles in length and 40 to 120 miles in width, with a probable average of about 75 miles, is too large and diversified to be handled as a unit, and may conveniently be divided into sections. It is the middle section, characterized by high, abrupt mountains, peculiar rounded hills and low plains, extending from the canal in a general west-southwest direction to a distance of about 150 miles from Panama, that is the subject of this paper. About 100 miles southwest from Panama, the broad Peninsula of Azuero projects southward about 60 miles from the main body of the Isthmus. It is the oldest part of the Isthmus country. West of it the coast is very irregular, being indented by many bays, some of which are long and narrow and beautiful examples of "drowned valleys." Off the southern coast are many high mountainous islands.

The chief section which I examined extended across the widest portion of the Isthmus from Punto Mariato, the southwestern extremity of the Peninsula of Azuero, till within five miles of the Caribbean Sea, or directly through the center of the largest tract of the Isthmus marked on recent maps as "unexplored." This was directly across the strike of the strata, and it is believed that all the principal formations developed in the district were seen, and the geological history is known with a reasonable degree of completeness. As Mr. Hill found, it is the general rule on the Isthmus that the formations become newer from south to north.

TOPOGRAPHY.

From the head of the Bay of Parita, 90 miles west-southwest from Panama, there extends westward along the Isthmus a distance of about 50 miles and over a width averaging about 20 miles, the most beautiful peneplain of small extent which I have ever seen. Nearly all parts of it must originally have been a perfectly base-leveled plain dotted with many monadnocks from 50 to 500 feet in height. Around the head of the Gulf of Montijo and near the foot of the mountains north and west of Santiago the plain is much dissected by cañon valleys of no great depth and often of considerable width. The interstream portions are llanos, or grassy plains, and on them live a large part of the inhabitants of the Isthmus.



The town of Santiago de Veraguas is centrally located on the western part of the plain and Aguadulce is an important place near its eastern border.

This remarkable inland topographic depression is bounded on the north by a high, steep chain of mountains, which is the primary axis of this portion of the Isthmus and bears the name of the Cordillera de Veraguas. The system is made up of exceedingly steep, narrow ridges, which mostly rise to a height of about 5,000 feet but further westward attain elevations of 8,000 and in the volcanic peak of Chiriqui 10,500 feet, and form a chain trending in a general east-west direction parallel with and close to the Caribbean coast. It is the eastward extension of the main plateau of Costa Rica, but has here been more deeply trenched by erosion. The change from the low plain on the south to the high sierra is effected by a series of lower mountains (montañas) or foot-hills, whose summits gradually rise from the level of the monadnocks on the plain to the crest of the cordillera.

On the north of the main chain, the surface descends very rapidly to a dissected plain, which slopes more gradually to the sea, two to five miles distant from the foot of the sierra. This also is a dissected plain of erosion. The streams issue from the deep mountain valleys and flow across it in narrow, rocky cañons.

Southward from the Aguadulce-Santiago plain lies the mountainous land of the Peninsula of Azuero, but its central range, the Sierra Guanico, trends north-south, being therefore at a right angle to the Cordillera de Veraguas. From the axis of the peninsula, along which the sierra attain altitudes of 2,000 to 3,000 feet, the mountains descend in sloping spurs eastward to the Bay of Parita and on the west to the Gulf of Montijo. From some points of view the interior of the peninsula seems to be occupied by several parallel north-south mountain ranges with irregular crest lines, being sometimes reduced to a range of mere hills and again rising to mountain ridges several thousand feet high. On the west of the Gulf of Montijo the

which are elevated above remnants of a low coastal plain which once occupied the site of the gulf.

On the west of the Aguadulce-Santiago plain, by the increase of the monadnocks into a group of pointed hills occupying most of the surface, a more elevated, broken country is produced, which separates this plain from the plain of David in the province of Chiriqui. Thus the former plain is surrounded on three sides by mountainous tracts and is only open to the sea at its eastern end.

Eastward from the head of the Bay of Parita, the Cordillera de Veraguas, with its spurs, occupies the greater portion of the Isthmus (the coastal plains being limited to narrow strips), until about 20 miles west of the line of the Panama railway and canal, where the high sierra abruptly terminate and a different type of topography prevails eastward.

The topography of the country in the vicinity of the Panama railroad between Panama and Colon has been so ably discussed by Mr. Hill that I will avoid retraversing the ground except to make a few general remarks. Like the preceding observer, I was strongly impressed by the fact that there is not along this portion of the Isthmus a well-defined central range such as geographers have pictured as a connecting link between the Cordillera of North America and the Andean chain of South America, but rather a great group of peculiar pointed hills, extending from the islands in the Gulf of Panama, two-thirds of the way across the Isthmus, and which may be described, where not too closely grouped, as monadnocks rising from a low base-level developed on both sides of the Isthmus but nowhere greatly elevated above the sea. I was also impressed by the ancient type of the erosion topography and by the great depth of weathering. It is beyond question that this portion of the Isthmus has not been submerged at so late a period as the Pleistocene, and, in fact, it has been a remarkably stable portion of the continent since rather early in the Tertiary era.

seems to occupy the entire southern part of the Peninsula of Azuero, forming important mountain masses in the interior and exceedingly ragged cliffs on the coast. It is beautifully exposed on the shore of the Pacific Ocean on the west side of the peninsula, both north and south from the mouth of the Torio River. Here it is a massive fine-grained crystalline of very basic composition and a characteristic green color. Unfortunately, my petrographical knowledge was very crude at that time and no fragment of this rock was brought away. Because of its general resemblance to a Jurassic diabase in northern California, I discriminated it as a diabase, but I am now more inclined to believe that it is a peridotite, although nowhere prominently serpentinized. One of the principal constituents is a semi-vitreous, transparent mineral of a greenish gray color which may be olivine.

An important part of the eruptive mass is an equally fine-grained but dark brown and black rock, which under a hand microscope was seen to be composed of black crystals of hornblende and a lesser quantity of light brown feldspars, and hence resembling a diorite. This appears to be in the form of huge dikes cutting the green rock. The whole formation is streaked by many exceedingly irregular veinlets of white quartz and calcite. Some veins contain a red mineral of the color of cinnabar, but the staining matter is probably iron oxide.

Up the Torio River, the green rock sometimes assumes a schistose character, sometimes that of a non-laminated slaty rock, and again is clearly an eruptive. It is possible that the complex may include highly metamorphic sedimentaries. Everywhere it is characterized by the veinlets of quartz.

By far the most peculiar thing connected with this formation is certain large irregular masses of structureless, hard, bright red quartz which are of frequent occurrence in the green rock near its contact with later formations, and in the interior of the peninsula has weathered out and lies in great boulders in the bed of the Torio River. Some of these masses contain hundreds of cubic feet and others seem to occupy ancient fissures several feet wide. The only thing closely resembling this quartz or chert that I have ever observed is heavy-bedded portions of the radiolarian cherts of the

Franciscan series in California, but the occurrence appears to be different except that in a few cases the latter also have been invaded by and are enclosed in eruptives.

The age of this igneous complex will be discussed after the succeeding formation has been described.

