

GEOLOGICAL MAP OF THE EASTERN PART OF THE STATE OF PARAHYBA DO NORTE

GEOLOGY OF THE NORTHEAST COAST OF BRAZIL.

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INTRODUCTION

So little is known of the geology of northeastern Brazil that no apology is needed for the obvious imperfections of the present paper. Most of the notes were taken during a trip along the coast and several trips across the sedimentary beds in 1899, but I was previously somewhat familiar with the geology of the region through my work there while a member of the Geological Survey of the Empire (the *Comissão Geologica do Brazil*), and from subsequent trips to the interior of Pernambuco. Fortunately I have been able also to obtain valuable contributions from several correspondents whose names are mentioned in the paper to supplement my own observations.

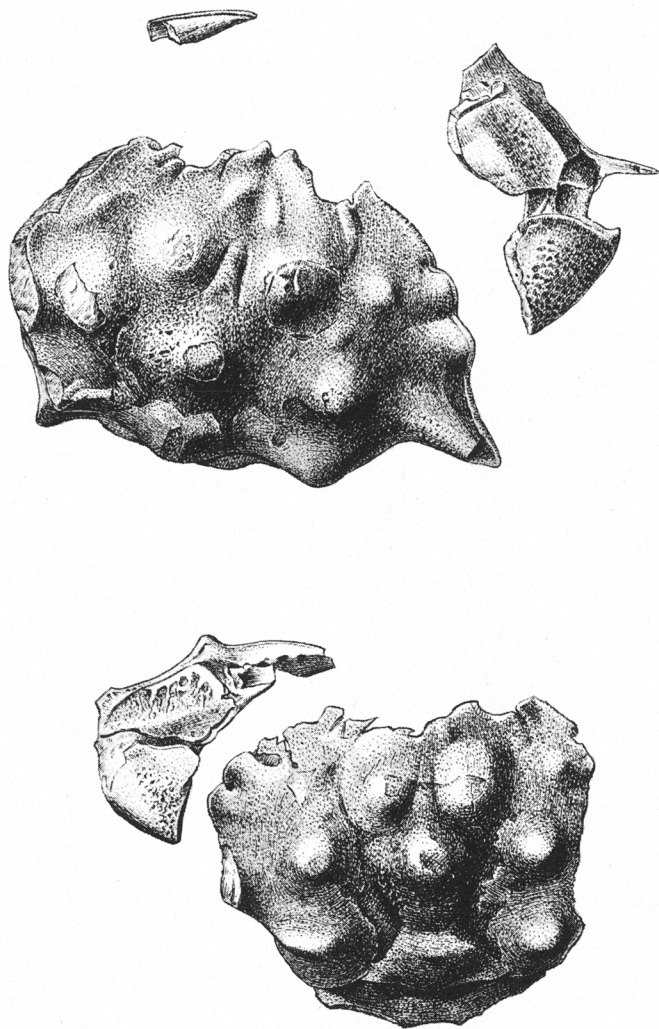
GEOLOGY OF THE STATE OF PARAHYBA DO NORTE

RESULTS OF PREVIOUS AND PRESENT INVESTIGATIONS

Aside from the very brief references cited beyond, the only paper ever published on the geology of the state of Parahyba do Norte is that of E. Williamson.* Mr Williamson says the rocks of that state are Tertiary, Cretaceous, and Laurentian, but he mentions no paleontological reasons for these divisions. So far as the Tertiary and Cretaceous divisions are concerned, Mr Williamson's classification seems to be correct, as will presently appear.

Although I have visited Parahyba several times, the trips have been hurried, and it has never been possible for me to make a careful search for fossils. Since my last visit, in 1899, however, Mr H. G. Sumner, superintendent of the Conde d'Eu railway, has secured and kindly sent me a few fossils recently found in quarries at the base of the hills near the railway station at that city. These fossils are of great importance and interest, for they are the first and only ones thus far found which throw a decided light on the geologic age of the beds at and about

* This paper was read in April, 1867, before the Geological Society of Manchester, England, and published in its *Transactions*, vol. vi, pp. 113-122, under the title "Geology of Parahiba and Pernambuco gold regions."



ZANTHOPSIS CRETACEA RATHBUN SP. NOV. FROM PARAHYBA DO NORTE

Parahyba.* They consist of some teeth and fragments of bones of a fish, portions of the carapaces of two crabs, and one somewhat crushed cephalopod: The cephalopod, Dr J. P. Smith † tells me, is a species of *Sphenodiscus*, one of the so-called "Ceratites," and of positive Cretaceous age.

MISS RATHBUN'S DESCRIPTION OF ZANTHOPSIS CRETACEA

The crabs were submitted to Miss Mary J. Rathbun, of the Smithsonian Institution, and she has kindly furnished the following description:

Zanthopsis, McCoy

Zanthopsis, McCoy, Ann. Mag. Nat. Hist. (2), iv, 162, 1849. *Zanthopsis cretacea*, Rathbun, sp. nov.

Carapace about one and three-fourths times as wide as long. Surface densely granulate, posterior portion punctate; regions fairly well delimited. Six prominent nodules: two median, one occupying the greater part of the mesogastric region, one surmounting the cardiac region; the other four are branchial, the anterior pair in line with the gastric nodule, the posterior pair a little in front of the cardiac nodule and a little outside the anterior pair; these last are high and subconical; the posterior pair are lower and broader than long. Four less conspicuous nodules also exist—one on each protogastric lobe, one on each hepatic area. A long, low protuberance lies behind each lobe of the front. The grooves on either side of the narrow mesogastric region are rather deep.

The width between the outer angles of the orbits is a little less than one-third the width of the carapace; the front occupies nearly half the space; it is produced and divided by a median V-shaped notch into two lobes, with oblique margins, forming a triangular tooth at the inner end, and a right angle at the orbital end. The orbits are directed forward; their margins show two fissures, separated by a narrow, non-projecting lobe; the outer angle is a little more advanced than the outer angle of the front.

The long antero-lateral margin bears at its middle two somewhat dentiform, upturned lobes, defined on either side by deep grooves. Between these lobes and the orbit, the antero-lateral margin is nearly straight; behind the lobes, the margin forms the anterior border of a long, stout spine occupying the lateral angle of the carapace. Postero-lateral margin concave. Posterior margin not distinguishable.

The only appendages preserved are, in the larger specimen, a portion of the right cheliped (carpus and palmar portion of propodus), and a fragment of the left dac-

* Hartt mentions estherians found by Agassiz in certain green shales at Parahyba, from which he, Hartt, infers that the beds are of fresh-water origin and equivalent to those of Bahia. C. F. Hartt: "Geology and Physical Geography of Brazil," p. 445.

These fossils, however, were never identified, and as estherians are not necessarily of fresh-water origin, and inasmuch as the cephalopod shows that the deposits are marine, the correlation must be regarded as unwarranted. Capanema says of a visit to Parahyba: "A badly preserved crinoid leads me to suppose that the rock belongs to the Cretaceous," an equally hasty conclusion. *Trabalhos da Comissão Científica de Exploração*, I, Seção Geologica, p. cxxii, Rio de Janeiro, 1862.

† Professor of paleontology in Stanford University.

tylus; in the smaller specimen, the carpus and propodus of the left cheliped. Upper surface of these two segments reticulated. Dorsal face of carpus subtriangular, the distal margin being a little longer than the other two. The palm is nearly one and a half times as long as wide and a little longer than the fingers; a blunt longitudinal carina runs along its outer third; outer margin furnished with a long slender spine near its proximal end and a thick rounded lobe opposite the base of the fingers. Outer margin of propodal finger rimmed. Judging from the socket of the movable finger, it lies above and overlaps the immovable one; the latter is provided with a median dentated ridge which may have served as a cutting edge against that of the overlying dactylus.

The length of larger specimen from median frontal sinus to rear of cardiac region is 34 millimeters; length from tips of frontal teeth to same point, 35.3 millimeters; width of carapace (approximate), 67.2 millimeters; width between outer orbital angles, 22 millimeters; width of front, 10.5 millimeters.

The type locality is the quarry at the base of the hill in the city of Parahyba do Norte, Brazil; two specimens.

The genus *Zanthopsis* contains several species described from the Eocene of Europe. *Z. cretacea* differs from them all in the character of the nodulation. It resembles *Z. kressenbergensis*, Meyer, in having a long lateral spine, but this spine is much stouter in our species. The long spine on the propodus of the cheliped is unique. Specimens are in the National Museum of an undescribed species of *Zanthopsis* from the Eocene of Alabama.

The specimens here described are deposited in the U. S. National Museum at Washington, D. C.

DOCTOR WILLISTON'S DESCRIPTION OF *CIMOLICHTHYS* N. SP.

The fish remains from Parahyba do Norte, Brazil, have been referred for determination to Dr S. W. Williston, of the University of Kansas, who kindly furnishes the following description :

"The specimen of *Cimolichthys* preserved is a fragment of the skull, contained in a small block of rather hard limestone. The only characteristic portion is a part of the right dentary, 65 millimeters in length, containing five teeth of the inner row and eight or ten of the outer row. This portion, however, is so characteristic of this peculiar genus of Cretaceous fishes that there would seem to be little doubt of the affinities of the specimen, incomplete as it is. It can be referred almost unhesitatingly to the genus *Cimolichthys* (*Empo*), an opinion concurred in by Mr Steward, who has studied our Cretaceous fishes and who has examined the present specimen. The material, however, is hardly sufficient to render the specific determination certain, should the beds whence the specimen comes yield other species of the same genus upon further examination. For this reason I refrain from giving the present species a name.

"*Cimolichthys* has been known hitherto only from the Upper Cretaceous of Europe and North America. The type of the genus, *C. lewesiensis*, is from the Upper Chalk of England, while isolated teeth have been referred to the genus coming from the upper Plänen beds of Bohemia. In North America four or five species are known from the Niobrara and Fort Pierre Cretaceous of Kansas. It

would seem highly probable, therefore, that the horizon of the present species is in the upper part of the Upper Cretaceous.

"The genus is characterized by the dentition, especially of the palatines and dentaries. In the present specimen the two rows of teeth situated upon the dentary have a great resemblance to those of the American species, especially *C. naepiolica*. The inner row of large teeth have the characteristic compressed form

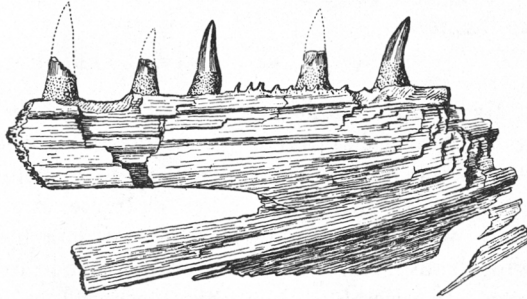


FIGURE 1.—Right Dentary of *Cimolichthys* n. sp. Natural size.

with anterior and posterior cutting edges placed somewhat obliquely. They are unstriated. The base is much elevated and conical, and the five teeth preserved are nearly all of the same size, with only slight discrepancies in the intervals between them. The outer teeth appear to be in a single row. They are small and tuberculiform, about one millimeter in height, and with intervals between them of about the same. The surface of the dentary has been mostly destroyed.

	Millimeters.
"Space occupied by five inner teeth.....	55
Height of middle tooth above bone.....	12
Height of base.....	4
Width of tooth where joined to base.....	4
Space occupied by eight teeth of outer row.....	10"

AGE AND ANALYSIS OF PARAHYBA LIMESTONE

The chief point of interest in this small collection of fossils is that it settles definitely the Cretaceous age of the leaden gray limestone at the base of the hills about the city of Parahyba.

A specimen of the rock containing the fossils was analyzed in duplicate and found to be fairly good limestone.

Analysis of the Cretaceous Limestone from Parahyba do Norte

	Per cent
Silica (SiO ₂).....	7.32
Iron (FeO).....	1.26
Lime (CaO).....	45.82
Magnesia (MgO).....	3.95
Carbon dioxide (CO ₂).....	41.48
Sulphuric acid (SO ₃).....	0.44
Total.....	100.27

This rock was examined under the microscope in the expectation of finding microscopic organic remains, but no fossils were found.

The strata forming the higher parts of the hills appear to rest conformably on these lower marly beds, but the upper beds have yielded no fossils.

COASTAL SEDIMENTS

Mr Sumner's house, on top of the hills south of the governor's palace, in the city of Parahyba, has an elevation of 46 meters above tide-level. A well was dug here 28 meters deep; it penetrates only the pink, red, and mottled sands and clays characteristic of the coastal sediments. Many white quartz pebbles the size of a hen's egg and more or less white kaolin were found in the earth taken from this well. The section seems to resemble closely that exposed in the bluffs at Cabo Branco.

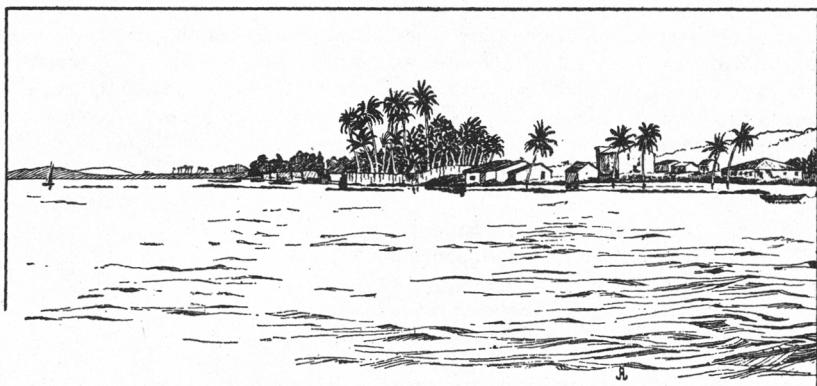


FIGURE 2.—Ponta de Pedras, Pernambuco, looking Southwest.

No unconformity has been found between the highly colored upper beds and the gray calcareous Cretaceous beds at the base of the hills. The line of demarkation between the weathered and the unweathered beds, however, is so uneven that it looks as though the weathering had affected both the upper and lower strata in much the same manner, regardless of geologic age.

FOSSILS FROM SANDSTONE EXPOSURES OF THE COAST

Further light is thrown on the geology of Parahyba and Cabo Branco by the exposures on the coast south of the cape. Ponta de Pedras is a village on the coast of Pernambuco, in south latitude 7 degrees 37 minutes, between the mouth of Rio Goyana and the northern end of the island of Itamaracá. On the beach in front of the village yellow fossiliferous calcareous sandstones are exposed from about 2 meters above mean tide to and below low tide, and extending about 200 meters along the beach.

The expedition stopped at this place June 17, 1899, just long enough to examine the rocks and gather a few fossils. These fossils were examined by Mr Ralph Arnold, who kindly made the following determinations and correlations :

*Fossils from Ponta de Pedras, Coast of Pernambuco **

	Also found at—
1. <i>Cypræacteon pennæ</i> White	Rio Piabas.
2. <i>Volutilithes radula</i> (White, not Sowerby)	{ Olinda.
3. <i>Volutilithes alticostatus</i> , White } ? <i>V. radula</i> , White }	{ Maria Farinha.
4. <i>Acmaea</i> sp. nov.	
5. <i>Natica neverita</i> sp. undet.	Montserrate, Bahia.
6. (<i>Neritina prolabiata</i> , White.)	
7. <i>Turritella elicita</i> (White, not Stolitzka)	Maria Farinha.
8. <i>Vicarya</i> ? <i>daphne</i> White.	Maria Farinha.
9. <i>Capulus</i> sp. nov.	
10. <i>Hyponyx</i> sp. nov.	
11. ? <i>Melania terebriformis</i> Morris ?	{ Itamaracá.
12. <i>Crepidula</i> sp. nov.	{ Montserrate, Bahia.
13. <i>Lucina tenella</i> Rathbun.	{ Rio Piabas.
14. <i>Nucula marix</i> Rathbun.	{ Maria Farinha.
15. <i>Leda</i> (<i>Nuculana</i>) <i>swiftiana</i> , Rathbun	{ Maria Farinha.
16. <i>Corbula</i> ? <i>chordata</i> White.	{ Sergipe.
17. <i>Corbula</i> sp. nov.	{ Rio Piabas.
18. <i>Dosinia brasiliensis</i> White.	{ Sergipe.
19. <i>Glycimeris</i> (<i>Axinea</i>) <i>binemini</i> White.	{ Rio Piabas.
20. <i>Cardium</i> (<i>Oriocardium</i>) <i>soaresanum</i> Rathbun.	{ Maria Farinha.
	{ Itamaracá.

Of the twenty species here listed, five are new, five are reported from Rio Piabas, state of Pará, nine are found at Maria Farinha, two at Montserrate, Bahia, two in the state of Sergipe, and one at Olinda, Pernambuco. Two were also found at a new locality discovered by the writer at the northeast end of the island of Itamaracá. The specimen from Itamaracá was found in a bed of brown sandstone. The Itamaracá locality is only 11 kilometers south, and Maria Farinha is only 27 kilometers south of Ponta de Pedras.

The resemblance of the fauna found in the Ponta de Pedras rocks to that of the Maria Farinha beds is at once apparent, while the proximity of the localities to each other bears out the theory that the same beds are repeated at these two or three localities. I have elsewhere pointed out

* Collected by J. C. Branner, June 17, 1899.

that the Maria Farinha beds are Tertiary and not Cretaceous, as was supposed by Hartt, Rathbun, and White.* Mr Arnold bears me out in this conclusion, and he is positive that the beds at Ponta de Pedras are to be correlated with those of Maria Farinha, which Professor Gilbert D. Harris regards as of Midway Eocene age beyond any question.