The Torio Limestone.—The next formation seen in going up the coast from the Torio River is a hard, light gray, massive limestone. It is sometimes nearly pure and is then sub-crystalline. More often it is very impure but its outcrop always reveals its calcareous character. In places it abounds in fossils (mostly shells of marine brachiapod or lamellibranchiate species) which are so cemented into the rock that they can not be separated from it. In a few places the rock is a regular breccia-conglomerate of fossils and rock fragments from older formations, including the green igneous rock. Like the preceding formation, it is exceedingly well supplied with irregular veinlets of white quartz and calcite, which are not common in any succeeding formation. It is impossible to tell the thickness of the limestone, but it is at least several hundred feet. The strike of the formations along this coast is generally parallel to the beach, and hence it is difficult and often impossible to determine their thickness.

Limestone is exposed along the coast at low tide in several small irregular patches. In the case of the most southerly ones it is surrounded by and appears to overlie the igneous *massif*. At several places it is exposed very close to the latter and contains strata of conglomerate which dip away from the contact and which contain fragments of the green igneous rock; hence, it is evidently newer than the latter.

This limestone is well exposed on the Torio River, a few miles from the coast, in many irregular patches of light gray limestone, some of which are of small extent and others quite important. It is here always well stratified, being moderately thin-bedded and dipping steeply in one or another direction. It clearly overlies the green igneous formation, but along the contact is much contorted, and masses of dark gray diorite of fine grain but distinct holocrystalline structure, have been injected into the limestone.

The green igneous rock and the limestone are closely related in

age and have had the same life history since they were formed. Together they have been subjected to mountain building forces, being irregularly folded and faulted, and dyke rock injected into the fissures; they have been metamorphosed to the same extent; and they both have the abundant irregular veinlets of white quartz and white calcite, indicating general fracturing. So far as appearances go they are much older than any other formation yet found on the Isthmus.

While examining the green eruptive I was impressed by a marked resemblance in many particulars to a diabasic formation of Jura-Triassic age in northern California, and thought the entire complex including the limestone might be of Jurassic age. The fossils in the limestone seemed not of types common to Carboniferous or older faunas, but appeared to be of a somewhat newer facies. For reasons which will appear later, I had to place this formation earlier than the late Cretaceous and hit upon the Jurassic as the age best indicated by the evidence. Lately, upon becoming acquainted with the characteristics of the Franciscan series of the Coast Range region of California (thought by Lawson to belong somewhere in the interval between the recognized typical Jurassic and the typical Cretaceous formations), I have recognized the fact that the Azuero-Torio complex and the Franciscan series have had an identical life history since their formation; that is, they have suffered the same orographic disturbances, alterations of a like degree and like character, and are separated from newer formations of known age by non-conformities of equal value.

Now, ordinarily lithologic resemblances are too uncertain a means of correlation in such widely separated districts as the Isthmus of Panama and California, but as suggestive of what correlations will finally be made, let us assume that the oldest series on the Peninsula of Azuero represents the same late Jurassic or

as the land area indicated by a non-conformity between the Franciscan and Knoxville of California. We will provisionally adopt this as a basis upon which to build up our Isthmian column of formations and will see how we will come out at the top or when we reach a formation whose age has been fixed by study of its fossils.

The Montijo Conglomerate.—On the eastern shore of the Gulf of Montijo, opposite the island of Cebaco, about one mile north of the Torio River, there is a great formation, hundreds of feet thick, of fine conglomerate, hard and gray in color. It is well stratified and dips usually at a high angle. There are occasional fossils, but, I fear, too imperfect for specific identification. Coarse conglomeraate and fine sandstone are both rare. The outcrop in the sea has a reddish tint.

The conglomerate formation is newer than the Torio limestone and is distinctly seen to rest on it. Between them is an important non-conformity. The green eruptive and limestone were contorted, faulted, the fissures filled with diorite, the white veinlets formed a larger part of the metamorphism accomplished, and the whole complex reduced by erosion from a mountain mass to comparatively low ground before the Montijo conglomerate was deposited on the submerged borders of the old land. This will rank with the great non-conformities in the United States. It appears to be of the same value as that separating the Franciscan and Knoxville series in California, and we will provisionally correlate the Montijo conglomerate with the latter formation of known early Cretaceous age.

The Montijo conglomerate is separated from the next newer formation by a non-conformity represented by a tilting of the formation and sub-aerial erosion. This was not nearly so long as the preceding erosion interval and appears to be of the same value as that separating the Knoxville and Chico in the Coast Range region of California. We shall therefore expect to find some evidence of

formation, being found nearly throughout its extent. Although there are some thin layers of fine gravel and sand, the great mass of the formation is a shale, everywhere characterized by the same dull greenish or olive tint. It is not hard rock, yet is sufficiently lithified to be used as a building stone. It contains but little iron and weathers usually into a yellow clay soil. In some places it abounds in fossils which are generally imperfect and so brittle as to be incapable of preservation. They are of marine species of gasteropods; lamellibranchiates and allied forms. They differ decidedly from the species at present so plentiful on the Pacific beach of the Isthmus, but certainly are not of such old types as the Carboniferous or Jura-Trias. As I remember the fauna it more nearly resembled the Chico than that of any other formation, but I can not say that they are specifically identical.

The Santiago formation forms the foundation of the entire Aguadulce-Santiago plain, over a large portion of which it is the surface formation. Here it always dips in some direction, but rarely at a high angle. It seems to have been formed into low folds and was perhaps faulted in places. It is extensively developed in the northern half of the Peninsula of Azuero, where it forms mountains. On the eastern shore of the Gulf of Montijo it can be traced south until it is seen to overlie the formations previously described in this paper. In this direction it loses its breccia beds, becomes more sandy, better lithified and titled at a high angle, even in places standing on edge. On the lower two miles of the Torio River and at a promontory a short distance south of the mouth of the stream, it is exposed in beds of hard sandstone and shale over one thousand feet in thickness and dipping steeply in a general westerly direction. Here it is in contact with the green igneous formation, fragments of which, particularly the red chert, are included in its basal breccia-conglomerate. Farther north it is seen to rest unconformably on the Montijo conglomerate and nearly abuts against and caps a boss of Torio limestone.

The non-conformity at the base of the Santiago formation is of the same general nature and probably the same time value as that which separates the auriferous slate series and the Chico series in northern California. All the preceding formations, no matter how

they may have been forced up into mountain masses, had been reduced by erosion to a comparatively low land much of which was a slightly rolling plain—a Cretaceous (?) peneplain—and upon this comparatively plain surface after submergence, the Santiago sandstone and shale were deposited and the breccia-conglomerate formed by combined wave and current action.

There are, perhaps, nowhere on the American Continent two formations, so widely separated, so nearly resembling each other as the Santiago series on the Isthmus of Panama and the Chico series in the western part of Shasta County, California. They are identical in composition, texture, lithification, color and relations to older and newer strata. It seems hardly possible that all the conditions of their deposition and subsequent history could have been so nearly alike unless they date from about the same period. We will, therefore, provisionally correlate these formations and assume that the deposition of the Santiago formation closed the Cretaceous period.

The Tertiary Basal Conglomerate.—On the Aguadulce-Santiago plain, apparently occupying broad shallow depressions in the Santiago formation, there are large patches usually elongated from northwest to southeast and having widths of one to five miles, of a series of newer and softer formations. Southwest from Santiago the basal formation is a conglomerate of dark dull red and brown color, often well lithified and always distinctly a rock as distinguished from mere gravel. In places it contains a few imperfect fossils. It is exposed to considerable thickness and may be 50 to 100 feet, but evidently varies much from place to place. It always dips decidedly but rarely very steeply toward the center of structural depressions. Eastward from Santiago it is reduced to 10 to 25 feet of a rather coarse, moderately well indurated, heavily-bedded sandstone of a dark purplish tint.

The Tertiary Red Shale.—Resting conformably upon the conglomerate is a thin formation (10 to 50 feet, averaging about 25 feet) of soft shale and clay, bright red and dark reddish brown in color, without fossils, and generally laminated but readily weathering into structureless clay. It is persistent throughout the plain wherever its horizon is exposed.

About five miles north of the port of Montijo, this red shale has been baked by the intrusion of an eruptive not exposed, into a bright red mica schist as ancient in appearance as Archæan schists in the United States, and sufficiently extensive to have a considerable road cutting entirely in it. This is one of the finest cases of contact metamorphism of comparatively recent date known to me.

The Panama Formation.—In the country southwest of Santiago there is above the red shale a harder, more massive formation, usually of lighter color. It varies from white through gray to a dull purplish tint. Never is it laminated but sometimes it is seen to be heavy-bedded. Macroscopically it appears to be composed of a fine granular material. I consider it largely a water-deposited fine volcanic ash or rhyolitic tuff. In places it is coarse-grained and even slightly conglomeratic, in which cases it is well indurated. Where not eroded the thickness is probably at least several hundred feet.

East of Santiago there is, above the red clay, a great series of usually soft and chalky, non-laminated but water-deposited, fine-grained, clay-like materials (rhyolitic and trachytic tuffs) of a color prevailingly white to gray and rarely red or brown. This white, chalky deposit has been penetrated at the Remanse mine to a depth of over 600 feet, but contains layers which weather out like lava. East of the Santa Maria River the formation is widely developed, although many of the small hills which stand on the plain appear to be composed of trap rocks such as diorite, porphyry, basalt, etc.

The series of soft formations over the Santiago shale, consisting of the purple basal conglomerate, the red shale, and the white and light gray semi-massive tufaceous formation, are conformable to each other, were laid down in immediately succeeding epochs in the same body of water and belong to the same period of geologic time. This was separated from the epoch of deposition of the much harder and older-appearing Santiago formation by a considerable erosion interval, during which was formed the broad shallow basins in which the Tertiary strata are now found.

In its rhyolitic composition, prevailing white color and chalky texture (but not its heavy bedding) the Panama formation more nearly resembles the lower 1,000 feet or volcanic division of the

Monterey formation (of Miocene age) developed extensively in the Coast Range region of California, than any other of that state. Both mark an epoch of very acid volcanic eruptions in their respective regions. However, the erosion interval at the base of the Isthmian Tertiary series hardly indicates a time sufficiently long to cover the whole or even any large part of the Eocene period, and we will, therefore, provisionally place the Panama formation in the early part of that period.

In all the formations which I have described, no clear evidences of volcanic action of a modern character are to be seen until we reach this last formation, which seems to be made up essentially of fine ashes. To the epoch of acidic volcanic eruptions, there ensued one of highly basic eruptions. The products of the latter occur chiefly in the form of plugs, dikes, sills and laccolites of diorite, andesite, basic porphyries and basalt which occur throughout the area of the rhyolitic tuffs and are even scattered through the red shale, basal conglomerate and the Santiago formation. These hard rocks resist erosion better than the tuff and crop out like dikes and bedded sheets, form most of the knobs and cap the peaks. Boulders derived through their partial decay are scattered all over the volcanic region.

It is a series of rocks of this character which forms the foot-hills of the great range of the Cordillera de Veraguas, north of Cañazas and the Remanse gold mine, over a belt about 20 miles wide. This was the region of chief volcanic activity, and in it the deposits are of great thickness. Here the basic intrusives make up a large part of the entire formation. In addition to the fine volcanic ashes, there are thick deposits of coarse gray ashes, much of which has the macroscopic appearance of a massive rock and is not water-laid. In fact, in this foot-hills belt the direct volcanic products of the rhyolitic and the basaltic epochs are so confusedly intermingled that it seems advisable to consider them as a unit and treat of them under the comprehensive term, the *Panama Volcanic Complex.*

This Panama series continues northeastward beyond Aguadulce, between the narrow, low, coastal plain and the high sierra, and is developed and well exposed in the vicinity of Panama. Between

here and the Culebra cutting on the proposed Panama Canal it has been studied by Mr. Hill and by him named (excluding the intrusives) the Panama formation. Microscopic examination shows that the early water-deposited portion in large part consists of a soda-rhyolite tuff or a soda-trachyte tuff.* The basic intrusives and their associated ash beds are strongly developed in the vicinity of Culebra, where they include such types as "basalts (olivine, diabases, and dolerites), augites (?) (both andesitic and porphyritic) and trachyte tuffs of similar materials, and one boulder bluff of hornblende augite (?), andesite, or porphyrite." Mr. Hill also makes the acidic distinct from and older than the basic eruptive epoch.

Now, subsequent to the intrusion of the Panama formation by these basalts and andesites, their débris was formed into the Bujio conglomerate, which is the basal formation of a series of sedimentaries developed on the Atlantic side of the Isthmus. The age of these formations is definitely fixed by abundant fossils. The range is from the Claiborne stage of the Eocene merely as far as the early Miocene, when sedimentation ceased in the Isthmian region and was not resumed until the early or middle Pleistocene. On the strength of this evidence, Mr. Hill correlates the basic volcanic epoch with the late Eocene and considers the Panama formation proper of considerably earlier age, probably Cretaceous.

There is no positive evidence of the pre-Eocene age of the Panama formation. As a matter of fact, it is my impression that the deposition of the rhyolitic tuff did not long precede the intrusion of the basalts and andesites. As the latter, we now know, occurred rather late in the Eocene period, we may reasonably place the former early in the same period. We will then divide the history of the Eocene period as follows:—

1. A short epoch of erosion.

2. An acidic volcanic epoch with partial submergence of land, and deposition of Panama formation proper in sea on borders of the volcanic range.

3. A basic volcanic epoch, with intrusion of Panama formation

* Determination by Turner from specimens submitted to him by Mr. Hill. See paper by latter, page 201.

and continuance of eruptions along volcanic range (Veraguas foot-hills belt and Culebra region).

4. The Claiborne epoch of sedimentation on Atlantic side.

This classification of the volcanic formations brings the Santiago formation precisely in the latter portion of the Cretaceous period, where we provisionally placed it because of its remarkable resemblence to the Chico formation of California, and seems to indorse our tentative correlations down to the very lowest formation.

The Cañazas Formation.—The village of Cañazas is situated in the foot-hills belt in the midst of mountains composed of the Panama series of volcanics. Beginning at about one mile east of the village, there is a small area, several miles in diameter, of finely laminated light gray and brown shale. It is evidently composed of volcanic ash which was deposited in a body of water, probably a small lake. There are slight traces of fossils. In the midst of the shale is a three-foot stratum of coarse volcanic ash, representing apparently a single shower. On the eastern and northern sides of the area, a coarse basal conglomerate composed of water-worn boulders of the lower portion of the volcanic series, is developed to a thickness of 50 to 100 feet. The formation dips southward 10° to 30°, having been concerned in the orographic movement which lifted the Cordillera de Veraguas. It is evident from the way in which the Cañazas formation is included in the Panama series that it represents local conditions—merely a lake of short duration in which was deposited several hundred feet in thickness of finely laminated tuff or shale. Its age is, therefore, probably Eocene.