About halfway between Ponta de Pedras and Parahyba similar rocks are exposed on both sides of the mouth of a river that enters the sea just north of Tambaba point. The rocks were examined on the beach



FIGURE 3.—Reef of Tertiary Sandstone, South of Jacumã.

about 2 kilometers south of the village of Praia de Jacumã, which is in south latitude 7 degrees 17 minutes. Here a reef of the yellow fossiliferous Tertiary calcareous sandstones like that of Ponta de Pedras extend out about 300 meters from the beach and rises a meter or more above mean tidelevel. The surface of this rock is black, and its yellow color only appears on a freshly broken face.

This Jacumã locality is just 22 kilometers on a line from the city of Parahyba, and is the nearest to Parahyba of any Tertiary locality that has been identified as such by its fossils.

The exposures between Jacumã and Cabo Branco were not examined.

*J. C. Branner: The oil-bearing shales of the coast of Brazil. Trans. Amer. Inst. Mining Engineers, 1900, pp. 17, 18 of the separate. The Tertiary age of the Maria Farinha beds was suspected at the time of the publication of Dr White's contributions. See Cretaceous and Tertiary, etcetera, by J. C. Branner, Trans. Amer. Phil. Soc., 1889, vol. xvi, p. 405.

At Cabo Branco a low reef about half a kilometer in length, of hard rough black rocks, barely uncovered at half tide, stands squarely out from the beach. Where examined near the shore these rocks are coarse sandstones, cemented with iron and barren of fossils. The rocks exposed in the cliff at Cabo Branco are chiefly sandstones. The lowest ones are the same as the dark red sandstones exposed in the reef offshore; next above this the rock is purple, red, and gray mottled clay. This clay ends a little more than 1 meter above high-tide level. Overlying

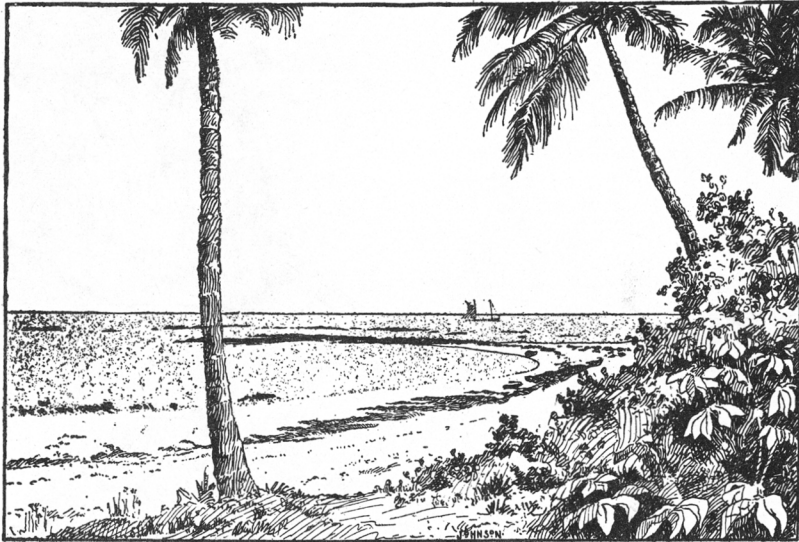


FIGURE 4.—General View of Tertiary Sandstone Reef.

the clay is a 5-meter bed of orange colored sands, false-bedded, with lumps and streaks of white kaolin splotching its exposed surface. This bed merges above into red and gray mottled sands and buff sands and loam at the top of the exposed face of the bluff. No fossils were found in any of these beds.

The top of the hill at Cabo Branco is about 20 meters above high tide. This point of land is the oceanward or eastern end of the plateau on which the city of Parahyba is built. The Cabo Branco hills continue as an unbroken bluff from 30 to 50 meters high in a northwesterly direction to that city, while the peninsula ending at Cabedello at the mouth of the Rio Parahyba do Norte is a flat sandy plain lying north of this bluff. As the beds exposed at Cabo Branco contain no fossils, it is impossible to say whether they are Tertiary or Cretaceous, but the strati-

graphic position of the beds makes it seem possible that they belong to the Tertiary.

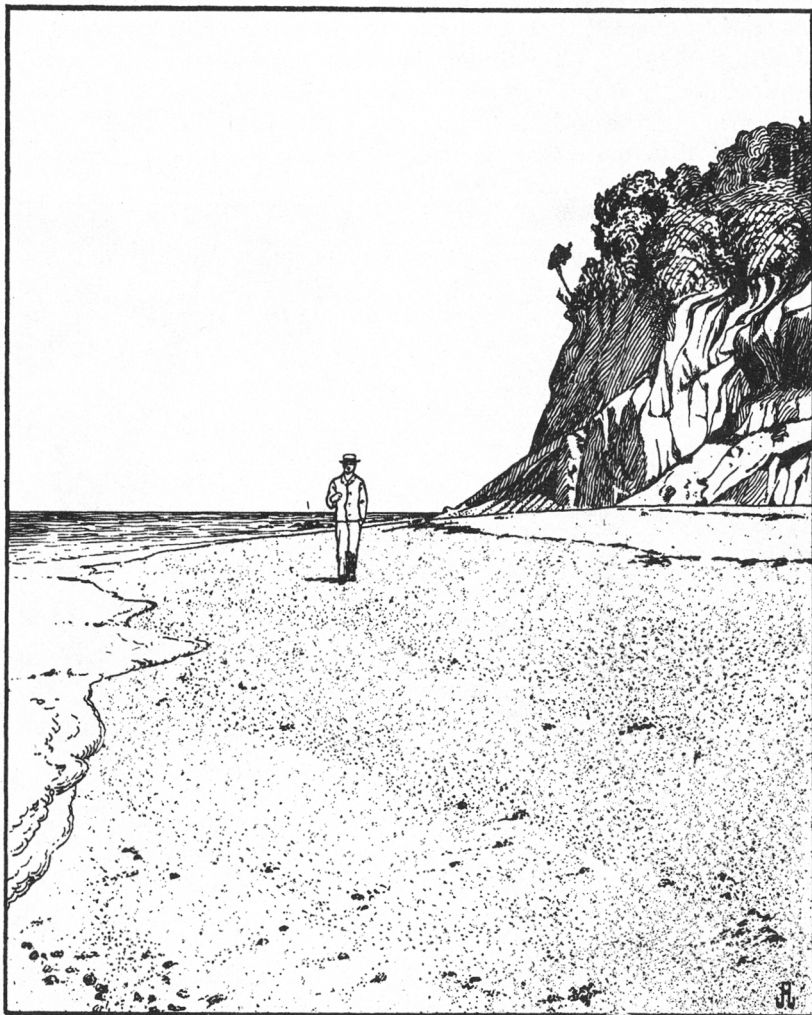


FIGURE 5.—Cabo Branco.

GENERAL GEOLOGIC RELATIONSHIPS

We have, then, in the state of Parahyba about the same geology that we have at Olinda, Maria Farinha, Iguarassú, and Itamaracá, namely, sedimentary beds of both Cretaceous and Tertiary ages dipping gently seaward.

It is to be expected, then, that the Conde d'Eu railway, running as it does along the valley of the Parahyba, is near the contact between the Tertiary and Cretaceous beds, and in the absence of paleontologic evidence there is no telling whether the sediments forming the hills south of the railway between Parahyba and Espirito Santo belong to the one or the other of these geologic divisions. The beds forming the hilltops nearer the coast are probably all Tertiary, but at the extreme western edge of the sediments one has usually nothing but the lithologic characters of the rock to guide him, and these, as a rule, are not to be depended on.

RESULTS OF EXAMINATION OF EXPOSURES ALONG THE CONDE D'EU RAILWAY

The following notes were made in two trips along the railway west of Parahyba and four trips between Cabedello and Parahyba:

Stations of the Estrada de Ferro Conde d'Eu

Kilometers.	Station.	Elevation above tide (aneroid).
		<i>Meters.</i>
0	Molhe (pier).....	....
2	Cabedello.....	3.0
11	Jacaré.....	....
20	Parahyba.....	1.0
....	Fabrica de Tecidos.....	....
32	Santa Rita.....	9.1
....	Usina S. João.....	....
40	Reis.....	9.1
46	Espirito Santo.....	....
51	Entroncamento.....	11.5
53	Cobé.....	....
66	Sapé.....	94.5
76	Araça.....	110.0
86	Pau Ferro.....	....
96	Mulungú.....	62.5
113	Caxoeira.....	65.5
118	Independencia (old Guarabira).....	70.0

The Conde d'Eu railway now runs from Cabedello, 20 kilometers north of the city of Parahyba, to Independencia, formerly called Guarabira, in the interior of the state, a total distance of 118 kilometers. From the accompanying sketch map it will be seen that it follows nearly due west up the Parahyba to Entroncamento 31 kilometers, where the main line turns northward and crosses the watershed into the drainage basin of the Rio Mamanguape and ascends the northern side of that stream's basin.

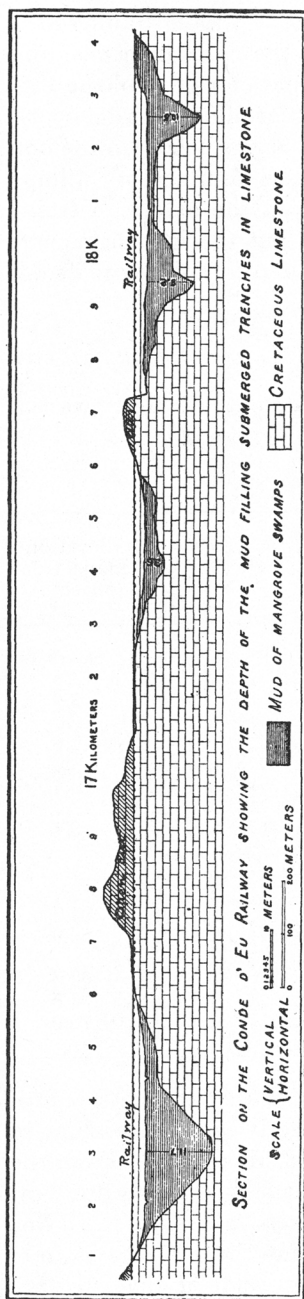


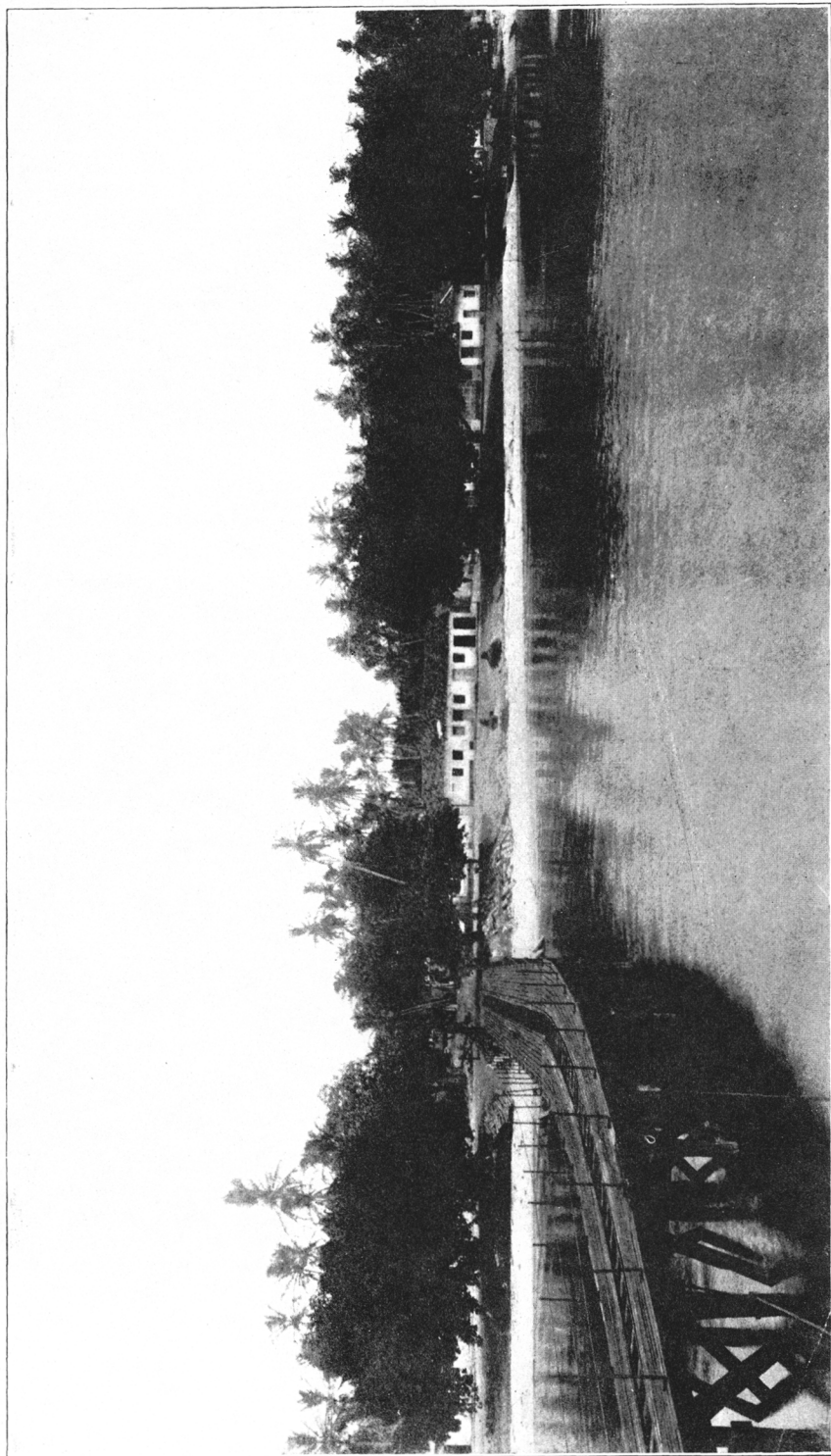
FIGURE 6.—Geological Section on the Conde d'Eu Railway.

Between Cabedello and Parahyba the line crosses an almost perfectly flat sandy plain that rises only 2 or 3 meters above tidelevel. In a well put down at the railway shops at Cabedello, marine shells are reported to have been found at a depth of 7 meters below the surface of the ground. The writer did not see these shells. On both sides of the peninsula there are small local exposures of slightly consolidated calcareous sands, in places made up largely of triturated calcareous seaweeds. These sands are apparently of late geologic origin.

A short distance north of the city of Parahyba the railway passes across alternate mangrove swamps and arms of high firm ground which extend from the hills of Parahyba toward the estuary. The high ground of these arms usually rises only a few decimeters above tide-level in the mangrove swamps. One of these ridges, however, has an elevation of several meters where crossed by the road, and there is a cut more than 2 meters deep for the railway bed. This cut is in the gray, marly looking limestone that resembles some of the Cretaceous limestone of the Sergipe basin. Unfortunately there was no opportunity to examine these beds for fossils.

Especial attention is directed toward this part of the railway line on account of the light thrown on the geographic history of the coast by the depth of the muck in the mangrove swamps.* This portion of the railway, the prolongation from Parahyba to Cabedello, was built in

*I am indebted to Mr Samuel H. Agnew, now superintendent of the Natal a Nova Cruz railway, for the copy of the profile and record of soundings on this part of the railway.



SAND PLAIN AT CABEDELLO, PARAHYBA DO NORTE

1887-'88. Where the line crosses the ends of the mangrove swamps northeast of Parahyba, great difficulty was experienced in building the road on the soft mud on account of its yielding and slipping from beneath the load of earth that had to be heaped on it to form the roadbed. As there are cuts in solid rock on both sides of one of the swamps, it was supposed that the swamps had rock bottoms, and soundings were therefore made in the swamp to find the depth to the rock. These soundings were successfully made with steel rods, and the mud was so soft that two rods were lost by being dropped endwise in the mud; they are said to have sunk almost as promptly as if they had fallen in water.

The accompanying profile shows the form of the rock bottoms of these swamps. The greatest depth of the mud found on the line was 11.70 meters. It seems evident that the swamps here fill gullies formerly cut in the gray Cretaceous limestone. Inasmuch as gullies can be cut at such a place only when the surface is above waterlevel, it is inferred that the land hereabouts formerly stood enough higher to allow water to flow down through these channels. The present conditions have been brought about by a depression of the old land surface that has carried the ancient valleys beneath the sea, and the upper ends of these valleys have been filled with silts and then overgrown with vegetation. The depth of these channels shows that the amount of the land depression was 12 meters at least; but inasmuch as the soundings were made close to the Parahyba hills, it seems highly probable that farther west the Parahyba estuary now covers the main channels and that they are much deeper than 12 meters.

The railway station at Parahyba is at the foot of the Cretaceous hills on one side, while to the west and north stretch the mangrove swamps of the Parahyba estuary. Three kilometers from the city of Parahyba the track of the railway skirts a steep-sided hill on the left, with a mangrove swamp on the right. The valleys along this portion of the road are flat-bottomed. At Usina São João the flat valley floor of the Rio Parahyba is about 4 kilometers wide. At kilometer 22 (from Parahyba) there is a great flat freshwater marsh whose sides end as sharply against the hills as if made by a body of water. The surface of this marsh is about 5 meters above tidelevel (aneroid). An attempt was made to build the railway across one of these marshes, but the roadbed sank under the load made by the fill and the line had to be changed. This fact is of interest in connection with the soundings made in the mangrove swamps between Parahyba and Cabedello already mentioned. It seems probable that the valley-cutting done during the period of elevation extended this far, and that we have here another silted-up narrow valley.

The railway cuts east of Santa Rita are in Cretaceous (or Tertiary) sediments, some of them false-bedded. At Santa Rita the railway station is 6 meters above the flat valley floor and 9 above tide-level. From Santa Rita to Reis the railway cuts expose only soil and sedimentary beds.

Between Reis and Espirito Santo the line of the railway crosses a series of short finger-like hills which project toward and into the marshes of the Parahyba valley from the high country south of it. Fresh-water marshes extend from near the station of Espirito Santo eastward for about 1 kilometer. This station is on a flat plain 4 or 5 meters above the level of the water in the fresh-water marshes. The railway here skirts the foot of the sedimentary plain which extends southward from the Parahyba river.