The Veraguas Crystalline Series.—The Cordillera de Veraguas, where I crossed it on the line of the old Santa Fe and Cocuya trail, about 120 miles west of Panama, is an immense igneous mass, probably 25 miles in width and attaining an altitude of 5,000 feet above the sea. It is made up of three rock types, specimens of which were submitted to Dr. U. S. Grant, who determined them. In the valley of the Rio Santa Maria on the southern slope of the range, the formation is mainly a rather coarsely crystalline plutonic rock of light yellowish gray color. With its abundant free quartz, it somewhat resembles a true granite on outcrop. The

interior is hard and often horizontally jointed, giving it a quasi-stratiform appearance. This was identified as rhyolite, but the fragment examined was small, and although the rock has the composition of a soda-rhyolite, its occurrence as an intrusive, and its coarse granitic structure, would seem rather to entitle it to be termed an alkaline granite.

The bulk of the main range or Sierra Balcazar, at the head of the Santa Maria River, was found to be composed of a very hard dark gray massive rock, which has been doubtfully identified by Dr. Grant as andesite, although upon closer examination, he thinks, it may prove a trachyte or even a diabase. In places it contains large phenocrysts of hornblende. This andesitic rock occurs in the deep valley of the Guaxaro River on the north of the divide; but a few miles farther north, a ridge nearly equally as high as the main divide, separating the Guaxaro from the Bijuco and Saltos Rivers, is composed to the very top of a massive coarse crystalline. This same rock is exposed to low levels in the valley of the Bijuco River. Dr. Grant says it is "composed mostly of flesh-colored feldspar, with some biotite and perhaps a little hornblende or augite," appearing like some of the nepheline syenites.

A little farther northeast, the Saltos and Santiago Rivers are flowing over precipices and huge boulders of the fine-grained dark gray and black andesite(?). The relation between the three rock types was not well made out, as the country is a dense jungle, but in general it may be said that the coarse crystallines form the core of the cordillera and the andesitic rock occurs as a thick coat originally completely covering them, but largely removed by erosion.

It is probable that the acid crystallines occur in the form of huge batholites which invaded the supposed andesite. But for evidence of their having been intruded subsequent to the late Eocene basic eruptive epoch, they might be supposed to represent the plutonic phase of the same volcanic activity as produced the Panama formation. Doubtless, these Veraguas crystallines (syenite and alkaline granite) belong to the same system of "pseudo granite or syenite" rocks mentioned by Hill as exposed in the plateau of Costa Rica, the Sierra San Blas, around the Sierra del Marta, on

the South American mainland, and at several places in the Antilles, "which have been pushed up into the Tertiary strata, and now form the core of great mountainous protuberances." The age of these syenitic batholites is variously given as "mid-Tertiary" and "late-Tertiary." It is probable that it was the uplift of the Isthmian Territory due to the upthrust of the crystalline magmas of the Cordillera de Veraguas and the Sierra San Blas which ended the Tertiary sedimentation along the Panama Canal section, and hence it may be provisionally considered middle Miocene in age.

Resumé of the Pre-Pliocene Isthmian History.

The "old land" or early representative of the Isthmus of Panama lay mainly south of the present Isthmus. That it was a land mass of considerable extent, is indicated by the heavy beds of conglomerate formed from it. Its formations and history are remarkably like those of the Coast Range Region of California, but it will probably be more advisable to connect it with the Andean Region on the south. The north-south ranges of mountains of this old land may have been members of the system of Andean ridges known to be of Cretaceous age and to be made of just such rocks as those of the Peninsula of Azuero. The eastern members of these parallel north-south mountain ranges of Cretaceous age persist in the northern portion of the present Andean region, but the western members we may suppose have been destroyed by erosion and subsidence, except this small remnant constituting the Peninsula of Azuero. On the northern border of this old land were laid down the formations which now make up the main body of the Isthmus.

During the Montijo epoch (probably early Cretaceous) the coast was sinking to allow the conglomerate to overlap upon the old land surface. An uplift added a belt of conglomerate to the land, even throwing it up into mountains. Then ensued a long period of sub-aerial erosion during which the mountainous land was mainly reduced to a low undulating plain—presumably a late Cretaceous peneplain. An extended submergence of the coastal portion of this old land mass enabled the accumulation of many hundreds of feet in thickness of Cretaceous(?) shales, fine sandstones,

and the peculiar breccia beds and breccia conglomerates so characteristic a feature of the Santiago formation.

Finally another orographic disturbance again folded the strata of the southern half of the Peninsula of Azuero into a mountain system, tilting the Santiago formation almost to a vertical position. Associated with this movement was an uplift of the sea-bottom on the north of the "old land" and an extension of its limits to at least the northern edge of the Aguadulce-Santiago plain. During the following short epoch of sub-aerial erosion, broad shallow basin valleys were eroded in the surface of the Santiago formation. Early in the Eocene period, the plain was submerged and the Tertiary basal conglomerate and overlying red shale were deposited on its surface. The evidence is very clear that the material was derived from the south. Indeed, I think the "old land" still remained in large part above sea-level, and its red residuary soil furnished the material for the lower Eocene formations.

Now a radical disturbance of the quiet of this land was inaugurated. Far out in the sea, at the edge of the sub-marine shelf which bounded the "old land" on the north, was a line of weakness. Here the earth was fissured along an east-west belt on the site of what is now the southern foot-hills belt of the Cordillera de Veraguas and extending thence east over the site of Panama. Lava and ashes issued from volcanic vents, the latter to be largely deposited in the shallow sea between the volcanic range and the old land. At first the material was very acid, but later came highly basic eruptions. A broad strip was added to the old land merely by the accumulation of igneous débris. Then came an epoch of quiescence, during which the fossiliferous late Eocene and early Miocene sedimentaries were deposited in the sea on the north side of the volcanic range.

The next event was the profoundest disturbance of which we have a record, that has ever affected any part of the Isthmian country. This was the upthrust of the Cordillera de Veraguas to a high mountain range, and the invasion of the volcanic series by huge batholites of alkaline granite and syenite. The old Andean system of orographic disturbances had ceased and instead had come into action, as Mr. Hill has indicated, the Antillean system.

The new folds had an east-west trend and the Cordillera was built across the ends of the old north-south system.

We are now ready to formulate a great principle in the geological history of the Isthmus. From the earliest times of which we have any record to the present day, there has been a tendency toward a southward tilting of the entire country. While a great highland belt was being added to the Isthmian country on the north side of the Aguadulce-Santiago plain and its original far eastward extension, the "old land" area on the south was being destroyed, partly by the action of the sea along the shore and partly by subsidence. The whole of the presumably pre-Cretaceous land area of this region has gone beneath the Pacific's waters, except the southern part of the Peninsula of Azuero, and perhaps a few small areas west from the Gulf of Montijo. Eastward from the Peninsula of Azuero, the sea has swept over the "old land" and the plains belt north of it and in the vicinity of Panama has even invaded the volcanic highland.

DEVELOPMENT OF PRESENT TOPOGRAPHY.

Under this heading it is proposed to outline the chief physiograpic events of the later geologic history of that portion of the Isthmus lying west of the Panama Railroad and east of the province of Chiriqui. The description of the various Pleistocene formations has been reserved for this section of the paper, as their history is inter-related with that of the geomorphogeny of the land surface.

The earliest date with which we are now concerned is the close of the great Panama epoch of volcanic activity. As the Panama series is made up of a vast thickness of consolidated tuffs, with intruded and intercallated sheets, irregular masses, trap dikes and volcanic necks of diorite, andesite, basalt, etc., it may be presumed that the surface at the close of the period was a very uneven one, with a type of topography similar to that so beautifully exemplified in the recent volcanic ranges in Guatemala and Nicaragua; that is, it abounded in cone-shaped peaks and craters, with variously-shaped basins between the individual volcanoes. Through this land of heterogeneous topography the streams were forced to flow hither and yon by the accidents of unequal deposition of ejected

material, as they passed from one basin to another. No relics of this necessarily unsystematic drainage system are left. In other words, in none of the streams of the Isthmus can the determination of the course be traced back to this volcanic period. Indeed, the volcanic cones and craters themselves have all disappeared (except possibly the recent volcano of Chiriqui), and all the medium and minor features of the topography are due to sub-aerial erosion.

The Tertiary Dissected Peneplain.—Soon after I first recognized the cone-shaped elevations and low isolated hill ranges on the Aguadulce-Santiago plain as monadnocks on a Pleistocene peneplain, I noticed that while they vary in height between 50 and 500 feet, nearly all of those in any given section of the plain attain about the same elevation. Many of the hill ranges have comparatively even crest-lines, and a few are flat-topped as though they are remnants of a plain. Indeed, the summits of practically all the monadnocks on the plain will fall naturally in a slightly deformed, nearly destroyed plain. At first I thought this was a constructional plain or the original surface at the close of the volcanic period; but I found that the monadnocks are composed of a great variety of formations, among which I may mention Santiago shale, Eocene red clay, the tuffs of the Panama series and the dikes and volcanic necks of the same. Besides it is impossible that the original surface in such a volcanic region could have been so perfect a plain as is indicated by the summits of the monadnocks. It is quite evident that there had here been some erosion, and the manner in which the supposed plain of the summit level of the hills beveled the edges of the inclined strata suggests peneplanation.

Transferring our attention to the top of the high sierra which bound the view on the north, we find that the Cordillera de Veraguas appears from a distance as an extremely abrupt single ridge, somewhat broken in places by valleys eroded in its flanks, and having a comparatively uniform altitude of about 5,000 feet. But when we travel about within its limits, we find that it is in reality only a deeply dissected plateau. All the adjacent ridges rise to about the same height and often have even crest-lines for several miles. There are some extended flats at the level of the mountain summits, as the high llano on which flows the upper stretches of the Rio de

Los Saltos. The valleys are merely deep, narrow, steep-sided ditches carved from the plateau by the streams. Eliminating them, the whole country over a width of about 20 or 25 miles would be a high plateau, arched a little along the central line, but otherwise remarkably even.

Upon first recognizing the existence of this uplifted and dissected plain, I attributed it to the original constructional surface, but a little reflection showed this to be untenable. The volcanic cones, craters, and other causes of unevenness in the original surface have disappeared over the cordilleran region. Even the Panama tuffs so well represented in the foot-hills on the south of the high sierra, and which must have lapped over onto this region, have been completely removed.

To my mind the most unanswerable argument in favor of the idea of great erosion over the Veraguas Mountain belt is in the fact that at places the syenite rises to the level of the old plain. This coarse crystalline certainly did not solidify at or very near the surface, but must have been buried under a considerable mass of other rocks. Moreover, the "higher" strata are absent on the north side of the mountains along the coast of the Caribbean Sea. On the whole, I consider the evidence of erosion over the cordilleran region to form the ancient plain of the sierra summits sufficiently strong to make it practically a demonstration.

Between the Aguadulce-Santiago plain and the high sierra is a belt of lower mountains or montañas, 10 to 20 miles in width. It is made up of separate ridges trending in various directions, and of isolated peaks. At first sight the whole seems to be an unsystematic collection of steep-sided and narrow-crested hills of various heights; but from certain advantageous points of view the impression is forced on the observer that if a plane were drawn from the edge of the dissected plateau over the cordillera to the summit plane of the monadnocks on the low plain, many of the summits of the foot-hills would fall in this plane *and none above it.* Where erosion has been very active in this belt, the ridges have been reduced below the old plain surface, but the bulkier ones with comparatively even crests, and the larger isolated peaks form a sloping, dissected plain almost as perfectly as do the monadnocks below.

That this plain does not represent the original constructional surface is demonstrated partly by the total disappearance of the cones and craters, but better yet by the fact that at many places among these montañas, the structural features are beautifully displayed, especially through the presence of thick, originally nearly horizontal lava sheets, now dipping steeply in the opposite direction from the slope of the supposed ancient plain which bevels their upturned edges. Indeed, the volcanic strata of the foot-hills north and west of Santiago have a prevailing northerly dip or toward the cordillera, only a part of which dip I think was original.

It has been shown above that there exists over the entire width of the Isthmus west of the head of the Bay of Parita (the Peninsula of Azuero possibly in part excepted), an uplifted, deformed and nearly destroyed ancient plain of erosion. In the comparatively short time in which, it is known, this plain was formed, it is impossible that it can have been the work of the sea. Marine erosion proceeds rapidly relatively to the land surface exposed to its action, but very little of it is acted on by the sea at one time. The construction of broad submarine shelves requires an extremely long time and a sinking coast with the accumulation off shore of thick sediments. In the light of recently acquired knowledge on the subject, I do not think it is necessary to indulge in any elaborate discussion to demonstrate that the leveling of the Isthmus was done by the ordinary agencies of sub-aerial erosion—that the now dissected plain was one of land surface denudation, or, in other words, a peneplain.

The age of the supposed upper peneplain may be roughly fixed by a study of the newest formation involved in the denudation and by a comparison of the erosion accomplished since the uplift of the peneplain with that of certain portions of the United States where physiographic studies are well advanced.

The newest formation under the plain seems to have been the alkaline granite and syenite batholites of the cordilleran region, of an age certainly newer than the Eocene and probably about middle Miocene. Some time was required for the removal of a considerable thickness of strata from over the crystallines, and this may throw the time of uplift of the peneplain forward to at least the late Miocene.

Over the Aguadulce-Santiago plain the uplift has been slight (50 to 500 feet) and the strata soft; hence, erosion here has proceeded to such an extent as to leave the original peneplain surface remaining only in widely separated tracts of exceedingly limited area. In the foot-hill region, the erosion of valleys from 1,000 to 2,500 feet in depth has carried away fully two-thirds of the strata between their bottoms and the old peneplain. In the cordilleran region, the old plateau is nearly thoroughly dissected by valleys several thousand feet in depth and of no mean width. The valleys in this Cordillera de Veraguas may be directly compared with those of the Black Hills of South Dakota, the deep cañons of the Sierra Nevada and Klamath Mountains of California, and certain deep but not broad valleys of the Appalachian region, as those of the West Virginia plateau. Taking into consideration the hard crystalline rock, but otherwise favorable conditions for rapid erosion, the valleys of the cordillera need not have required such a long period of erosion as the first and last of those in the United States mentioned above, although it is hardly possible that they could have been excavated solely within the Pleistocene era. I believe the evidence warrants our provisionally classing the uplift of the peneplain as an event of the Pliocene period.

The late Tertiary uplift was of the nature of a broad arching of the rocks with an east-west axis occupying the position of the present high sierra. The peneplain in the cordilleran region was not immediately raised to its present altitude of about 5,000 feet, for part of the uplift is due to movements as recent as the late Pleistocene.