The Cretaceous (or Tertiary) beds end on the railway line between Espirito Santo and Entroncamento, and the first crystalline rocks appear shortly before the latter station is reached. At Entroncamento, 31 kilometers from the city of Parahyba, freshwater marshes of the Parahiba are about 7 meters above tidelevel. The immediate valley of the Parahyba is less than 1 kilometer wide where crossed by the railway, and is flat, ending against rounded and gently sloping hills.

Following up the main line north of Entroncamento there is a railway cut exposing schists with quartz veins about 200 meters south of Cobé station. One kilometer north of Cobé is another cut in quartz-veined schists. One and a half kilometers beyond and north of Cobé, and at an elevation of 58 meters above tide, waterworn pebbles, some of them as large as one's fist, are exposed along the railway at a depth of from 1 to 2 meters below the surface of the red soil and following the surface contour of the hills. In some places, however, these pebbles are wanting.

The station of Sapé is on the flat plateau-like divide between the Parahiba and Mamanguape rivers; its elevation is 94.5 meters above tide. Looking southward from Sapé one may see that the floor of the Parahyba valley is remarkably flat and even, while the skyline beyond is much broken. For 20 kilometers the railway follows the flat plateau; this same taboleiro extends eastward nearly to the sea, forming the tablelands between the Parahyba and the Rio Mamanguape. There are but few exposures along the railway where it crosses this flat plateau, so that the geology is not well shown. So far as it is visible, it seems to be a plain of crystalline rocks cut off rather evenly and having a thin coating of sedimentary beds spread over it. At the margins of the plain the cuts expose crystalline rocks overlain with waterworn boulders. About 2 kilometers west of Araça the railway descends from the plateau of particolored sediments into the Mamanguape valley. At an eleva-

tion of 73 meters and up to 82 meters above tide, there are waterworn boulders, some of them half a meter in diameter, overlying crystalline schists. Farther down the side of the valley the schists are all more or less decomposed and are overlain with a line of waterworn pebbles, and above these is the soil of a deep red color.

Two or 3 kilometers east of Pau Ferro are good exposures of the schists with overlying waterworn boulders. The gravel is from 1 to 2 meters thick and especially heavy about 100 meters east of the station of Pau Ferro. The gravel bed is generally covered by from 1 to 2 meters of soil.

At Pau Ferro station (66 kilometers from Parahyba) a well has been dug east of the railway track in the lower part of the valley, and from this were taken many waterworn boulders. The pebbles in the vicinity are subangular rather than round, though clearly waterworn. Northwest of Pau Ferro are several cuts along the railway in which schist is exposed with waterworn materials overlying it. One of these cuts is about 5 meters deep; the gravel beds overlying the schist are a meter or more in thickness, but they thin down and almost disappear in places. This sheet of waterworn gravel passes completely over the lower watersheds. The soil over the schist is in places not more than half a meter thick. There are white bands of pegmatite in some of the exposures of crystalline rocks.

Mulungú station (elevation, 62.5 meters) stands on a black clay or soil that forms the flat floor of a narrow valley draining into the Rio Mamanguape. This black muck-like soil looks like the bottom of an old lake or swamp. The soil is the so-called "massapé." In the dry season it opens in big cracks.

In the Mamanguape valley there are several lakes apparently in process of filling up with organic matter.

On the divide between the Mamanguape and Caxoeira station, at an elevation 94 meters, some of the schists are very micaceous, and the pebble bed is heavy, coarse, and widespread. South of Caxoeira station (93 kilometers from Parahyba) schists decayed in places so closely resemble the particolored sediments on the coast that at a distance of 10 meters they could not be distinguished from each other. On closer inspection the bedding planes (or schistosity) of the schist may be traced through the colored earth. The earth produced by the decomposition of the schist here is sometimes highly colored and sometimes gray.

Independencia, formerly known as Guarabira, is the terminal station of the railway. It is 98 kilometers from the city of Parahyba, and has an elevation of 70 meters above tide, and is about 45 kilometers from the seacoast. The rocks exposed in place about the town are all schists,

but among the heaps of stones brought together for building purposes are occasional small blocks of a diabase-like rock, evidently boulders of decomposition. The schists are cut by many quartz veins and the slopes of the low hills are strewn with a thin covering of waterworn boulders. Some of these boulders are nearly half a meter in diameter.

In a cut made in the town for the prolongation of the railway the schists are well exposed; they are not much crumpled but they split readily. From the hills about Independencia the topography has the appearance of a peneplain into which the streams have cut their valleys and above which the higher peaks rise.

There are a few places along the line of this railway where there are large exfoliated boulders or bare rounded rocks in place.

Alagôa Grande was not visited, but Mr H. G. Sumner tells me that the hills in the vicinity of that place are all of granite or other crystalline rocks. The accompanying plates from photographs by Mr Sumner show the character of the topography of that region.

The writer has not examined the geology farther west in the state of Parahyba, but a few notes of value are available from the observations of others.

In 1854 a French physician, Jacques Brunet, was authorized by the president of the province of Parahyba to explore its interior. He sent to Mr Burlamaque, of the Museo Nacional, at Rio de Janeiro, two fossil shells found in the Serra de Teixeira.*

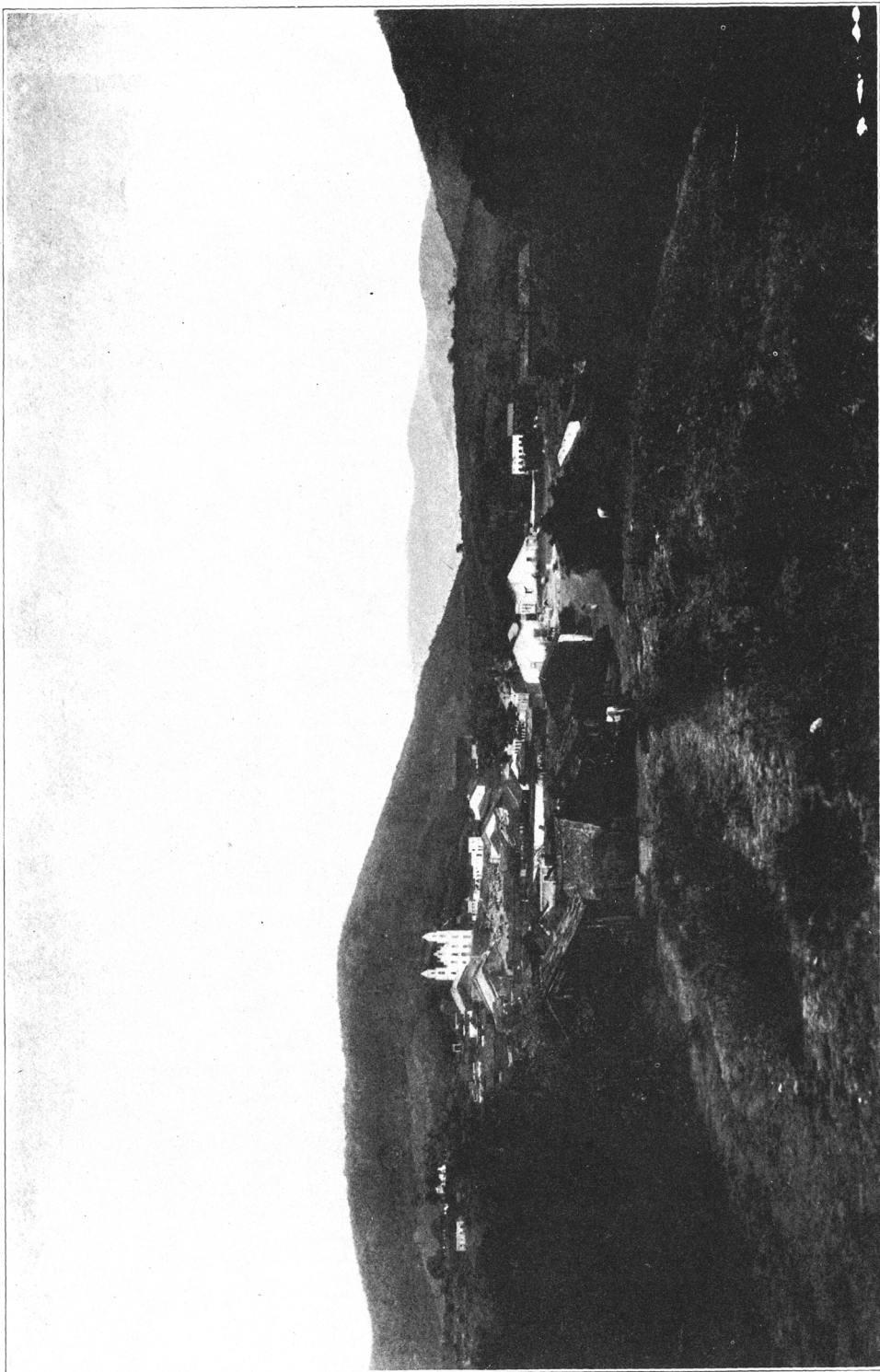
In a somewhat later paper Dr Burlamaque says † that Brunet sent specimens of limestone from Rio do Peixe and São João in the extreme western part of Parahyba; he also sent salt-bearing clays from Area. These localities are not far from the Cretaceous beds of the interior of Ceará.

Williamson's trip to the interior, made in 1866, extended to Piancó, about 265 kilometers west of Independencia. The rocks over most of this distance are reported by him to be granites, gneisses, and schists, but on the western side of the Serra da Borborema, "at Teixeira, where granitoid rocks abound, large quantities of brecciated conglomerates, sands, and marls are found flanking the mountains and covering the valleys." ‡ It seems probable that these sedimentary beds are the ones from which Brunet obtained the fossil shells, and that they are the re-

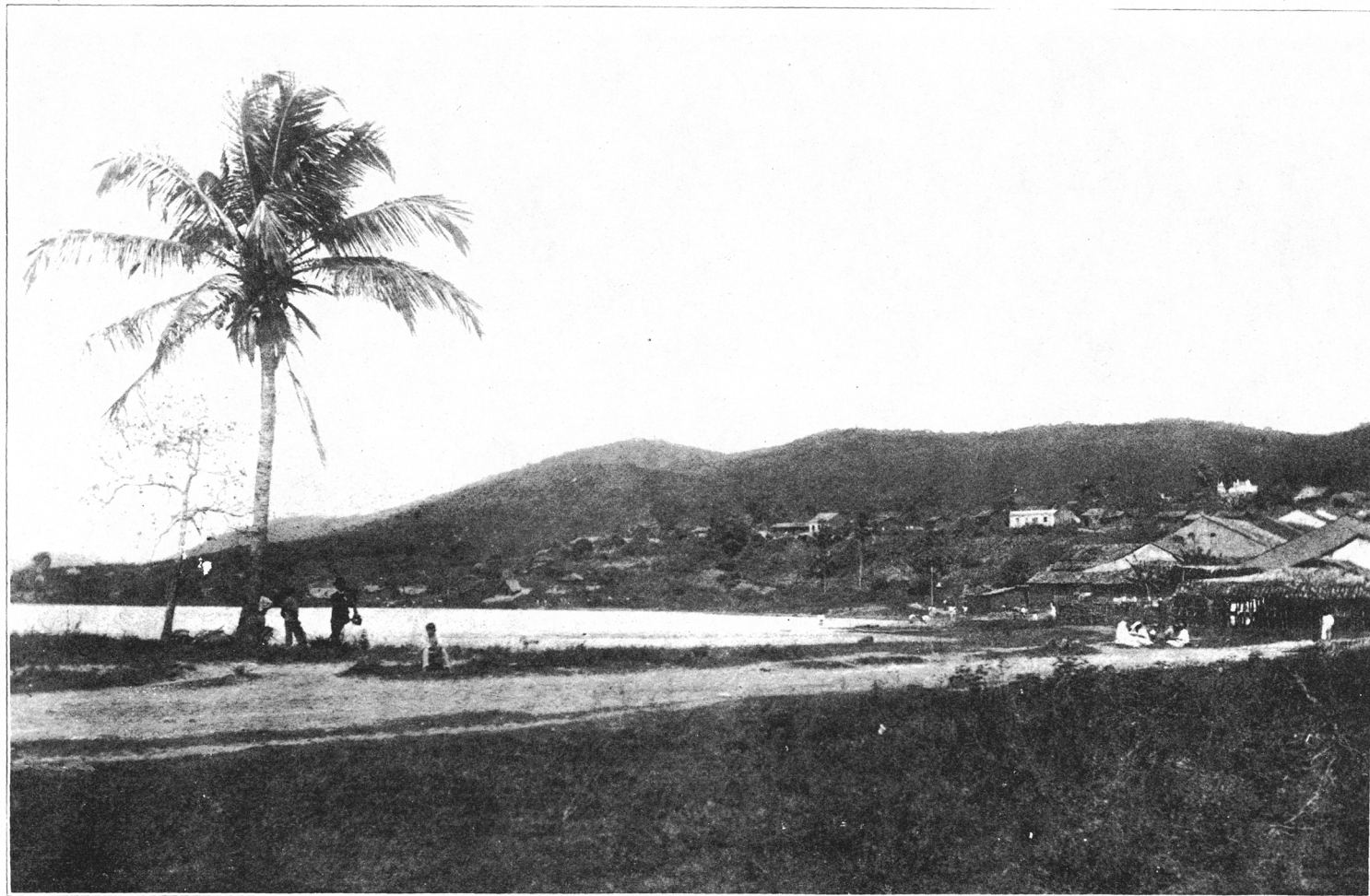
* Notícia acerca dos animaes de raças extinctas descobertos em varios pontos do Brazil. Pelo Dr F. L. C. Burlamaque. Bibliotheca Guanabarensis. Trabalhos da Sociedade Vellosoana, 1855, pp. 19, 20.

† Notícia acerca de alguns mineraes e rochas de varias provincias do Brazil, recebidos no Museo Nacional durante o anno de 1855. Por Dr F. L. C. Burlamaque. Revista Brasileira, Rio de Janeiro (1858), vol. ii, pp. 73-104.

‡ Williamson: Geology of Parahyba and Pernambuco gold regions, Trans. Manchester Geol. Soc., 1867, vol. vi, p. 115.



GRANITE HILLS AT ALAGOA GRANDE, PARAHYBA DO NORTE



LAKE IN THE GRANITE REGION OF ALAGOA GRANDE, PARAÍHYBA DO NORTE

sidual eastern and southern edges of the great Crétaceous area of the interior of Ceará and Piauhý, or perhaps they might more properly be called the fragmentary outliers between the Cretaceous area of the interior and the Cretaceous along the coast, and known to occur at Parahyba and in the states of Alagôas and Sergipe.

A short paper published by a Brazilian engineer in 1886 contains a few points of interest in connection with the geology of the interior of the



FIGURE 7.—Idealized Section from Cabo Branco to Frontier of Ceará.

state of Parahyba.* This writer mentions the existence of caves in the interior of Parahyba, a fact that leads to the inference that there are limestones in the region referred to. He also mentions† the finding of the bones of large extinct animals—probably mastodons. He speaks of the existence of iron, coal, lead, marl, limestone, and flint in the interior, but he does not specify the localities.

CONCLUSIONS REGARDING THE GEOLOGY OF PARAHYBA DO NORTE

1. The leaden gray rocks exposed at the base of the hills at the city of Parahyba are fairly good limestones and are of Cretaceous age.

2. The yellow Calcareous sandstones exposed on the coast south of Jacumã and at Ponta de Pedras are equivalent to the Maria Farinha beds of Pernambuco and are of Tertiary age.

3. The particolored beds forming the tops of the hills at Parahyba and those in the bluffs at Cabo Branco are probably the weathered portions of the Tertiary, but no unconformity is known between them and the Cretaceous beds.

4. In the absence of fossils it is not possible to distinguish between the Cretaceous and Tertiary, and hence the sedimentary beds exposed along the Conde d'Eu railway cannot at present be assigned to either group with certainty.

5. The sedimentary beds form the highlands along the line of the railway from Parahyba to a point between the stations of Espírito Santo and Entroncamento—a distance by rail of nearly 30 kilometers.

6. The sedimentary beds (Tertiary and Cretaceous together) have a width along this coast of only 30 or 40 kilometers.

7. The sedimentary beds are not thick, and the underlying crystalline

* Relatório que o engenheiro de minas Francisco Soares da Silva Retumba dirigio ao Exm. Sr Dr Antonio Hereulano de Souza Bandeira, Presidente da Parahyba. Pernambuco, 1886, 46 pp.

† Loc. cit., pp. 16-17.

rocks are reported to be exposed at Batalha on the Rio Parahyba, within the area covered by the sedimentary beds.

8. It seems probable that the sediments all dip gently eastward, so that the Cretaceous beds are occasionally exposed inland, while they are not visible on the coast.

9. The watershed between the Parahyba valley and that of the Rio Mamanguape is of crystalline rocks, thinly covered with sedimentary beds. The waterworn material of the plateau is coarser on the lower slopes than on the top of the plain.

10. The Cretaceous beds rest on schists and other crystalline rocks.

11. The schists are nearly everywhere cut with quartz veins; these veins are generally less than half a meter in thickness.

12. The schists are not much wrinkled, but they stand at high angles—from 50 to 75 degrees.

13. The crystalline rocks are all more or less decomposed, so that many of the railway cuts through them have been made with picks. In some places they have been blasted. The cuts in the hard rocks, however, are nowhere more than 4 or 5 meters deep.

14. In the vicinity of Independencia the crystalline rocks contain dikes of dark diabase-like eruptives.

15. The crystalline rocks of the interior have been called Laurentian by Williamson, but while they lithologically resemble some of the so-called Laurentian beds of Canada, no trustworthy evidence has been found of their age or ages.