The Pleistocene Peneplain.—When I first traveled over the beautiful grassy plain with island-like clumps of dark green arborescent vegetation, between Aguadulce and Santiago, I assumed without serious questioning that it is an old coastal plain of aggradation, and the isolated, often cone-shaped elevations on it, volcanic cones. But when I came to study the strata under it, I found, instead of the loose sands and clays of Pleistocene age that I had expected, conglomerates, breccias, shales and tuffs of Eocene and earlier age, the whole horizontal in a general way, but considered in detail always dipping perceptibly and often decidedly in some direction.

The plain everywhere bevels the edges of the slightly upturned strata.

Toward Aguadulce there are broad stretches of open grassy plain which are remarkably even but not flat; that is, they are characterized by long, extremely gentle even slopes which form shallow basins, in the deepest portions of which a few streams may be found in the rainy season. Farther west toward Santiago, the plain becomes more rolling and monadnocks more numerous. Because of an uplift the streams do not now flow on the peneplain, but have eroded beneath its surface valleys to as much as 100 feet in depth. On the inter-fluvial portions the original peneplain surface remains as grassy llanos, very slightly arched in the center and remarkable for their long, slight, even slopes. Low ranges of hills (residuals) traverse the plain in various directions and often isolated, rounded elevations are encountered.

Standing on the foot-hills of the cordillera and looking over the plain, it is seen to be a perfectly base-leveled area of denudation. The shallow basins, the low divides, and the cañon valleys disappear with distance and we see only a land apparently as flat as the ocean except for the many monadnocks which rise sharply from it. It is the most beautiful and perfectly base-leveled land with which I am acquainted.

The Pleistocene base-level is found at intervals along both coasts of the Isthmus and was recognized by Mr. Hill at Colon, in the truncated summits of the Monkey Hills, and at Panama, where it constitutes the terrace on which the city is mainly built. Mt. Aucon, which rises prominently just beyond the city, and most of the islands in the bay, were monadnocks or residuals on this peneplain. It was once developed over the area of the Gulf of Panama, but within its limits is now represented by a single remnant, a flat-topped island about 10 miles southwest of the city.

At the foot of the Cordillera de Veraguas on the northern or Caribbean side of the Isthmus, base-leveling was effected on the hard crystallines and andesite(?) of the Veraguas series over a belt at least several miles wide. This has since been uplifted and tilted toward the sea. The streams have eroded in the plain narrow cañon valleys from one to several hundred feet deep, but all the

ridges thus formed have an even and gentle slope toward the ocean. That they represent a plain of sub-aerial erosion is evident from the presence on the summits of many of them of gold-bearing river gravels, the remnants of old delta-like alluvial fans formed at the mouths of the mountain valleys.

The Pleistocene peneplain rises very gradually and evenly from about 25 feet above high tide level at Aguadulce to 370 feet at Santiago, a distance of 40 miles. From Santiago it has a more rapid slope to the head of the Gulf of Montijo, and in consequence it is deeply dissected and to a great extent destroyed in this region. Here is an excellent area for studying the question of its age, as it shows the maximum erosion. Cañon valleys from 100 to 200 feet deep and 100 feet to half a mile wide have been excavated by insignificant streamlets. Over areas as large as a township in the United States, the divides have been so generally reduced that it is difficult to detect any trace of the plain. Yet the altitude at which it is due is known from neighboring areas.

It is true that the slope, the softness of the formations, the absence of heavy vegetation, and the division of the year into one extremely dry and one extremely wet season, favor rapid erosion, but time is required to make a valley even on a precipitous mountain-side. Undoubtedly such a late age as the opening of the Recent period, the Wisconsin epoch or the Iowan epoch of United States geology, can not be entertained. It is doubtful even if all the erosion could have been accomplished since the opening of the Illinoian epoch. The Kansan epoch appears to have been too remote, and as for the Lafayette epoch, which closed the Pliocene history in the Eastern United States, it is out of the question. Considering the favoring conditions of erosion, I am averse to placing the uplift of the peneplain so far back as the early Pleistocene. So we will provisionally identify it as Middle Pleistocene in age.

PLEISTOCENE FORMATIONS.

There is in various parts of the Aguadulce-Santiago plain a bed of exceedingly finely divided clay which dries into coarse grains by the development of fine cracks. It is of a very light gray or

ashy color with brownish red spots due to iron staining. Stratification lines there are none unless very indistinct. There are no fossils, no hard iron concretions and no pebbles or other rock fragments. It is not residuary as it occurs over quite different formations without change of character.

This clay is overlaid conformably but with a sharp division, by a peculiar soft conglomerate of impure, light brown limonite pebbles, brown silt and clay, forming the surface formation in many parts of the plain. It is usually 6 to 8 inches thick except near waterways, where it increases to several feet. Often it is distinctly stratified and evidently waterlaid.

This ash-colored clay and the fine brown conglomerate are fresh-water deposits made at a time that the plain was low and liable to overflow from the sluggish streams. This was previous to the uplift of the plain and trenching of the present valleys and hence the deposits may be considered of Middle Pleistocene age.

In the town of Santiago, whose population is about 6,000, nearly one-third of the paving blocks are silicified wood. This was gathered from the plain in the vicinity where fragments of this material and even whole logs are widely scattered on the surface. North of Santiago, the plain over entire square miles has fragments of carnelian and agate very abundantly distributed in the soil. Numerous veins of quartz and chalcedony have been formed in the sub-soil within a few feet of the surface. This epoch of silicification preceded the uplift and dissection of the peneplain.

The Aguadulce Formation.—In the vicinity of the town of Aguadulce, the sea invaded the plain, leveled it off and deposited over the Panama formation a thick layer of gravel and sand which extends back several miles from the present seaward margin of the plain, but disappears so gradually that its actual original extent is hard to determine. There are a few low, broad beach ridges. The deposit is a mixture of more or less water-worn pebbles mostly local in origin, of coarse and fine sand, of clay and of limonite. The latter is the most important constituent and in places cements the gravel and sand into a dark reddish brown conglomerate or impregnates the clay so as to make it a veritable low-grade iron ore. Fragments of this impure limonite bestrew the surface and outcrop in large masses. It seems to indicate esturine conditions.

In this formation near Aguadulce are many small, smooth, subangular pieces of limonitic chert and hardened clay which have a peculiar semi-glazed surface and a uniform light brown color. A great number of these same water-worn brown pebbles are scattered over the plain far from the sea, particularly in the vicinity of the more important stream courses. They appear to be the river deposits of a certain age, as none were formed before or since. It is a singular fact that very similar pebbles of semi-glazed brown river gravel are widely distributed in the drift of northwestern Illinois, where I have described them under the name of "Freeport gravel," and they occur in southern Missouri and Arkansas, where I have traced them into connection with the Lafayette deposits. No suggestions of correlation are intended by this comparison.

The Aguadulce formation represents a slight local depression immediately preceding the uplift of the Pleistocene peneplain and may be classed as Middle Pleistocene.

The San Carlos Formation.—At many places on the Pacific side of the Isthmus are remnants of a coastal plain of aggradation which has been uplifted 20 to 100 feet above high tide level and partly destroyed by marine action. A beautiful example is the San Carlos plain, lying between 30 and 50 miles west-southwest of Panama, and extending from a 100-foot white sea-cliff inland probably five miles to the base of a mountain mass. Since its uplift, it has been dissected by narrow cañon valleys, but the inter-stream portions in general remain intact so that from a distance it looks like a remarkably level plain. The divides are flat instead of slightly arched as in the case of the Pleistocene peneplain. As might be expected, the sea-cliff shows that the plain is composed of a marine deposit of mainly horizontally stratified fine sand and beach gravel.

The sea-cliff about one mile east of San Carlos exposes the formation to perfection. In the maximum thickness of 100 feet there is included three divisions. At the base is a bed of very coarse gravel and boulders up to several tons in weight, which is well lithified and composed largely of the porphyritic and crystalline volcanic rocks of the Isthmus, in particular a red porphyry. It is of a dull brownish color. The surface is very irregular, rising from

below sea-level to about 50 feet above it. Some of it forms reefs at the outer edge of the beach at low tide.

The middle division is a false-bedded series of alternating layers of fine gravel and coarse sand. It has a greater variety of pebbles than that below and among the species represented are biotite granite and separate foils of biotite, a mineral very rare in the Isthmian country. Between the two gravel members, there is a sharp but irregular line which affords some evidence of two periods of deposition, separated by marine erosion.

The upper third of the cliff consists of heavily-bedded, horizontal, semi-lithified fine sand and silt of a light yellowish color with a tendency to buff. In some layers there is a large constituent of grains much finer than sand, so that these beds resemble loess.

So far as I have been able to learn, the San Carlos plain of aggradation is continuous, back of the immediate coastal lands, with the Aguadulce-Santiago plain of denudation. While base-leveling was in progress on the land along the coast, the eroded materials were deposited, as the San Carlos formation, in the sea just off-shore, and as fast as its surface rose to that of high tide level, its area was added to that of the land as a continuation of or appendage to the plain of denudation.

The rather small size of the cañon valleys eroded in the San Carlos formation since its elevation indicate an age rather late in the Pleistocene era. In quantitative terms, this erosion may be directly compared with the post-Illinoin erosion in the Mississippi basin and the erosion accomplished on the Red Bluff formation of the Sacramento Valley.

I wish to remark here that those who are not intimately acquainted with climatic conditions on the Isthmus of Panama, may be misled by statements of its supposed heavy annual precipitation, which is said to vary for different parts of the country from 100 to 250 inches per year. It will be natural to infer that the streams must be in a state of almost chronic flooding and erosion extremely active. Now, on the southern side of the Cordillera de Veraguas, where are situated the Pleistocene formations whose age I have endeavored roughly to determine by erosion studies, there is a comparatively dry belt, with six months in which scarcely a drop of rain falls,

and during the rainy season, the streams are not more flooded than those of the Sacramento Valley in the winter season. It is unwarranted to assume that erosion has been very much more active here than in the Mississippi Basin or the Sacramento Valley. This applies only to the comparatively dry belt above mentioned.

On the whole, I think we are justified in provisionally placing the San Carlos formation in the Middle Pleistocene.

The Mariato Formation.—On the eastern side of the Gulf of Montijo, about seven miles north of the mouth of the Torio River, there is a grassy and level but dissected old coastal plain, occupied by the hacienda of Mariato. It is elevated 20 to 40 feet above sea-level. On the seaward margin it has been much eroded, and at "the port" it is seen to be composed of horizontally stratified, reddish colored clay, which is very sandy above and gravelly below. The pebbles are well rounded, but mostly of soft rock which can be broken with the point of a knife. This marine deposit rests on an ancient submarine shelf carved from the Santiago formation, upon whose nearly flat surface it thins out in passing inland.

This Mariato coastal plain has the same relation to the neighboring mountains, to a low coastal plain of later age, and to the present rivers and bays, as the San Carlos Plain. Lithologically, the Mariato formation is much like the Red Bluff in California (which means little), and it has been eroded to about the same extent as the latter under approximately similar conditions, which is significant.

THE MIDDLE PLEISTOCENE UPLIFT.

If all the fragmentary coastal plains, the Pleistocene peneplain on the Pacific side of the Isthmus, and the base-level on the Caribbean side at the foot of the Cordillera de Veraguas, were uplifted at the same time, as the evidence indicates, we have a definite and perhaps important orographic disturbance in the middle part of the Pleistocene era. This was not a mere epeirogenic uplift, without deformation, of the entire Isthmus, but a broad arching of the country in a system outlined in previous disturbances. The actual amount of uplift along the line of the present shores was quite

insignificant, a little more than 100 feet at San Carlos probably being the maximum. The plains were tilted toward the seas on both sides of the Cordillera de Veraguas, and from the angles at which they slope it is probable that along the axis of the cordilleran region, the land rose as much as several thousand feet. In traversing that region, even before recognizing the significance of the tilted plains, I was satisfied that the sierra had suffered a considerable uplift in comparatively recent times. I now know that the whole region has been bowed. Some of this arching may be due to a recent movement perhaps not yet ended, but a considerable part dates from this Middle Pleistocene disturbance.

On the western side of the Peninsula of Azuero, south of the tilted Mariato coastal plain, the Pleistocene peneplain was developed on hard formations, but it has been uplifted and cañoned by the streams. It rises inland at such a rate as to indicate that the central line or mountain axis of the peninsula has risen since Middle Pleistocene time as much as 1,000 or more feet.

A RECENT DEPRESSION OF THE COASTAL LANDS.

The outline of the Isthmus of Panama is that of a land whose borders have recently subsided and been partially submerged. Especially is this true of the Pacific side. West of the Peninsula of Azuero are several beautiful examples of drowned valleys. That of Montijo begins far inland as a common river valley of the cañon type, and an age subsequent to the uplift of the Pleistocene peneplain. As it proceeds southward it opens up into a broad topographic depression partly of structural and partly of erosive origin. Tide water ascends in this to 40 miles from the open ocean, and the body of water gradually widens until it is several miles in width and has become the so-called Gulf of Montijo, partly closed in from the open sea by several large islands. The "gulf" is shallow and in its upper portion great mud-flats are exposed at low tide. Evidently the depression which admitted the sea into the old valley had a very small amplitude.

Around the extremity of the Peninsula of Azuero, the evidences of a recent subsidence are very clear. It always seems that the depression has been most on the ends of long headlands and relatively

slight at the heads of deep bays. This seems to point to a slight tilting of the interior toward the sea. Indeed, I am not certain that the real nature of the movement was not a slight arching of the Isthmus as in previous periods of disturbance. Away from the coastal lands, especially in the high mountains, I found, instead of traces of a recent subsidence, rather strong evidences of an uplift which was probably contemporaneous with the submergence of the coasts.

The geologically very recent age of the depression is exemplified by the small amount of marine erosion which has been effected on the precipitous headlands and mountainous islands. As Mr. Hill has mentioned, the cliffs of marine erosion are only from 20 to 100 feet in height, and above them the land presents the type of topography indicative of slow subaerial erosion. Since the coast line reached its present position on the land slopes, the bench cut by the waves is insignificant, comparatively speaking, and can not have required a very long time. A movement and consequent shifting of the shore-lines has certainly occurred recently. It was not one of uplift of the land, for there are no raised shore lines. Wave-cut benches above the present shore line (the single marine shelf of the Middle Pleistocene base-level excepted) are totally absent from the Isthmian country. As indicated by various phenomena, the recent movement has been one of subsidence on the coasts.