16. The general topography shows that there has been a late depression of this coast region; that the water filled the valleys near the coast, and that these valleys afterward silted up and are now partly occupied by mangrove swamps. This history is borne out also by the soundings made in the mud of the mangrove swamps near Parahyba.

17. The depression of the coast was more than 12 meters.

18. The remains of extinct Pleistocene vertebrates are reported from the interior of the state.

19. Fossils and limestones are reported from the interior of the state, but no facts are available to indicate whether these limestones and fossiliferous beds belong to the Cretaceous or with the Paleozoic series. The lithologic character of some of the limestones and the geographic position of the rocks suggest that they are Cretaceous.

GEOLOGY ALONG THE PERNAMBUCO COAST SOUTH OF RECIFE

LOCATION AND CHARACTER OF THE EXPOSURES

In July, 1899, I made a trip on foot along the coast south of Pernambuco, and some of the observations on the geology are appropriate here

Following the beach southward from Pernambuco, the Tertiary hills that are exposed north and west of the city only reach the coast again to the south near the village of Paiva. Here they are about one kilometer to the southwest of the beach. The beds are horizontal, and are composed of sands, clays, and gravels, and contain no fossils.

TRACHYTES

Two kilometers northwest of the point known as Pedras Pretas the hills come quite down to the beach, but here the hills are of trachyte, with a thin covering of Tertiary sedimentary beds capping them. Near the cape Pedras Pretas the trachytes are quite bare, but over them are a few waterworn quartz pebbles showing that the Tertiary beds have been stripped away.

On weathering the trachyte turns red, yellow, and purple. It has been quarried at the point of land for making street paving blocks for the city of Pernambuco, but the quarries are now no longer worked. Specimens of these trachytes were collected and submitted to Mr H. W. Turner, who kindly furnishes the following descriptions:

"These rocks are typical trachytes. Macroscopically they are fine grained purplish rocks with rather abundant phenocrysts of feldspar, some of which attain a length of 6 centimeters.

"Microscopically the trachyte is composed of idiomorphic feldspars in a fine grained groundmass of feldspar laths, with indistinct boundaries, which show a tendency to arrange themselves in parallel lines, which curve about the ends of the feldspar phenocrysts, thus exhibiting a typical trachyte texture. Some of the phenocrysts, as well as the larger part of the microlites of the groundmass, extinguish sensibly parallel to their direction of elongation, and have an index of refraction less than that of the balsam. They are thus orthoclase. A few of the phenocrysts are micropertchite, showing minute lamellæ, presumably of albite and orthoclase intergrown. These lamellæ extinguish at different angles. A few feldspar laths of the groundmass show albite twinning and extinguish at slight angles. These are probably oligoclase. There are some elongated grains of quartz without crystallographic boundaries present, and these appear to have formed after the feldspars, but, nevertheless, to be original. The microlites show no tendency to arrange themselves around these quartz grains, and in some cases the ends of the feldspars are enclosed in the quartz. A few flattened, nearly rectangular prisms with high relief and brilliant interference colors extinguishing parallel to the prism are probably zircon. There are also rather numerous opaque grains of iron oxide, probably magnetite. The section is obscured by a dust of particles, some of them nearly opaque, but where thin are translucent with red-brown color. These are perhaps limonite formed from the alteration of magnetite, for the magnetite grains show a thin rim of similar material. These reddish grains give the purple color to the rock. A little carbonate is also noted."

On the Pedras Pretas point are several blocks of the trachyte, beautifully pitted by sea urchins. These blocks are now so far above mean

tidelevel that they can not be occupied by sea-urchins. It is evident that there has been a recent elevation of this part of the coast, amounting to about 2 meters. There are many other large masses in place similarly pitted.

I recall no other occurrence of trachyte in Brazil. D'Orbigny says that trachytes accompany the porphyries of the western side of the Cordilheiras, but he adds: "No one has noted them in Brazil or in the Guyanas, and I have only seen them in the Cordilheiras or on their western slopes." *

GRANITE AT GAIBÚ

South of Pedras Pretas the next rocks of interest in this connection are exposed at the village of Gaibú, just north of Cabo Santo Agostinho. The rocks at this place are coarse grained gray granites. They are exposed at the foot of the hill, southwest of the village, where an old fort stands on them.

Southwest of the village of Gaibú is a high hill of Tertiary sedimentary beds overlying the granite. Following the foot path across Cabo Santo Agostinho, from Gaibú to the village of Suápe, the granite continues halfway up the hill, but the top of the ridge is of Tertiary sediments. About the light-house on the cape, and especially on the north side of it, are many enormous exfoliated boulders of granite.

GRANITES AND DIORITE OF CABO SANTO AGOSTINHO

The granite runs all the way round Cabo Santo Agostinho from Gaibú to Suápe in one form or another, and only on the top of the ridge are

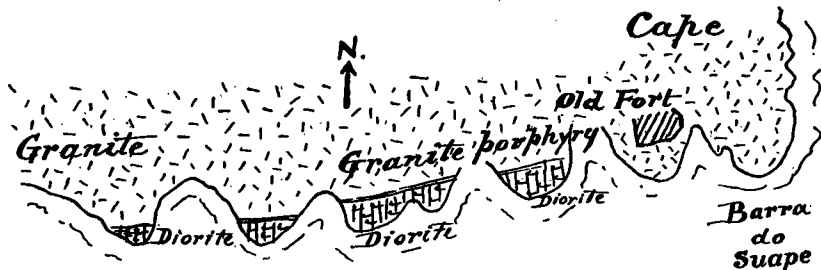
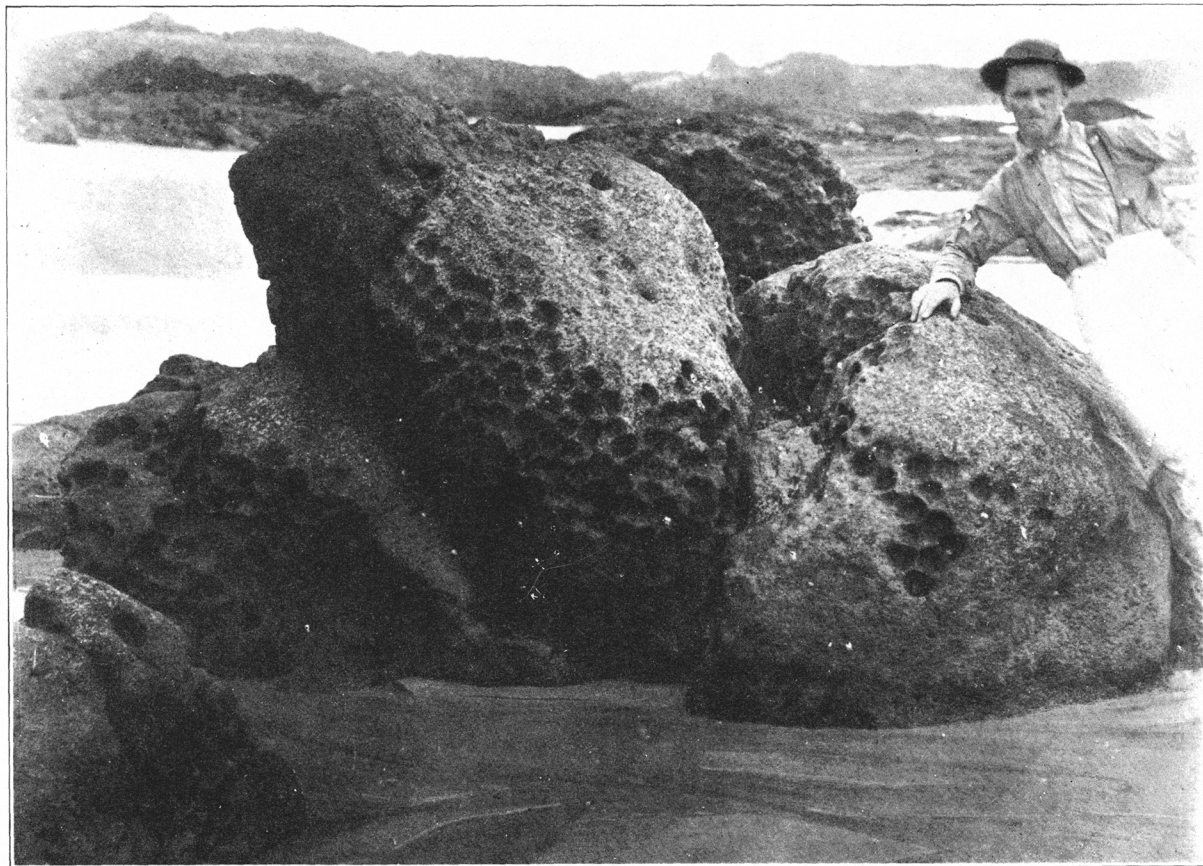


FIGURE 8.—Geology on South Side of Cabo Santo Agostinho.

there patches of Tertiary sediments.† On the south side of the cape are several quarries in the granite-porphyries, all of them now idle.

* Voyage dans l'Amérique Méridionale, t. III. 3^e Partie, Géologie, pp. 215-216. Paris, 1842.

† The rocks here spoken of as Tertiary have thus far afforded no evidence whatever of their age. Their stratigraphic position and their lithologic characters would both admit of their being Cretaceous quite as readily.



SEA URCHIN BURROWS IN TRACHYTE AT PEDRAS PRETAS, PERNAMBUCO



GRANITE POINT AT GAIBÚ CABO SANTO AGOSTINHO, PERNAMBUCO

On the south side of the cape the granites are of two kinds—coarse granites and granite-porphyrries. Through the porphyries is an altered dike of diorite, running about parallel with the hill, between the old fort at the bar and halfway to the village of Suápe. The rock on both sides of the diorite is granite-porphyry, and small dikes of the porphyry penetrate the larger dike of dark green diorite. The old fort on the point of the cape near the Barra do Suápe stands on the porphyry, but farther north the rock is a granite. These three rocks from Cabo Santo Agostinho have also been described by Mr Turner as follows :

“The granite from cape Santo Agostinho is a coarse rock composed of orthoclase, microperthite, and quartz, with frequent wedges of a strongly pleochroic green-blue amphibole between the other constituents.

“This amphibole is in the form of longitudinally striated prisms, which are black as seen with a hand lens. The pleochroism is strongest (dense blue) where the cleavage lines are parallel to the horizontal cross-hair. The extinction was not determined on account of the dense color.

“A fragment of this amphibole was treated with hydrofluosilicic acid, there resulting little hexagonal sodium fluosilicates, a few octahedral anisotropic crystals of undetermined nature, and some thorn-like anisotropic forms radiating from a center much resembling calcium fluosilicates. The presence of sodium, together with the character of the pleochroism, suggests that this amphibole is allied to riebeckite. Calcium is present in some analyses of riebeckite.*

“The granite forming a dike in the diorite is, macroscopically, a light colored coarse rock, composed of light-buff feldspar, quartz, and dark-greenish material.

“Microscopically, it is composed of orthoclase, microperthite, and quartz, with a little reddish-brown strongly pleochroic biotite and a strongly pleochroic green-blue amphibole, with marked cleavage resembling riebeckite and similar to the amphibole described under the preceding specimen.

“The granite porphyries from cape Santo Agostinho are macroscopically light-gray fine grained granolites, showing porphyritic quartzes up to $1\frac{1}{2}$ millimeters in diameter and porphyritic pinkish feldspars up to 2 millimeters in diameter.

“Microscopically, the rock contains numerous phenocrysts of turbid feldspars, often in simple twins, and squarish and hexagonal, sharply idiomorphic, quartz phenocrysts in a microgranular groundmass of quartz and feldspar. The feldspar, both in the phenocrysts and in the groundmass, is largely microperthite, but orthoclase is also present. There are occasional small opaque grains of metallic iron oxide, probably magnetite, and grains and minute prisms with high relief, showing strong cleavage and bright interference colors extinguishing parallel to the prism.

“In one specimen of the granite porphyry there are very abundant minute rectangular pleochroic crystals showing a single cleavage parallel to the sides of the rectangle. The pleochroism is reddish brown when the vertical cross-hair is parallel to the cleavage, and nearly black at right angles to this direction.

“The diorite from cape Santo Agostinho is macroscopically dark and fine grained, microscopically a cataclastic igneous rock, showing crushed feldspars and

*Dana: System of Mineralogy.

secondary amphibole in a fine feldspathic groundmass. The rock has undergone strong shearing. The feldspars are in part twinned on the albite law and one or two on the Carlsbad law, and they show an index of refraction greater than that of the balsam. One quartz, apparently original, was noted. The feldspars are undoubtedly plagioclase, probably andesine. One grain of quartz that appeared to be original was noted. There is magnetite present, and abundant minute secondary grains of undetermined nature."

One of the rocks collected on the south side of Cabo Santo Agostinho, where the relations of the granite, granite porphyry, and diorite to each other is not altogether clear, is described by Mr Turner as a *meta-rhyolite*, "evidently original glass, now devitrified," an occurrence of interest in connection with the rhyolites at Santo Aleixo.

ROCKS OF SANTO ALEIXO

The next rocks of especial interest are those of the little island of Santo Aleixo, 30 kilometers south of Cabo Santo Agostinho.

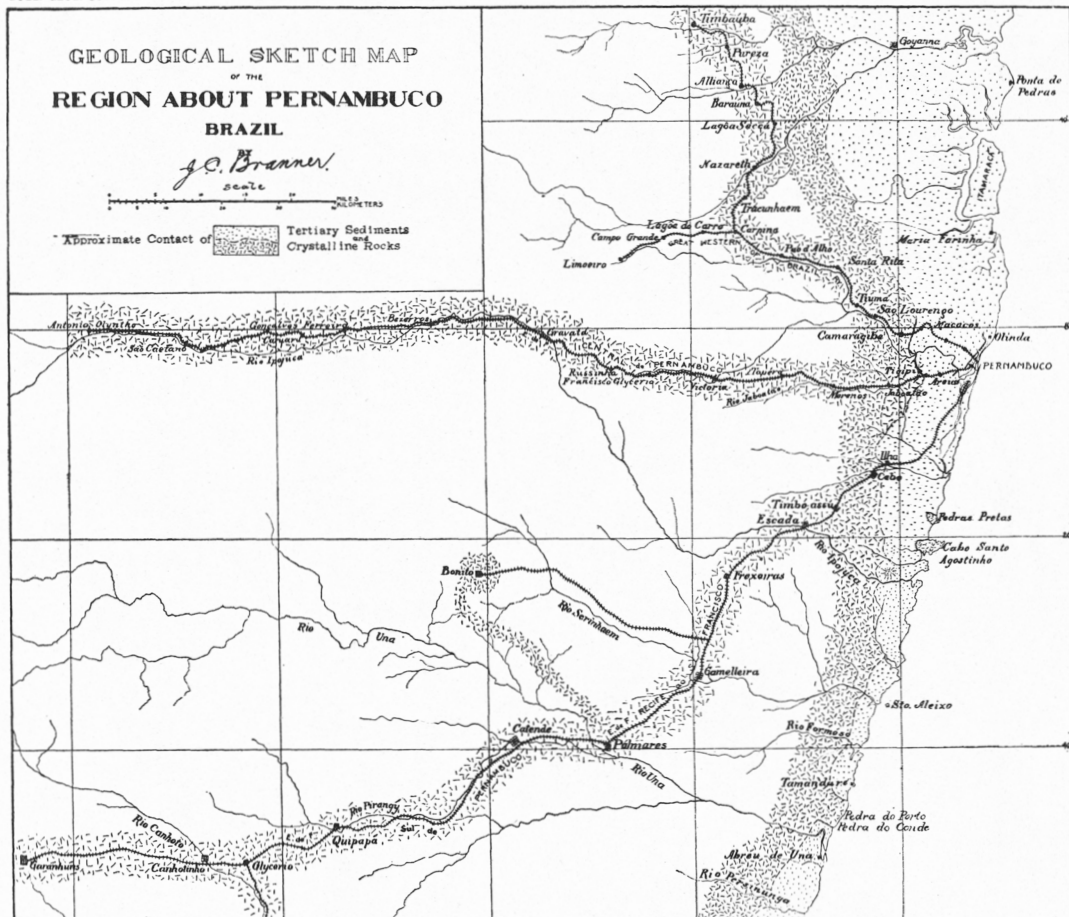
On the beach opposite and west of the island, and just south of Seramby point, the sands are black instead of the usual straw color. As this is the only place at which such sands were seen on more than 300 kilometers of beach examined, it seems that these must have been derived from the eruptive rocks of the island of Santo Aleixo opposite. Specimens of this sand were collected, and Mr Turner, who kindly examined them for me, says of them:

"The most abundant mineral is the black iron oxide, which is not magnetic except with the electromagnet, which was used to separate it from the remainder of the powder. This iron oxide gives a reaction for titanium, and hence is rather certainly ilmenite. Corundum, garnet, and feldspar are also present, and several other minerals, as yet undetermined."

The rocks which form nearly all the little island of Santo Aleixo are rhyolites. Several years ago I submitted to Dr George H. Williams specimens that I had collected on Santo Aleixo. He found them to be rhyolites, and wrote as follows regarding them:

"They are quartz orthoclase aggregates with almost no bisilicate constituents, but their structures are varied. One of the specimens has a granular holocrystalline groundmass of quartz and feldspar, some chlorite, possibly representing original hornblende or mica, and considerable blue tourmaline. The other Santo Aleixo specimen is a fine granophyre. Porphyritic quartz and feldspar lie in a holocrystalline groundmass which is filled with beautiful spherulites, showing the black cross between crossed nicols. . . . There is no nephelene in any of these rocks."

Professor Derby has lately suggested in a private letter, dated July 29, 1901, the theory that the Santo Aleixo rocks "might prove to have



GEOLOGICAL MAP OF THE REGION ABOUT PERNAMBUCO

some connection as an acid phase with the Fernando de Noronha eruptive epoch, and that the same magma might give a granite in the neighborhood."

RIO FORMOSO ROCKS

The Tertiary sediments are exposed in all the prominent hills and occasionally on the streams or estuaries at low tide south of Santo Aleixo as far as the mouth of Rio Formoso. At Rio Formoso the granites are exposed on the south side of the river about 3 kilometers from the sea, and from that point up stream as far as the town of Rio Formoso. There is therefore only a narrow belt of the Tertiary at this place.

The hills near the coast are all Tertiary and isolated, but between them are occasional exposures of soft sediments that appear to be of later Tertiary age. Along the shore, between the mouth of Rio Formoso and Praia da Gamella is an interesting exposure of these later Tertiary rocks. The beds are horizontal, and are being rapidly attacked by the waves, marked changes having taken place between January, 1876, when the locality was first examined, and July, 1899. The lowest bed exposed is soft white sandstone, 2 meters thick. On top of this is a bed of soft black sandstone, the two being separated by about 2 centimeters of yellow clay. On top of these two beds is beautiful white quartz sand from 3 to 6 meters thick. The bed in place is 3 meters thick, and in some places it has been blown over and another 3 meters heaped on top. This sand appears to be available for the manufacture of glass, and there is an abundance of it.

These Tertiary beds are exposed from Gamella nearly to the hill on which stands the church of Nossa Senhora de Santa Anna and against which the beds end. The hill of Nossa Senhora de Santa Anna is of Tertiary rocks also, but these beds belong to the older series.

GRANITE OF PEDRA DO PORTO

Northwest of the village of Tamandaré the horizontal colored Tertiary is exposed in the hills at two places. About 6 kilometers south of Tamandaré the hills come down to the coast and the granites are beautifully exposed on the beach at a point known as Pedra do Porto. The following is Mr H. W. Turner's description of the granite found at the Pedra do Porto :

"The biotite-granite from Pedra do Porto is macroscopically a light gray coarse rock, with large pink feldspar phenocrysts in a coarse groundmass of quartz, feldspar, and biotite.

"Microscopically composed of orthoclase, microperthite, microcline, micropegmatite, oligoclase, quartz, and biotite. As accessories there are present iron-oxide, apatite, titanite, and a xenotime-like mineral."

This granite is beautifully veined with quartz, some of the veins being a meter thick. Gigantic blocks are exfoliating on an impressive scale. From 200 to 300 meters offshore is a small barren rocky island of this same granite. The hills of the granite on the landward side of the beach are 30 or 40 meters high. A little more than a kilometer south of Pedra do Porto is another exposure on the beach of the same kind of granite. This place is called the Pedra do Conde, and near the beach the granite blocks are beautifully exfoliated. About half a kilometer south of the Pedra do Conde are two round bare islets of granite about 150 meters offshore.

South of this point there are no granites or other crystalline rocks exposed in place on or near the beach as far as Maceio. The rocks seen in place are all Tertiary or recent. The particolored cliffs visible at so many places along the coast are all Tertiary sediments. At a few places, however, there are large granite boulders exposed on the beach and underlying the Tertiary beds. On account of the large size of these boulders, some of them a meter or more in diameter, it is assumed that the granite in place is very near the surface wherever they are found. The following are the places at which the granite boulders occur on the beach: Camáxo, south of Maragogý on the coast of Alagôas; Barreira do Boqueirão just north of Rio Porto Calvo; Morro de Camaragibe about 3 kilometers south of Rio Camaragibe, and Riacho Doce just north of the village of this name.

The following is Mr Turner's description of the granite found at the mouth of Riacho Doce:

"Microscopically it is a medium grained granite composed of orthoclase, microcline, oligoclase, and quartz. The quartz occurs in aggregates of interlocking grains of smaller size than the feldspars. There is a small amount of a yellow-brown nearly opaque substance filling cracks and forming rhombic crystals, presumably secondary. There is a little muscovite and black opaque grains, apparently iron-oxide."

The observations made along the coast on the stone and coral reefs and on the geographic development of the region are reserved for a separate paper.

RÉSUMÉ OF THE GEOLOGY OF THE COAST SOUTH OF PERNAMBUCO

1. The Tertiary rocks form only a narrow coastal belt between Pernambuco and Maceio; they are nowhere more than about 14 kilometers wide.
2. The underlying crystalline rocks are exposed on the coast at only four places between Pernambuco and Maceio: at Pedras Pretas, Cabo Santo Agostinho, Santo Aleixo, and Pedra do Porto.

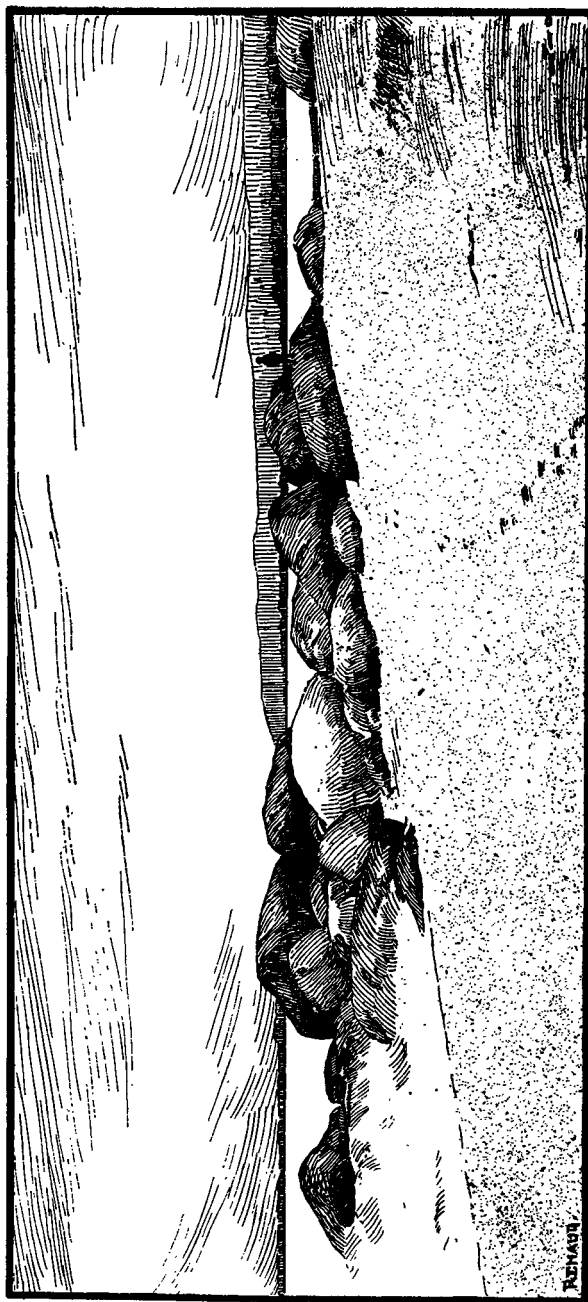


FIGURE 9.—*Exfoliated Blocks of Biotite-granite on Pedra do Conde Beach.*

3. The rocks at Pedras Pretas are trachytes.
4. Rhyolites form the island of Santo Aleixo, and occur also on the south side of Cabo Santo Agostinho.
5. The rocks of Cabo Santo Agostinho are chiefly granites, granite-porphyrries, and diorite.
6. The rocks of Pedra do Porto and Pedra do Conde are granites.
7. The eruptive rocks exposed along the coast are all older than the coast Tertiary deposits.
8. Thus far the Tertiary rocks along the coast have yielded no fossils, and they are assigned to the Tertiary on the theory that they are the same as the fossiliferous beds at Olinda and Maria Farinha, north of the city of Pernambuco.
9. The Tertiary sediments have a maximum thickness along this part of the coast of about 75 meters only.
10. There has been a late elevation of the coast amounting to about 2 meters.

GEOLOGY ALONG THE RECIFE AO SÃO FRANCISCO RAILWAY AND ITS
PROLONGATION, SUL DE PERNAMBUCO *

RAILWAY STATIONS AND TOPOGRAPHY ADJACENT THERETO

The following is a list of the stations on the Estrada de Ferro Recife ao São Francisco, with distances and elevations above sealevel, and also of its prolongation, Sul de Pernambuco:

Kilometers.	Station.	Elevation.
		<i>Meters.</i>
0.00	Cinco Pontas (city of Pernambuco).....	2.43
2.76	Afogados	4.23
8.72	Boa Viagem.....	7.75
12.27	Prazeres	9.80
....	Pontezinha.....	....
24.22	Ilha	2.10
31.51	Cabo.....	13.30
38.36	Ipojuca.....	53.50
45.03	Olinda.....	98.50
51.83	Timbo-Assú.....	96.00
57.67	Escada.....	92.44
63.91	Limoeiro.....	99.60
70.14	Freixeiras.....	124.87
78.29	Aripibú.....	119.70
86.87	Ribeirão.....	95.60
95.78	Gamelleira.....	90.50
104.02	Cuyambuca.....	94.40
113.02	Água Preta.....	142.86
124.73	Una, or Palmares.....	120.00

* The notes on the geology along this railway were made in five trips over the line east of Una, three trips over the line east of Glycerio, and two trips over the line as far as Garanhuns. I am especially indebted to Mr Frank Clemetson, acting superintendent, for his kind cooperation in studying the geology along the line of this railway.



CHARACTERISTIC TOPOGRAPHY AND VEGETATION OF THE PERNAMBUCO COASTAL SAND PLAIN

Estrada de Ferro Sul de Pernambuco

Kilometers.	Station.	Elevation.
		<i>Meters.</i>
129.78	Pirangy.....	120.00
133.58	Boa Sorte.....	125.00
142.44	Catende.....	153.00
155.74	Jaqueira.....	185.00
158.30	Colonia.....	189.00
163.82	Marayal.....	215.60
167.86	Florestal.....	246.74
174.72	Barra da Jangada.....	296.00
.....	Pery-Pery.....	.....
183.71	São Benedicto.....	368.60
197.37	Quipapá.....	427.47
209.65	Agua Branca.....	563.43
214.46	Glycerio.....	529.19
227.98	Canhotinho.....	497.27
242.79	Angelim.....	647.30
253.52	São João.....	699.90
271.16	Garanhuns.....	866.30

The terminal station of the Recife ao São Francisco railway in the city of Pernambuco is called Cinco Pontas. It will be seen from the elevation given in the table above that this station is on the flat plain on which most of the city of Pernambuco is built. Between this place and Afogados the railway runs near the mangrove swamps that cover much of this plain. Afogados, the next station, is on the edge of a mangrove swamp which extends for some kilometers still farther south and west.

About 300 meters northeast of Boa Viagem station the railway passes from the mangrove flats on to the white sandy plain like that about Areias station on the Central railway. This sandy plain extends eastward to the sea. Near the sea it is planted with coconut palms. The accompanying illustration gives a good idea of the general appearance of this flat sand-covered plain.

Southwest of the Boa Viagem station the railway continues over the sand plain, but it gradually approaches the Tertiary hills that rise to the northwest of the railway line until they are within a stone's throw of the track.

Prazeres (kilometer 12) is still on the sandy plain, but the hills to the west are only about a kilometer from the line at this place. At Pontezinha there is a small isolated hill about 200 meters west of the station and another a kilometer to the northwest. Half a kilometer beyond Pontezinha the railway crosses the mangrove swamps and Rio Jaboatão; the swamps extend 2 kilometers beyond the river nearly to Ilha station.

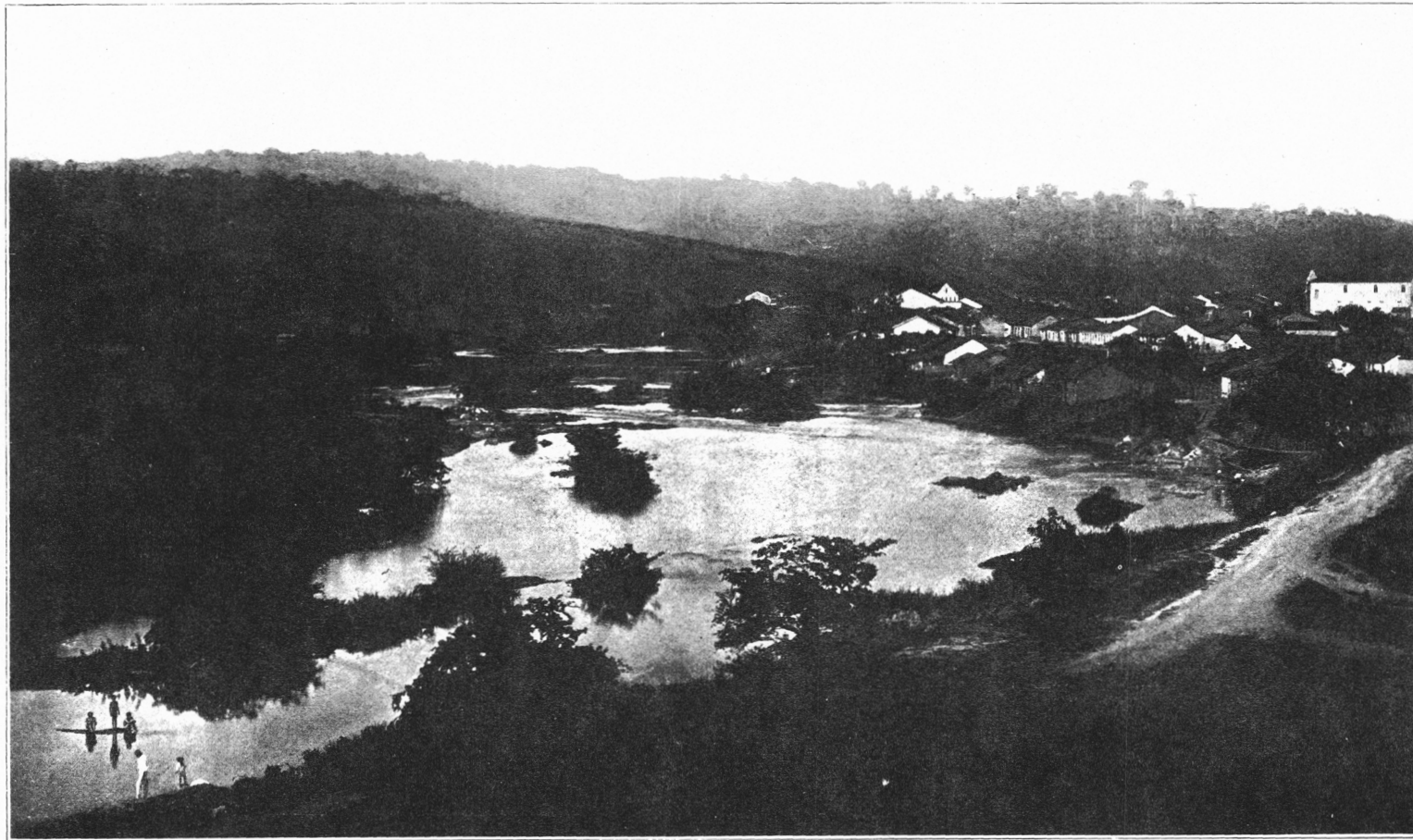
West and northwest of Ilha the Tertiary hills are about half a kilometer from the railway station. Half a kilometer beyond Ilha the hills are about 100 meters northwest of the railway. Where quarries have been opened in these hills the exposures are quite red. Just west of Ilha two streams, the Rios Gurjahú and Pirapáma, join each other, and the hills on the northwest side of the road follow up the left side of the Gurjahú and appear again on the point of land between these two streams. At Cabo (kilometer 31.5; elevation, 13.3 meters) the hills south of the railway are within a stone's throw of the station. At this place the railway leaves the low flat coastal plain and enters the hills. In the outskirts of the city of Cabo there are several cuts, all of them exposing red, yellow, and mottled earth resembling the highly colored Tertiary beds. The rocks, however, are not Tertiary, but crystalline rocks decomposed in place. The hills about Cabo and west of there as far as Boa Sorte are from 50 to 75 meters above the drainage. The region is thus a hilly but not a mountainous one.

ROCK DECOMPOSITION

The granites and gneisses along the railway are usually deeply decomposed, having red, yellow, white, brown, purple, or mottled residuary clays exposed in the railway cuts, and exfoliated boulders of decomposition or rounded bare bosses over the surface of the ground. The depth of the decomposition of the rocks is fairly well shown in a number of the deep cuts along the line of the railway, but it is a notable fact that in many even of the deepest of these cuts the total depth of the decomposition is not shown. A rather remarkable thing about the deep cuts in the residuary earth is that many of the faces exposed in such cuts are nearly vertical, and yet they have stood for many years without falling. The following are some of the deeper cuts where decomposition is well exposed:

One kilometer south of Limoeiro station a cut 14 meters deep has the rock decomposed to the level of the railway track. On the divide east of Palmares cuts 12 meters deep expose red and yellow residuary earth crossed by quartz veins.

At Palmares station (kilometer 124; elevation, 120 meters) there is a cut 6 or 7 meters deep in decomposed crystalline rock. The residuary clay is red and purple and is crossed by the broken quartz veins. The earth of the upper part of the cut is apparently handled material derived from the same decomposed rock, for the quartz that appears as vertical veins in the lower part of the exposure is scattered in subangular fragments along horizontal bands through the upper part of the earth exposed in the cut.



BANDED GNEISS EXPOSED IN THE RIO UNA AT PALMARES, STATE OF PERNAMBUCO

At Pirangý (kilometer 129; elevation, 120 meters) the residual earths are of a deep red color with yellow and purple streaks. Two and a half kilometers west of Pirangý is a cut 12 meters deep in decomposed crystalline rocks.

At and immediately west of Boa Sorte (kilometer 133.5; elevation, 125 meters) the cuts expose decomposed schists with the residuary earths of strikingly brilliant colors—red, white, yellow, and purple.

In the rear of the station at Jaqueira is a cut in yellow and reddish yellow earth. One kilometer east of Colonia are deep cuts in decomposed crystalline rocks. The earths are highly colored.