The Parita Formation.—Around the head of shallow, sheltered bays, there have been built up, since the subsidence, low coastal plains, sometimes of considerable extent, even several miles in width. The best developed is at the head of the Bay of Parita. It consists of dark bluish gray silty muck and gray sand. This has been built up to a level mainly a few inches above that of high tide, although on the inland borders there are extensive tracts which are flooded at spring tide, as at the Aguadulce Salt Works. The plain is traversed by deep, narrow tidal channels.

These flats must have required a considerable period for their formation, and during it the coast-line has been remarkably permanent. They are connected with low alluvial bottoms of small extent along some of the rivers which enter the sea through the

coastal flats, and which correspond to the alluvial plains of Modern age along nearly all our rivers in the United States.

Modern Stream Gravels.—Along many of the streams of the Isthmus there are beds of large boulders, coarse gravel and sand, which form terraces or elevated alluvial plains, not nearly as high as the ancient river gravels on the Aguadulce-Santiago plain, but still for the most part out of the reach of the present streams. They are the gold-bearing gravels. They seem to indicate a slight uplift of the land in a time very recent. It is this elevation of the interior which I correlate in a general way with the recent subsidence of the coastal regions and consider both to have occurred at about the opening of the Modern or present epoch of the Pleistocene era.

SUMMARY OF POST-EOCENE EARTH MOVEMENTS.

The disturbances of the level of the land on the Isthmus of Panama, since the Eocene period, may be summarized as follows:

1. A marked elevation supposably at about the middle of the Miocene period.

(*a*) A long quiescent period resulting in the formation of the Tertiary peneplain.

2. Another marked uplift, inferentially in some part of the Pliocene period.

(*b*) Erosion of deep valleys in the mountains and formation of Pleistocene peneplain.

3. An uplift near the middle of the Pleistocene period. Insignificant in amount on coasts as compared with previous uplifts.

(*c*) Excavation of cañon valleys in uplifted coastal plains and deepening of cordilleran valleys.

4. An extended but slight submergence of coastal lands near the opening of the Modern epoch, with probable correlative elevation inland.

(*d*) Formation of low coastal plains on the Pacific side and coral reefs on the Caribbean side of the Isthmus, as at Colon.

ORIGIN OF ISTHMIAN STREAM COURSES.

The courses of nearly all the streams of the central portion of the Isthmus of Panama are governed primarily by the general slope of the dissected peneplains. They rise at the axes of the great structural arches and flow directly down the slopes of the tilted peneplains into the sea. Several small streams in the foothills north of Santiago may be exceptions, as their courses seem to have been determined in part by the northwest to southeast strike of the strata, but, in general, I believe the drainage to be independent of the rock structure. Certainly there has been a radical readjustment since the Eocene volcanic period, and this seems to have been accomplished mainly during the inception of uplift of the Tertiary peneplain. The stream courses seem to have been brought under some straightening process which may have been the rapidity of tilting of the peneplain.

In the Montijo basin the drainage has been reversed through the elevation of the Cordillera de Veraguas and the submergence of the "old land" on the south. Most of the rivers on the western side of the Peninsula of Azuero flow down out of the mountains toward the northwest and they may be relics of the drainage system in the basin before the reversal. Just when that occurred I could not determine.

PLEISTOCENE OSCILLATIONS OF THE SOUTHWEST COAST OF NORTH AMERICA.

The same evidences of a geologically very recent depression of the coastal lands are found all along the Pacific side of the continent as far north as the Bay of San Francisco. Prof. A. C. Lawson* and Dr. H. W. Fairbanks† have recently discussed the subsidence on the Californian coast. Here the recent submergence appears to have been rather local in character. The late Pliocene and early Pleistocene submergence of the southern California coast, marked by raised shore-lines, did not extend as far as the Isthmus of Panama, and I hardly think was represented on the coast of southern Mexico and Central America.

*Bulletin of the Department of Geology, University of California, Vol. I, No. 4, December, 1893.

†American Geologist, Vol. XX, No. 4, October, 1897.

The city of Mazatlan, Mexico, is situated on a short drowned valley. From here southward, the ocean is mainly bordered by mountains, the bases of many of which rise directly from the sea. At San Blas there is a representative of the low coastal plains of Modern age, formed since the depression. The beautiful land-locked harbor of Acapulco is another instance of a short deep valley converted into a bay through the subsidence of the coast.

From Cape Corrientes to Salina Cruz, close to the Guatemala line, the coast is very precipitous and mountainous. Then there is a radical change, for the mountains trend off to the east into the interior, and across Guatemala, a broad low coastal plain lies next the Pacific. This may be as much as 15 miles or more in width and is backed by a high volcanic range, including the famous "Volcano of Water" and the "Volcano of Fire," near the city of New Gautemala. These volcanoes are of quite recent formation, and their topography is markedly different from that of the greater part of Mexican and Central American Mountain Ranges. While sailing along the coast between San Francisco and Panama, I distinguished two principal types of mountain ranges. One is characterized by distinct erosion topography, with sharp, rocky peaks, deep valleys and numerous ravines. Most of the mountains seen from the sea even in Central America are of this class. It is the only one represented, except as to the peak of Chiriqui, on the Isthmus of Panama.

The other type is characterized by high, cone-shaped peaks, remarkable for their long, slightly curved, but even slopes. The smoothness of the topography in strong contrast to the roughness of the other type, will appeal even to the unscientific observer as indicating an extremely recent age.

The low coastal plain of Gautemala extends to Acajutla in San Salvador, where it has been bowed up about 40 feet by a slight disturbance perhaps connected with the active volcano seen near by. The sea has eroded a low cliff into the arched strata and revealed a harder formation under the light-colored sand of which the low coastal plain is largely composed. This lower formation I believe to belong to another coastal plain which was largely submerged and the present low coastal plain built on it.

South of Acajutla, the low coastal plain is represented, but at and near La Libertad, in San Salvador, the land next the coast is an elevated plain, much dissected by cañon valleys and remarkably like an uplifted and dissected Pleistocene peneplain. It rises rapidly to the foot of the mountains several miles distant inland. South of here the immediate coastal lands consist chiefly of the low plain, especially along the coast of Nicaragua. At Corinto, a low, narrow ridge of reddish colored stratified rock like sandstone forms a rim outside of the low, coastal plain, which latter is miles in width and traversed by broad crooked estuaries or salt-water channels so common in the low coastal plain region. The sandstone ridge at Corinto seems to be a remnant of another coastal plain now largely submerged and the present low coastal plain built on it.

It is evident to me that from the Isthmus of Tehuantepec to the mainland of South America, the Pacific coast has had the same history. During the Pleistocene era there have been two coastal plains formed. The first or Middle Pleistocene plain was mainly one of erosion inland and aggradation on the seaward border, and was more extensive than the present coastal plain. Then there was a tilting of this plain toward the sea, with local variations of the disturbance. As a general thing the plain was elevated, and dissected by stream erosion inland and largely destroyed by marine erosion on the seaward margin. About at the close of the Pleistocene period, a movement of depression submerged the seaward portion, forming islands from some of the isolated low mountain masses which formerly stood as monadnocks on the plain. Subsequently the sea built another coastal plain over the portions of the old plain which were but slightly submerged.

The subsidence of the Pacific coast of Central America and the Isthmus of Panama was very slight, probably nowhere amounting to as much as several hundred feet. On the Mexican coast and farther north it seems to have been greater in general but more local in character. The occurrence of such a slight subsidence in the Recent period along over 3,000 miles of coast is remarkable, and indicates that the disturbance was one of a continental nature.

Berkeley, California,
February 9, 1901.