At Florestal (kilometer 167.8; elevation, 246 meters) there is a cut 12 meters deep in decomposed schist-like rock. The rocks at the bottom of this cut are not decomposed.

Just west of Barra da Jangada station (kilometer 174.7; elevation, 296 meters) is an 8-meter cut in decayed crystalline (schistose) rocks. A hundred meters east of Pery-Pery station decayed crystalline rocks are cut. One hundred and fifty meters farther west there is another cut 10 meters deep.

West of São Benedicto there are several deep cuts nearly all of them in decomposed rocks. West of Quipapá several cuts in decomposed rocks expose kaolin, but the residuary earth is mostly of a red color. On the watershed west of Agua Branca the railway cuts are from 12 to 15 meters deep in decomposed rock cut by quartz veins; the residuary earth is highly colored, and shows marked bedding or the foliated structure of schists. At Glycerio* (kilometer 214; elevation, 529 meters) there is a cut from 9 to 12 meters deep in decomposed crystalline schists. This rock was faulted before it decomposed. The residuary earth is mostly of a purplish color.

STRUCTURAL FEATURES

Returning to Cabo, we may now consider the nature and structural features of the rocks exposed along the line of this railway. From Cabo west and south the road passes over crystalline rocks nearly all the way to Garanhuns, a total distance of 240 kilometers. These rocks seem to be granites, gneisses, and schists, but under the circumstances of profound decomposition in most cases and lack of opportunity for careful examination in others, nothing more than impressions can be set down for many of the exposures. Wherever it was possible to observe it, the approximate direction of the strike of the beds was noted.

Between Timbo Assú (kilometer 51.8) and Escada (kilometer 57.6)

* At this place the connection is made with the Alagoas railway to Maceió. For notes on the geology of that line see Proc. Wash. Acad. Sci., vol. ii, pp. 195–201.

many exposures show the rocks to be banded gneisses or schists. This ribbed nature of the rocks is well brought out on weathered exposures. In the Rio Ipojuca, at and near Escada, and at Limoeiro, the exposures show this bedding or schistosity to have an east-west strike. The same east-west strike is shown over the exfoliated bosses half a kilometer east, and again west of Aripibú station (kilometer 78). A short way east of Gamelleira station (kilometer 95.7) the rocks exposed look like granites, and east of Agua Preta (kilometer 113.6) station the rocks are massive like granites. About Palmares (kilometer 124.7) the rocks have a banded structure rather more marked than that of gneiss. At the bridge west of the station the structure is well exposed in the bed and on the sides of Rio Una. The strike here is northeast-southwest. At Pirangý (kilometer 129.7) the rocks are decomposed; the northeast-southwest strike of the beds (or schistosity) is plain.

Between Bôa Sorte and Catende the strike is northeast-southwest. One kilometer west of Catende the strike is again northeast-southwest. Between Catende and Jaqueira the same strike is exposed in the bed and along the sides of Rio Pirangý.

At Marayal station (kilometer 163.8), 10 meters above the stream, the schistose rocks, with pegmatite dikes, strike north 20 degrees east and dip south 70 degrees east; farther west, however, the strike changes back to northeast-southwest, while at Florestal (kilometer 167.8) the dip is northeast about 30 degrees. Four kilometers above or west of Florestal the rocks in the river bed strike northwest-southeast. Three kilometers east of Barra da Jangada schistose rocks dip northeast 40 degrees; 2 kilometers east of Barra they dip south 30 degrees east. At and just west of São Benedicto (kilometer 183.7) the rocks are schistose, with a north-south strike and an east dip of from 80 to 90 degrees. About a kilometer west of São Benedicto there is either a dike or vein of bluish-black rock exposed in the railway cut. One kilometer east of Quipapá schistose rocks have an east-west strike.

About 150 meters east of Quipapá (kilometer 197.3; elevation, 427 meters) dark mica-schists (?) are well exposed by the track and strike nearly east-west. On the watershed west of Quipapá the rocks have a local strike of nearly north-south and dip east. Two kilometers east of Agua Branca schistose rocks dip east 40 to 45 degrees. The rocks between Quipapá and Agua Branca are faulted and somewhat wrinkled. Between Glycerio and Canhotinho the mica-schists dip to the southeast.

At Canhotinho (kilometer 227.9; elevation, 497 meters) the gneiss is cut by numerous quartz veins. Three hundred meters west of the station the rocks are crystalline schists striking north-south (?) and cut by numerous quartz veins.

Between Canhotinho and Angelim bosses of crystalline rocks are exposed here and there over the campos, and the surfaces show numerous veins of quartz and dikes of pegmatite.

About 5 kilometers west of Canhotinho schists dip south at an angle of 50 degrees. A little farther west there are exposed soft bedded rocks resembling sandstones. Still farther west are schists dipping south 25 degrees west 60 degrees.

Three hundred meters west of Angelim (kilometer 242.7; elevation, 647 meters) are granites and crystalline schists.

Between Angelim and São João there is a line of hills south of the railway, about 100 meters above the railway level, in which the rocks appear to be bedded and to dip north at an angle of about 30 degrees. In the railway cuts the exposures show the schistose rocks for a distance of 2 or 3 kilometers to dip southwest at an angle of about 45 degrees. These rocks are cut by many veins.

At São João (kilometer 253.5; elevation, 699.9 meters) crystalline schists are exposed in the cut just west of the station. They dip northeast.

The rocks at and about Garanhuns are all either gneisses or granites. Most of the surrounding plateau, however, is covered by the products of the decomposition of these rocks.

TOPOGRAPHY OF THE REGION

Some of the topographic features of the region traversed by this railway are worthy of attention. The plateau on which Garanhuns (elevation, 866 meters) stands has an elevation of a little more than 1,000 meters at its western rim at Poço, about 35 kilometers west of the town.* At the west of Cimbres the plateau is said to rise more than 1,000 meters above sealevel. The streams that head in this high region have cut their valleys in this plateau to a depth of 400 and 500 meters. There are no longer mountain chains over the plateau, but neither is the sky-line, as seen from the hills about Garanhuns, a flat or even one. The upper portions of the valleys are rather narrow and steep-sided.

South of the railway between Garanhuns and São João the following is the profile of the highest hills. These hills are only from 100 to 150 meters high south of the railway half a kilometer from São João.



FIGURE 10.—Profile of the Hills South of Glycero.

* Doctor L. Lombard.

At Canhotinho the railway is in the narrow valley of Canhoto, where the steep hills are about 100 meters high. The hills are much more open than they are from the Rio Canhoto.

WATERWORN GRAVELS

The following notes were made on the occurrence of waterworn materials along the line of this road. In most cases, perhaps in all of them, these waterworn materials clearly belong with the streams near at hand. At Rebeirão a streak of waterworn quartz gravels is exposed 2 meters below the surface of the soil; at Cuyambuca (kilometer 104) a layer of subangular quartz pebbles is shown 2 meters beneath the surface of the yellow soil; 1 kilometer west of Catende waterworn pebbles are ex-



FIGURE 11.—Outline of the Hills South of Railway between Garanhuns and São João.

posed 2 meters below the surface; a short way farther west similar gravels are covered by from 3 to 7 meters of soil; about 5 kilometers west of Catende a bed of gravel 1 meter thick is exposed on the north side of the track.

At another place the pebbles are from 1 to 2 meters below the surface, but only from 7 to 15 meters above the present stream. Four kilometers east of Quipapá waterworn quartz pebbles are exposed at several places above the present stream, the Pirangý. One and a half and 3 kilometers west of Canhotinho waterworn cobbles are exposed by the railway 10 meters above the stream.

OBSERVATIONS AWAY FROM THE RAILWAY

These notes have a greater value when taken in connection with observations made off the line of the railway.

Trips have been made by the writer from Palmares north to Bonito, and from Pão d'Assucar, on the Rio São Francisco, to Aguas Bellas, west of Garanhuns.

The whole country about Bonito is of granite, and the Serra da Bonitinho is likewise of granite. There are some striking cases of fluting of gigantic blocks of granite on the highway between Palmares and Bonito.

In the valley below the town of Bonito some of the bare granite bosses show angular inclusions of other and darker rocks.

Between Pão d'Assucar and Aguas Bellas the rocks are granites and gneisses, with some highly metamorphosed rocks. The latter include inconspicuous beds of crystalline limestone in the Serra dos Meninos near Aguas Bellas. The granitic rocks were observed at Lagoa da Lagea, 8 leagues east of Aguas Bellas, and at Pedra Pintada, 12 leagues west of Garanhuns.*

Two interesting papers have been likewise published by Doctor L. Lombard on the geology of the interior of the state of Pernambuco, and inasmuch as Doctor Lombard's papers were published only in Portuguese, where they are inaccessible to geologists, I give here his conclusions so far as they relate to the geology of the state of Pernambuco in the vicinity of the Recife ao São Francisco railway.

One of Doctor Lombard's papers † contain the results of two months' work in the region south of Garanhuns, and covers an area of about 3,500 square kilometers. He summarizes the geology of the region as follows:

"The terranes of this region belong to the lower part of the primitive terrane here represented by gneiss in contact with granite. Mica schists are rare. The only ones I found are on Rio Salgadinho, where they resemble a gneiss poor in feldspar. The gneiss and granite merge together without exhibiting any sharp lines of distinction. Outcrops of later basic eruptive rocks are rare, and the disturbances of the beds of gneiss were caused by eruptions of granite and perhaps of granolite."

Doctor Lombard's second paper ‡ treats of the region between Garanhuns and Buique and of the country around Buique. The area covered by his map is about 5,000 square kilometers.

He found the region between Garanhuns and Buique to be of granite and gneiss. Descending the Serra de São José, the gneiss dips northeast at an angle of 20 degrees. In the basin of the Rio Ypanema the rocks are more granitic. Near Rio Cordeiro a dike of diabase was seen. The Serra de Buique is of granite, but along the southeast side of the Serra there are limestones. Nothing is told of the geologic position of these limestones. The mountain masses and the plateau west, north, and northeast of Buique are of sandstone resting on granite. The moun-

* Further notes on the region about Aguas Bellas are given in the Amer. Jour. Sci. for Feb., 1902.

† Relatório sobre a exploração da parte sul do Estado de Pernambuco entre Palmares e Bom Conselho. Por L. Lombard. Recife, 1895, being pages 51-62 of the Relatório apresentado ao Exm. Sr. Governador do Estado . . . pelo Dr Rodolpho Galvão, Secretario dos Negocios da Industria. Recife, 1895.

‡ Relatório sobre a exploração mineralógica de Garanhuns á Buique e da zona salitrosa de Buique. Por L. Lombard; pages 123-140 of the report above cited. Recife, 1895.

tains known as Coqueiro, São José, Catimbao, Quyrí d'Alho, Andorinho, and Chapeo are all of sandstone. These sandstones dip toward the southeast at an angle of from 10 to 15 degrees.

The sandstones contain mica, waterworn quartz pebbles, and bits of kaolin. They yield some salt and saltpeter, which are extracted by leaching, and certain organic substances the character of which was not determined.* Doctor Lombard regards these sandstones as of "primitive or pre-Cambrian" age.

In the absence of fossils it is hardly worth while to speculate on their age. It seems much more probable, however, that these sediments belong to the great Cretaceous area that covers a large part of the interior of Piauí, Ceará, Paraíba, and Pernambuco. The elevation of the Buique sandstones (between 800 and 900 meters above tide) appears to make it improbable that they belong to the Tertiary.

L. E. Dombre, a French engineer connected with the department of public works of the province of Pernambuco, traveled through the interior of that province in the years of 1874 and 1875, and in his letters to the director gave many valuable notes upon the geology of the region visited.†

Dombre went as far west as Floresta, but reference is here made only to his notes upon the geology in the vicinity of Recife ao São Francisco railway.

Of the general character of the geology Mr Dombre says † that the few

* This organic matter is known in the region in which it is found as *borra*. A sample of it was given me by Doctor Lombard, and was submitted to Dr J. M. Stillman, the head professor of chemistry at Stanford University, who gives me the following as the results of his chemical examination:

"The substance submitted under the name of *borra* appears to be largely earth, sand, and gravel cemented together by or permeated with a substance or mixture of substances of organic origin and of deep chocolate brown color. The organic matter is of that class of substances which have been at times called mineral resins—*Erdharze*—for want of more definite names.

"The *borra* is brittle and hard, does not melt or soften appreciably by heating. At high temperatures it gives off vapors of pungent odor and burns with a yellow flame, leaving an earthy residue in the form of the original mass and composing by far the greater part of the entire mass. Rubbed to a fine powder and extracted with alcohol and ether the *borra* gives a small quantity of colorless extract of a bitter taste. The residue from the alcohol-ether extraction when treated with caustic soda solution gives a solution of dark brown color, reprecipitated on neutralizing with acids as a brown resinous mass, insoluble in water, and but slightly soluble in alcohol, to which, however, it imparts a color by partial solution. That portion of the organic matter not dissolved by hot caustic soda was in the form of a dark brown pulverulent mass mixed with inorganic residue, and is not easily soluble in the common solvents. In concentrated sulphuric acid it dissolves at least partly with a dark brown color.

"My interpretation of the above is that the organic matter in the *borra* is a mixture of substances largely oxygenated and of faintly acid character, such as are often characterized as 'mineral resins,' or as are intermediate between these and the so-called humus substances. The organic matter is present in too small quantity and too difficult to separate from its earthy admixture to be more definitely characterized."

† Viagens do Engenheiro Dombre do Interior da Provincia de Pernambuco em 1874 e 1875 In French and Portuguese 12°, 86 pp. Recife, 1893.

‡ Loc. cit., p. 36.

sedimentary basins seen by him are completely metamorphosed and contain no fossils. He makes no mention, however, of the location of such sedimentary rocks.

The rocks about Panéllas, north of Quipapá, he found to be fine-grained gray granites. At Pesqueira, northwest of Garanhuns, he found granites, and the Serra de Ororobá, near Cimbres, he found to be of granite exposed in solid rounded peaks.*

Between Pesqueira and São Bento he found only granites.† In the vicinity of Bom Conselho (Papacáça) he found "everywhere the same terrane of granite or porphyry,"‡ while at Ipueiras, southwest of Bom Conselho, he reports gneiss and schist and an "irregular bed of white crystalline limestone."

RÉSUMÉ OF THE GEOLOGY ALONG THE RECIFE AO SÃO FRANCISCO RAILWAY

The crystalline rocks through the region of the Recife ao São Francisco railway are much faulted. These rocks are chiefly granite, gneisses, and schists.

West of Canhotinho a few exposures look like sedimentary rocks, but these beds were not carefully examined and it may be that the appearance of bedding is due to metamorphism.

The strike of the beds (or the schistosity?) is somewhat constant along the northeastern half of the railway line, but farther west the dip and strike vary greatly in amount and direction. These changes are enough to show that no trustworthy conclusions can be drawn from similarity or dissimilarity of dip and strike in widely separated districts in the Paleozoic regions of Brazil.

It is still supposed by some people living in the state of Pernambuco that the rounded bosses of granite and the great rounded boulders found over the hilltops along the line of this railway are of glacial origin. This is quite erroneous. The theory at one time advocated by Louis Agassiz and by Belt that this part of South America was covered by ice during the glacial period has been shown to be untenable. These particular boulders originated where they now lie, unless they may in some instances have rolled down the hillsides. Such boulders occur between Cabo and Ipojúca, 300 meters east of Olinda station (kilometers, 45), about Timbo-Assú, and at many other points along the railway.

Decomposition of the rocks is widespread, but the depths of the decomposition exposed in the railway cuts along this railway does not exceed 20 meters.

The sedimentary beds north and west of Buíque have yielded no fossils,

* Loc. cit., p. 81.

† Loc. cit., p. 83.

‡ Loc. cit., p. 37.

but it seems probable that they are a part of the Cretaceous area of the interior of Piauhý and Ceará.

In comparing the geology and geography along this railway with that along the Estrada Central, we find these two railways crossing similar belts as follows :

1. The low coastal plain of mangrove swamps and the sandy plain of Areias and Bôa Viagem.
2. The narrow line of Tertiary hills ending near Tigipió, on the Central, and between Ilha and Cabo, on the Recife ao São Francisco line.
3. A belt of low hills of crystalline rocks ending on the Central road at the base of the Serra da Russa, and on the Recife ao São Francisco line near Canhotinho, or possibly somewhat farther east.
4. An elevated region from which Paleozoic (?) sediments have been partly removed. On the Central railway this region begins with the Serra da Russa ; on the Recife ao São Francisco it begins near Canhotinho, and, extending westward, forms the mountain tops to and beyond Aguas Bellas.

GEOLOGY ALONG THE ESTRADA DE FERRO CENTRAL DE PERNAMBUCO*

RAILROAD STATIONS

The following is a list of the stations, distances, and elevations on the Estrada de Ferro Central de Pernambuco :

Kilometers from the Central, Pernambuco.	Station.	Elevation above tide.
		<i>Meters.</i>
0	Central (Pernambuco).....	2.4
6	Areias.....	5.0
8	Tigipió.....	11.0
..	Socorro.....	....
16	Jaboatão.....	45.0
27	Morenos.....	85.6
38	Tapera.....	155.0
51	Victoria.....	146.0
64	Francisco Glycerio.....	194.8
72	Russinha.....	308.8
89	Gravatá.....	446.0
112	Bezerros.....	459.0
127	Gonçalves Ferreira.....	509.1
136	Caruarú.....	537.7
161	São Caetano.....	548.6
180	Antonio Olvnto.....	565.0

* For the privilege of examining the geology along this railway I am indebted to Dr Antonio Pai Pires Ferreira, the obliging director of the railway at the time of my visit. Doctor Ferreira has also kindly furnished me with a large scale map of the line of the railway, and has sent me specimens of the São Caetano marble.

TOPOGRAPHY IN DETAIL AND THE ROCK EXPOSURES

From the central station, in the city of Pernambuco, to within half a kilometer of Areias station, the railway passes over a flat country, much of it covered with mangrove swamps. Half a kilometer east of Areias the road cuts a sand bank 5 or 6 meters in height. This bank is the margin of the flat sand-covered plain around Areias station. A few hundred meters east of Areias station the railway crosses a narrow steep-sided, flat-bottomed valley. West of Areias and east of Tigipió station is another valley of similar shape, draining into the Capibaribe. The valleys around the margin of this sand plain are dendritic in form and belong to a single type. The following sketch shows a cross-section of one of them:

These peculiar features are interpreted to mean that the Areias plain formerly stood at a greater elevation than at present, and at the time of this elevation steep-sided gullies or narrow winding valleys were cut by the streams around the margins of the plain. A subsequent depression carried the bottoms of these narrow valleys beneath the salt water, whereupon they were immediately silted up.



FIGURE 12.—Profile of the Hills at Areias.

Three hundred meters west of Areias station the railway line cuts the colored Tertiary sedimentary beds. These beds are red; most of them contain small quartz pebbles that are scattered through the strata rather than arranged in well-marked bands. At Tigipió a cut on the north side of the road shows waterworn pebbles in approximately horizontal bands.

At this same station the bottom of the creek valley is flat, as if belonging to the dendritic group around the Areias plain. The low hills east of Tigipió are of about even height. West of Tigipió the hills are at once higher—perhaps 70 meters higher than the railway. The Tertiary beds, such as are exposed at Dois Irmãos, Caxangá, and Macacos, on the north side of the open plain about Pernambuco, are but little exposed along the line of the Estrada Central. Beginning a short distance west of Areias, they are exposed to and at Tigipió station and end 2 or 3 kilometers west of there; even so they appear mostly in the tops of the hills at this western end of the beds. Two kilometers west of Tigipió a railway cut exposes a horizontal bed of waterworn gravel. Between 2 and 3 kilometers west of Tigipió decayed crystalline rocks are exposed in a cut on the south side of the track. These rocks, however, are exposed only in the lower portion of the cut. They are over-

lain by a bed, about half a meter in thickness, of coarse, waterworn quartz gravels, with from 1 to 2 meters of soil above it.

From this point westward the cuts expose no more Tertiary beds. Before reaching Jaboatão there are many exposures of decomposed gneiss or granite, in which are hard unaffected cores or boulders of decomposition. One of the largest of these cuts is about 3 kilometers east of Jaboatão. East of the cut there are exposures of granite in the valley. One kilometer east of Jaboatão there is a cut 12 meters deep. This exposes red residuary soil with large blocks of undecomposed gneiss scattered through it. Immediately east of Jaboatão station is a cut about 10 meters deep in a decayed gneissoid rock. At this station there are many exposures of crystalline rocks in the bed of the Rio Jaboatão. A little more than half a kilometer west of the station is a cut 10 meters deep. Very few of these cuts expose solid rock even at the bottom; but most of them still have some boulders of the unaltered rock left behind.

Three or 4 kilometers west of Jaboatão the railway cuts expose beds of subangular gravels 0.2 meter or 0.3 meter thick. These cuts, however, are not in the crests of the ridges, but more than halfway down their slopes. It seems probable that the gravels are left by the streams cutting their way downward, and that they do not belong to the Tertiary gravel sheets.

About 1 kilometer east of Morenos station (kilometer 27) there is a cut 10 meters deep, and several others not so deep, in red residuary earth. At Morenos station the Rio Jaboatão flows over and between blocks of granite. Five kilometers west of Morenos small fluted bosses of gneiss are exposed in the fields.

Between Morenos (kilometer 27) and Tapéra (kilometer 38) there are several cuts 10 meters deep. In some of them the rocks are decomposed down to the level of the railway track, while in others there remain here and there undecomposed lumps of the original crystalline rock.

Where the cuts expose the rock decayed in place along this portion of the line the residual clays are red, yellow, brown, and mottled, but red is the predominating color.

Three or 4 kilometers west of Tapéra the first bedded or foliated rocks were seen. East of the watershed between Tapéra (kilometer 38) and Victoria (kilometer 51) these rocks look like gneiss, with a general east-west strike. West of the watershed and to within 3 kilometers of Victoria station the rocks are schists and shales standing at high angles (60 to 80 degrees). East of Victoria for about 3 kilometers the rocks are more like granites. Immediately east of Victoria station is a cut about 8 meters deep. The bottom of the cut is in decomposed crystalline rocks

with quartz veins. Above this is a bed from 0.1 to 1.0 meter thick of heavy waterworn pebbles, and above this is from 0.5 to 2 meters of soil. It is to be observed that Victoria has an elevation above tide of 146 meters, and the gravel beds in the vicinity of the larger streams are provisionally referred to fluvial rather than to marine origin. West of Victoria the rocks still appear to be more or less schistose.

At Francisco Glycerio station (kilometer 64; elevation, 194.8 meters) the railway cuts in red clay expose a few waterworn quartz pebbles at the line of the junction between the soil and the hard rocks beneath. In the vicinity of this station a rather flat plain opens northward, while to the south and west rise mountains locally known as the Serra da Russa, with a maximum elevation of 503 meters near the railway line where it crosses into the valley of Rio Ipojúca. These mountains, however, are but the eastern and northern margin of the high and hilly plateau of the upper Ipojúca drainage. West of Francisco Glycerio the railway ascends the escarpment of the great plateau. Between Francisco Glycerio and Russinha, at an elevation of about 250 meters, the brilliant red and yellow colors so characteristic east of this place appear to end. West of here, also, the decomposition of the rocks does not seem to be so deep or so widespread.

Immediately west of Glycerio the country is soil-covered, and more than half of it is under cultivation. There are a few exposures of rock on the hillsides and in the creek beds. There is a rather persistent but in places pockety line of pebbles exposed in the cuts along this part of the railway. It is generally at the junction of the soil and the undecayed rocks beneath, and appears to be related genetically to the former but not far removed drainage of the region. The individual blocks of these gravels are often as large as a man's head.

Along the next 3 to 5 kilometers east of Russinha the rocks look like dark, very micaceous gneisses; they are cut by a few quartz veins and are deeply decomposed.

As one goes westward, Russinha (kilometer 72; elevation, 308.8) is the last station on the railway before reaching the crest of the Serra da Russa. A short distance west of that station the line crosses the watershed between the Rio Capibaribe drainage and that of Rio Ipojúca. West of Russinha there are many deep cuts along the line of the road that make excellent exposures of the geology; some of these cuts are as much as 30 meters deep measured on the upper slopes, and many of them are 15 meters deep. There are, besides, several tunnels in which the rocks are so solid that the tunnels do not require to be lined save at their mouths. One tunnel was being lined, however, at the time of my visit. Some of the rocks in these cuts are more evenly bedded, as if

they were shales and sandstones, while others are schistose or gneissic. They are much jointed and but a little wrinkled, and stand at high angles, 70 to 80 degrees, with a south (?) dip. In places they appear to be crushed and faulted.

Between Russinha and the tunnels the cuts nearer the station expose rather darker, more micaceous, and more decomposed rocks than those higher up the mountains. From near the top of the mountain there is a magnificent view toward the northeast and overlooking the hilly valley of the Capibaribe. Between the summit and Rio Ipojúca are some exposures of pinkish colored shales. After passing the divide of the Serra da Russa there is but a slight descent to Gravatá station, on Rio Ipojúca, in the bottom of the valley to the southwest of the mountain. Thus the Ipojúca at this station is not in a valley like that at Victoria or at Escada, but it flows through a wide, open, flat valley near the edge of a mountainous plateau having an elevation of 500 meters or more above the sea.

Two hundred meters east of Gravatá station (kilometer 89; elevation, 446 meters) there is a good exposure of the shales in a long shallow cut. These rocks are clearly bedded, and some of them have the appearance of altered silicious sediments like novaculites or diatomaceous shales. Under a microscope of low power they seem to be filled with elongated or lens-shaped grains of quartz or opal. They have a south dip of about 70 degrees.

The mountains seen south of Gravatá have exposures of bare rocks about their summits. Three hundred meters west of Gravatá, again 1½ kilometers west of Gravatá, and again 3 or 4 kilometers west of the same station are cuts along the railway, in which bedded rocks—schists or shales—are exposed with high (70 to 80 degrees) south dips.

A belt of gneiss-like, dark banded rocks, 2 or 3 kilometers wide, follows. From 1 to 2 kilometers east of Bezerros station and south of the river schistose rocks are exposed mostly with a south dip. There are several bosses and exfoliated masses of gneiss just east of Bezerros. At several places waterworn pebbles are exposed along the railway, but these exposures are all near the Rio Ipojúca. At Bezerros (kilometer 112; elevation, 459 meters) a cut in the rocks opposite the station exposes hornblende-schists crossed by large veins of pink feldspar. These schists have a south dip of only about 30 degrees.

South of Bezerros the Serra Vermelha is in full view. It appears to rise about 200 meters above the plateau. Bare rocks are exposed here and there over its sides, resembling granite or gneiss bosses. Dombre reports a bed of hematite iron ore in the Serra Negra, 2 leagues north of Bezerros.

Between Bezerros and Gonçalves Ferreira the railway appears to cross and recross the contact between coarse grained granites and schists. The dip of the schists changes, but it is always high, sometimes apparently on end, with an east-west strike. One of the cuts, 6 meters deep, exposes schists beautifully for several hundred meters.

At Gonçalves Ferreira station (kilometer 127; elevation, 509 meters) the rocks continue to strike east-west. The mountains about 2 kilometers north of the railway station expose enormous and beautifully exfoliated boulders and bosses of massive granite with black inclusions. One of these large blocks is beautifully fluted. From the railway station this mountain, known as the Serra de Imburana, is an impressive sight.

Where the railway goes round the west end of the mountain, there is exposed near the track a layer of coarse waterworn pebbles varying in size from 5 to 20 centimeters in diameter. These pebbles appear to be one of many separate patches rather than part of a sheet, though there may be such a sheet over the Caruarú plain. About 2 kilometers west of Gonçalves Ferreira, at the foot of the Serra Imburana, there is a fine exposure of a very dark gneiss with large pink feldspars.

Three kilometers east of Caruarú the railway passes from schists to granites; the schists appear to dip north at an angle of 80 degrees, as if passing beneath the granite mountain, Serra Imburana. Immediately east of Caruarú the granites contain aplite dikes.

Caruarú station (kilometer 139; elevation, 537.7 meters) stands on a flat plain near the base of a conical granite hill. In sight of the town both north and south are ranges of mountains approximately parallel with the Ipojúca valley and with the general direction of the railway. The granite peak at Caruarú exposes in places exfoliated blocks and bosses, but in July, 1899, the greater part of it was covered with vegetation. The rocks at the base of the peak are coarse grained granites, and these cover the country for miles around. The plain west of Caruarú is covered with a thin coating of waterworn quartz pebbles. There are no heavy forests hereabout; the vegetation is low and scrubby, probably owing to the droughts to which this region is sometimes subjected.

West of Caruarú there are many good exposures along the railway of coarse grained and beautiful pink granites, popularly known as "Scotch granite." These granites are cut here and there by big quartz veins and aplite dikes; in places the rocks are gneissic, occasionally they are decomposed.

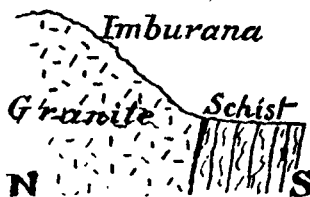


FIGURE 13.—Apparent Relation of Schists and Granites East of Caruarú.

Near São Caetano schists alternate with the granites, and the schists appear to form a belt lying north of the granites of Caruarú but south of those of the Serra Imburána. West and south of São Caetano the rocks are more like gneisses, but they show the banded structure of schists. West of São Caetano for 3 or 4 kilometers the dip of the rocks is south and about 65 to 70 degrees; farther west the dip is north and about 80 degrees.

There are limestones in the vicinity of São Caetano, but I was unable to visit the quarries. Dombre saw these deposits and states that they form a bed having an east-west strike at two outcrops, but he does not mention the thickness of the rocks.*

Through the courtesy of Dr Antonio Pai Pires Ferreira, the director of the Estrada de Ferro Central, I received a specimen of the limestone from the quarries south of São Caetano. It is a beautiful fine grained marble, capable of a high polish.

The following analysis by Professor L. R. Lennox shows it to be a remarkably pure limestone:

Analysis of the São Caetano Marble

	<i>Per cent.</i>
Silica (SiO ₂).....	.14
Oxide of iron and alumina (Fe ₂ O ₃ and Al ₂ O ₃).....	.14
Lime (CaO).....	55.19
Magnesia (MgO).....	.40
Carbonic acid (CO ₂).....	43.80
Phosphoric acid not determined.....	
	<hr/> 99.67

Antonio Olyntho (kilometers 180), the last station on this line, is likewise the highest, and has an elevation of 565 meters above sealevel. Before the arrival of the railway this place was known as Currálinho. The country around is a part of the elevated plateau extending west from the Serra da Russa. The valley of the Ipojúca is here a rolling flat valley, with mountains visible on the horizon to the north and to the southeast.

There are several good exposures of rocks at the station and north of the Y, and also along the railway track east of the station. In the cut north of the Y there are five or six faults from 2 to 4 meters apart and striking approximately east-west. The rocks here dip north at a high angle. The notes made at Antonio Olyntho station say that "the schistose metamorphic rocks have shales interbedded with them." But the metamorphic rocks appear to be tuffs, so that the series was probably

* Viagens do Engenheiro Dombre ao Interior da Província de Pernambuco em 1874 e 1875. Recife, 1893, p. 14.

originally deposited in water where clays alternated with the volcanic ejectamenta that form the feldspathic beds. A prominent feature of these bedded rocks is a felted appearance that is characteristic of the old Paleozoic rocks through the highlands of Brazil. In the felted silicious schists are occasional lenses or bands of flint or chalcedony closely resembling novaculites, some of them more than a meter in length and 20 centimeters wide; one was noted having a length of 3 meters and a width of 2 centimeters. These flints are partly surrounded by and partly penetrated by pink feldspars. The schists vary in color from nearly black where they are unweathered to gray where they are

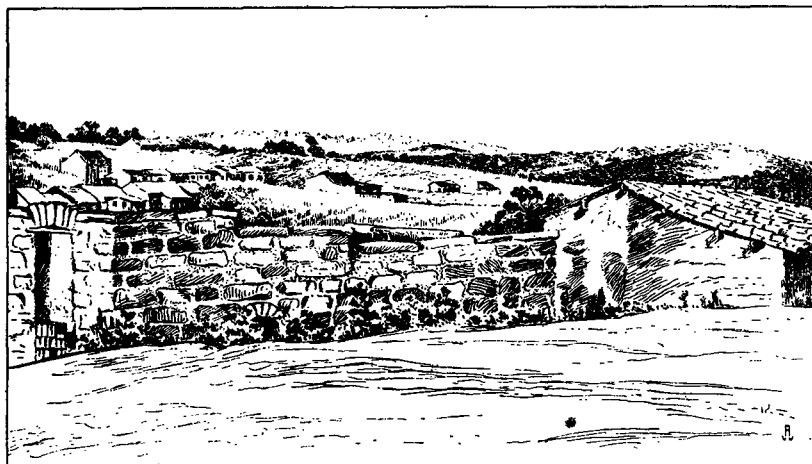


FIGURE 14.—Looking west from Antonio Olyntho.

weathered. The black ones are exceedingly hard. The pink feldspars are characteristic of all or nearly all of them, and many of them contain quartz lenses.

All of these bedded rocks are much jointed, the clean, smooth joints cutting for the most part square across the beds. The joints are from 1 centimeter to 15 centimeters apart.

The schistose rocks about Antonio Olyntho are slickensided. This fact, together with the faults exposed at Antonio Olyntho and the general structure, so far as it is visible between the Serra da Russa and the west end of the valley, lead to the conclusion that the region is much faulted, especially along the east-west belt crossed by the railway between Caruarú and Antonio Olyntho.

According to the observations of Dombre, the granitic rocks found about Bezerros continue to São Bento, about 40 kilometers south and a

little west of Antonio Olyntho, and granites are also reported by him between São Bento and Pesqueira farther west.

Since the preceding pages were written sections of the jointed and felted rocks found near Antonio Olyntho were submitted to Dr J. P. Iddings, who kindly writes of them as follows :

"The three sections sent me appear to come from the same rock. Under the microscope it is seen to be a metamorphosed granitic rock, or possibly granitic porphyry or a rhyolite. It consists of phenocrysts or the remnants of potash feldspar in a micro-granular groundmass of quartz and unstriated alkali feldspar. There is a sheared, streaked, flow structure, and it is plainly seen that there has been crushing and shearing and recrystallization of the minute crushed particles.

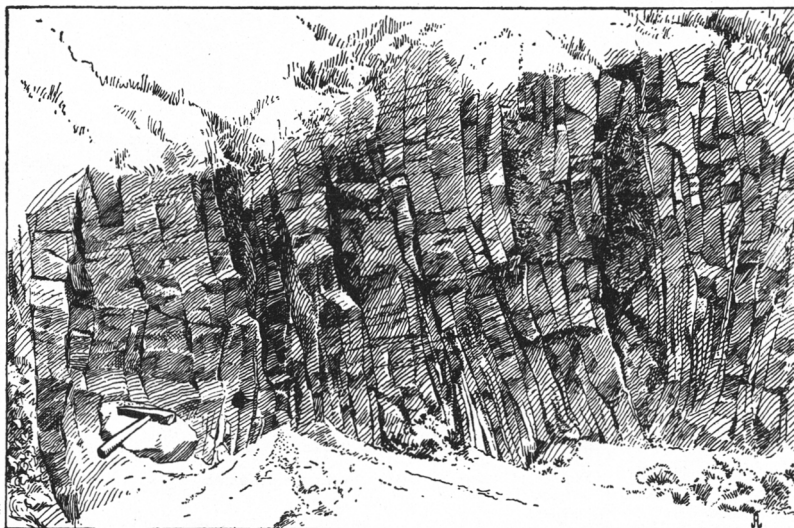


FIGURE 15.—*Jointed and metamorphosed Rhyolite Tuff near Antonio Olyntho.*

The large feldspars are partly shattered and split apart and the spaces between filled with granular quartz. The feldspars are microcline by the straining of orthoclase, the twinning being most noticeable where the stress appears to have been great. The minute grains of feldspar are unstriated, with low refraction, therefore alkali, presumably orthoclase (?) (unstriated microcline). In places the large untwinned feldspars are streaked with another unstriated feldspar in a perthitic manner. The grains of quartz and feldspar in groundmass are not evenly distributed, but are in streaked patches of many feldspar grains and many of quartz, suggesting that the original rock was a fine-grained granite, rather than a porphyry.

"There is very little of other minerals present. Small particles of colorless and yellowish muscovite in streaks, small crushed apatites, little crushed magnetite, little (?) hornblende, pale green. I should think the rock a crushed orthoclase granite, having very little mica and little else."

It should be added that I felt convinced while looking at them in the field that many of the rocks in and west of the Serra da Russa were metamorphosed sedimentary beds. The rock described by Mr Iddings belongs to what I supposed to be a metamorphosed tuff of some kind. Mr Iddings tells me that this is not impossible, but that there is nothing in the slides alone to show it.

I am further induced to think these rocks are rhyolitic tuffs partly by their constant evidence of bedding, by their association with shales, and by the agreement of their strike with the strike of the limestones at São Caetano, as reported by Dombre.

*CONCLUSIONS REGARDING GEOLOGY ALONG THE CENTRAL RAILWAY OF
PERNAMBUCO*

1. The Tertiary (?) beds are exposed along the Estrada Central only to kilometer 13 from the Pernambuco end of the line.

2. The topography about Areias and Tigipió suggests a late elevation and a still later depression of the region.

3. Whether the granites are older or newer than the schists is not clear from anything observed along this geologic section.

4. The colors of the residuary clays are much more brilliant from just west of Francisco Glycerio eastward—that is, from sealevel up to an elevation of about 200 meters—than they are at a greater elevation and west of there.

5. West of the Tertiary area the railway passes over granites, gneisses, and schists. From Russinha westward there are a few places at which stratified rocks are exposed. Some of these resemble altered tuffs and some are shales.

6. The bedded rocks include remarkably pure limestones (marbles) south of São Caetano, and these marbles also have an east-west strike.

7. Some of the metamorphosed beds have the felted appearance characteristic of certain Paleozoic rocks of the Minas Geraes highlands.

8. The region west of the Serra da Russa seems to be much faulted, the faults following the east-west strike of the rocks.

*GEOLOGY ALONG THE GREAT WESTERN RAILWAY FROM PERNAMBUCO TO
TIMBAUBA**

RAILWAY STATIONS

The following is a list of the stations, with distances and elevations:

* The author is indebted to the Pernambuco officers of the railway company for free transportation over the line for himself and five assistants and for every courtesy and attention that could add to the pleasure and interest of the trip.

Kilometers.	Station.	Elevation above flood tide.*
		<i>Meters.</i>
0.000	Brum	1.24
3.150	Encruzilhada.....	4.04
6.550	Officinas.....	10.04
13.750	Macacos.....	47.24
18.376	Camargibe.....	35.24
25.175	São Lourenço.....	31.24
30.120	Tiama.....	44.24
33.000	Santa Rita.....	53.94
48.822	Pão d'Alho.....	69.54
59.875	Carpina.....	182.64
67.243	Tracunhaem.....	90.74
72.944	Nazareth.....	57.84
80.000	Junco.....	.....
84.144	Lagoa Secca.....	46.24
91.244	Barauna.....	73.64
97.244	Alliança.....	59.24
107.600	Pureza.....	70.24
118.000	Timbauba.....	100.74

TOPOGRAPHY AND ROCK EXPOSURES ADJACENT TO STATIONS

The Recife or Pernambuco end of the Great Western of Brazil railway is at Brum, near the old Dutch fort between the city of Recife and Olinda. Brum stands upon a sand spit that rises but little more than a meter above high-tide level. The land is all low, sandy, and flat from Brum to Encruzilhada, 3 kilometers out. Two and a half kilometers beyond Encruzilhada the line of the railway comes to the foot of the Tertiary hills of highly colored sedimentary rocks. At Arrayal the hills east and north of the road are from 30 to 50 meters above the flat coastal plain. About one and a half kilometers beyond † Arrayal the railway leaves the plain and ascends through many cuts in the soft particolored Tertiary beds. The rocks exposed in these cuts are red, brown, purple, yellow, gray, white, and mottled. The beds are approximately horizontal, and the materials are mostly rather fine sediments, with here and there coarse waterworn gravels.

At Macacos station (kilometer 13.7) the elevation of the road is 47 meters, and the big cut near the station is 20 meters deep, all of it being

* The elevations as kindly furnished me by Mr John A. Lorimer, of the railway company, are referred to the bench-mark at the Arsenal de Marinha, at Pernambuco. This station is said to be 8.76 meters below flood tide. All elevations are referred to high tide by subtracting 8.76 meters from the elevations as used by the railway.

† These notes are written as if made on the outward trip; "beyond" a given point, therefore, always means along the line of the road and away from the Pernambuco end.



TERTIARY SEDIMENTS AT DOIS IRMÃOS NEAR PERNAMBUCO

in the particolored Tertiary beds. These beds were examined for fossils, but none were found.

It should be mentioned in this connection that the reservoir at Dois Irmãos, northwest of the city of Pernambuco, is on one of these Tertiary hills, and that the summit of that particular hill has an elevation of 81 meters above tide.

The cuts at and near Macacos have given the railway company much trouble on account of the landslips that often occur in them during the rainy seasons. The white layers are especially liable to cause these landslides. This is due to the fact that these white beds are mostly kaolin deposited from the decomposed feldspars of the underlying crystalline rocks. When these kaolins become wet they are exceedingly slippery.

About half a kilometer beyond Macacos, where erosion has cut deeply into the Tertiary sediments, the underlying granite is exposed in patches. One kilometer beyond Macacos the granite (or gneiss) is exposed by the railway track.

The exposures of the old crystalline rocks show that their upper surface is quite uneven, for the Tertiary sediments are exposed in many places at lower as well as at higher elevations than the granites.

At Camaragibe (kilometer 18.3; elevation, 35.24 meters), north of the track and half a kilometer beyond that station, granite is exposed. The Tertiary continues a little beyond this point, though it is more or less patchy north of Camaragibe.

The railway enters the valley of Rio Capibaribe at Camaragibe and follows it up to Pão d'Alho. It is worthy of note that the line of the railway, instead of following up the valley of Rio Capibaribe, leaves the plain through which that stream enters the ocean, passes through expensive cuts over the watershed at Macacos (elevation, 47.24 meters), and descends again to the Capibaribe at Camaragibe (elevation, 35 meters). Upon inquiring the reason for this, I was told that the railway was not built through the gulch past Apipucos on account of the soft and spongy nature of the soil that fills the narrow valley.

A kilometer below São Lourenço there are terraces along both the banks of Rio Capibaribe at an elevation of about 10 meters above mean waterlevel. These terraces are visible for some 3 or 4 kilometers along the river. At many places the rocks are well exposed in the bed of this stream.

From São Lourenço upstream for several kilometers the rocks exposed in the stream bed are gneisses. At São Lourenço the gneiss is cut by a granite (or pegmatite) dike.

About 200 meters beyond the station at Tiúma the railway cuts gneiss that is decayed to a depth of nearly 20 meters. Here and there through

the decayed mass are rounded (exfoliated) lumps of the unaltered rock. This cut is about 150 meters long. Near the top of the bank is a thin line of waterworn pebbles following the contour of the hills.

At Santa Rita, São Severiano, and Pão d'Alho the crystalline rocks are well exposed in the river bed. Below the bridge at Pão d'Alho the schists are decayed in place and exhibit the same bright colors as are found in the Tertiary sediments.

Beyond Pão d'Alho the slopes of the hills are gentler and the valleys broad, and the watersheds far away. On the hills between Pão d'Alho and Carpina (about 3 kilometers south of Carpina) the decayed crystal-

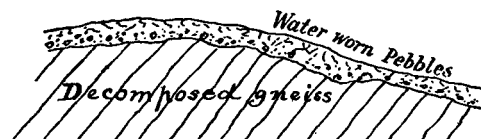


FIGURE 16.—Section on the Railway between Pao d'Alho and Carpina.

line rocks are covered by a layer of red clay, near the bottom of which is a layer of waterworn pebbles mingled with angular and sub-angular fragments of gneiss.

In every observed instance these bands of pebbles follow the contour of the hills and are within 2 meters of the surface of the ground. In some places—not hilltops—the waterworn pebbles are 5 meters below the surface of the ground.

Carpina (kilometer 59.8), it will be observed, is the highest point on the road (182 meters), and is on the watershed between the Capibaribe and Rio Goyanna. Looking northward from Carpina the mountains on the horizon have a serrate outline; toward the northeast they are less broken, while to the southeast the skyline is even and horizontal. To the east of Carpina, about 3 kilometers, there is one high peak that overlooks the surrounding country.

Between Tracunhaem (kilometer 67.2) and Nazareth gneisses and some granites are exposed by the railway track, but there are no waterworn pebbles in the soil. At Nazareth station (kilometer 72.9) the gneiss is wrinkled and decayed. At the little station of Junco, between Nazareth and Lagoa Secca, the decayed rocks look more like schists than like gneisses. One of the cuts is about 20 meters deep, and the decayed rocks are mostly red. About 150 meters beyond the station of Lagoa Secca (kilometer 84.1) a cut exposes a narrow band of waterworn pebbles in the soil.

At Barauna station (kilometer 91.2; elevation, 73.6 meters) the rocks are schists. In the railway cuts 300 meters beyond the station the schists are deeply decomposed, and bands of waterworn pebbles pass through the thick clays and sands that overlie the rocks decayed in place. Two or 3 kilometers beyond the station these clays and sands are from 6 to

10 meters deep, where exposed in the cuts, and bands of cobbles, many of them 20 centimeters in diameter, run straight through the hills.

The pebble bands are derived from quartz veins that penetrate the schists along this part of the line.

At Alliança station again (kilometer 97.2; elevation, 59.2 meters) the rocks are decayed crystalline schists or gneiss with waterworn quartz pebbles overlying them in places. The schists here contain much mica.

From 300 to 500 meters beyond Alliança waterworn quartz pebbles 10 centimeters in diameter are exposed in the railway cut 7 or 8 meters above the stream level.

At Pureza (kilometer 107.6; elevation, 70.2 meters) are decayed crystalline schists, and beyond the station the undecayed rocks are exposed in the bed of the stream. A

kilometer beyond Pureza there are waterworn pebbles at the track level, and at Timbauba (kilometer 118; elevation, 100.7 meters) large waterworn



FIGURE 17.—Section on the Railway near Barauna.

quartz boulders are exposed near and west of the railway station. Some of these boulders are 20 centimeters in diameter, and are both subangular and well rounded. The rocks in place at Timbauba are either crystalline schists or gneisses.

The terminal station of the railway at Timbauba is on the watershed between the drainage of Rio Goyanna and that of the Rio Parahyba. The country around is hilly, but the slopes as a rule are gentle, and most of them are covered with cultivated fields to their very summits. There was not time to ascend the higher hills; as seen from the village, many of them appear to rise to an even skyline a hundred meters or more above the station, while above these rise several higher peaks. The accompanying sketch is made from a photograph taken near the Timbauba station.

So little is known of the nature of the waters of Brazil that I give here the analyses ordered made by this railway of waters taken at five different points along its line. These analyses were made for the purpose of determining the availability of the waters for use in locomotive boilers, but they contain information of much interest in regard to the amount of total solids in the waters, and they show something of the character of these constituents. These waters are from springs near the stations named in the table.

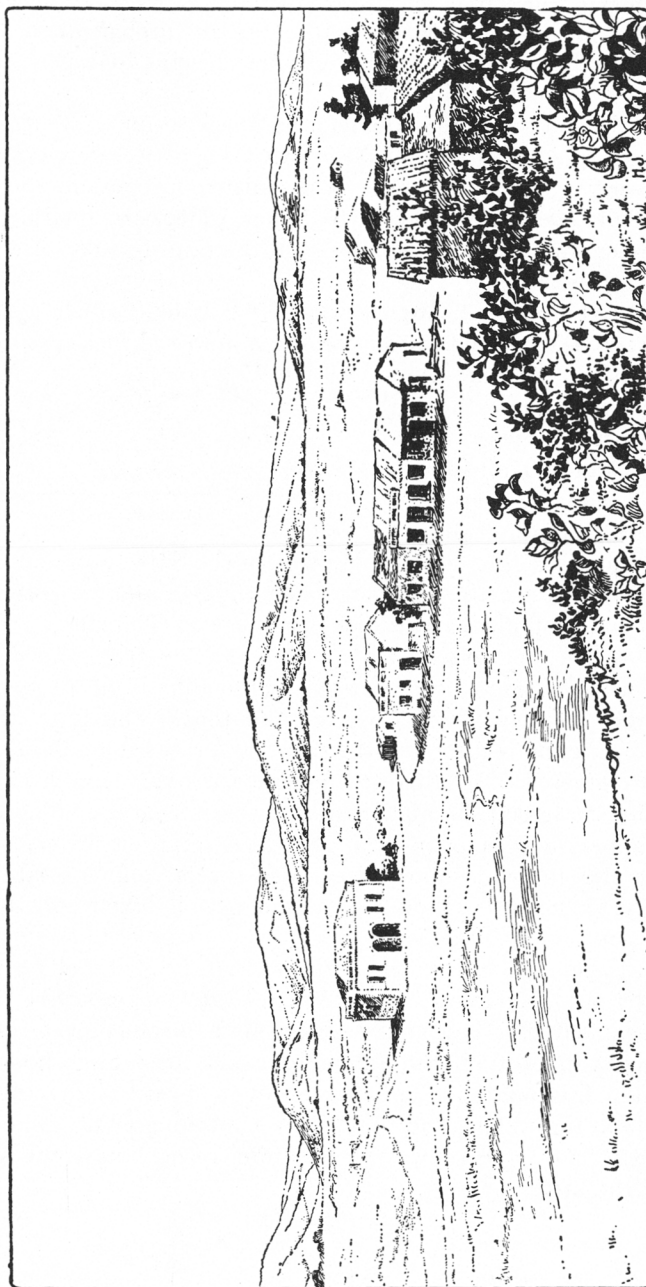


FIGURE 18.—The hills west end southwest of Timbauba.

*Partial Analyses of Waters along the Line of the Great Western of Brazil Railway
(expressed in Grains per Gallon)**

	Timbauba, 118 kilometers, elevation 100 meters.	Pureza, 107 kilometers, elevation 70 meters.	Junco, 80 kilometers.	Nazareth, 73 kilometers, elevation 57 meters.	São Lourenço, 25 kilometers, elevation 31 meters.
Total solids.....	82.39	24.01	49.35	60.34	19.39
Lime.....	7.30	3.10	5.66	5.26	3.00
Magnesia.....	4.40	0.40	2.20	4.30	0.42
Chlorine.....	43.56	11.16	16.20	27.72	8.28
Total hardness.....	26.30	6.58	16.50	21.80	6.58
Permanent hardness.....	21.00	6.58	11.90	15.40	6.58
Degree of hardness.....	10.00	3.00	5.00	7.00	3.00

The facts of general interest shown by the geology along this railway line are here brought together.

CONCLUSIONS REGARDING THE GEOLOGY ALONG THE GREAT WESTERN RAILWAY

The particolored Tertiary beds forming the hills around the plain on which Pernambuco stands form only a narrow belt where they are cut across by the Great Western railway. These beds end a short distance beyond Macacos, so that the entire belt has here a width of only about 12 to 15 kilometers.

The Tertiary beds where exposed along the railway are without fossils, but what appear to be the same beds, where less weathered, as at Olinda, contain marine fossils, which are regarded by Professor Gilbert D. Harris, of Cornell University, as of Eocene-Tertiary age.†

The Tertiary sediments were laid down on an uneven surface of crystalline rocks—granites, gneisses, and schists.

The crystalline rocks are exposed from near Macacos to Timbauba, a distance of about 100 kilometers by the railway line.

Inland from the main Tertiary sediments waterworn materials cover the lower slopes of the hills, but these materials have not been observed at a higher elevation than a little more than 100 meters above tidelevel.

The marked colors characteristic of the Tertiary beds are sometimes

* For a copy of these analyses I am indebted to Mr John A. Lorimer, chief of locomotion on the railway.

† It is possible that there may be a thin bed of Cretaceous between the Tertiary and the schists and granites.

found where the old crystalline schists, gneisses, et cetera, are decayed in place. It is therefore believed that some of the coloring of the Tertiary sediments is due to the weathering in place of the crystalline rocks, and that some of the Tertiary beds have therefore always been highly colored. In other instances the coloring has taken place subsequent to the deposition and elevation of the Tertiary beds. This is shown by the size and character of the particolored areas.

There is a notable topographic contrast between the region of Tertiary sediments and the region of old crystalline rocks. The soft Tertiary beds rise to an approximately even elevation and are cut by steep-sided, narrow, closely spaced valleys or gorges, while the region of old rocks is more rounded in outline and the valleys are broader and the elevated watersheds farther apart.

GEOLOGY ALONG THE NATAL A NOVA CRUZ RAILWAY

RAILROAD STATIONS AND TOPOGRAPHY ADJACENT THERETO

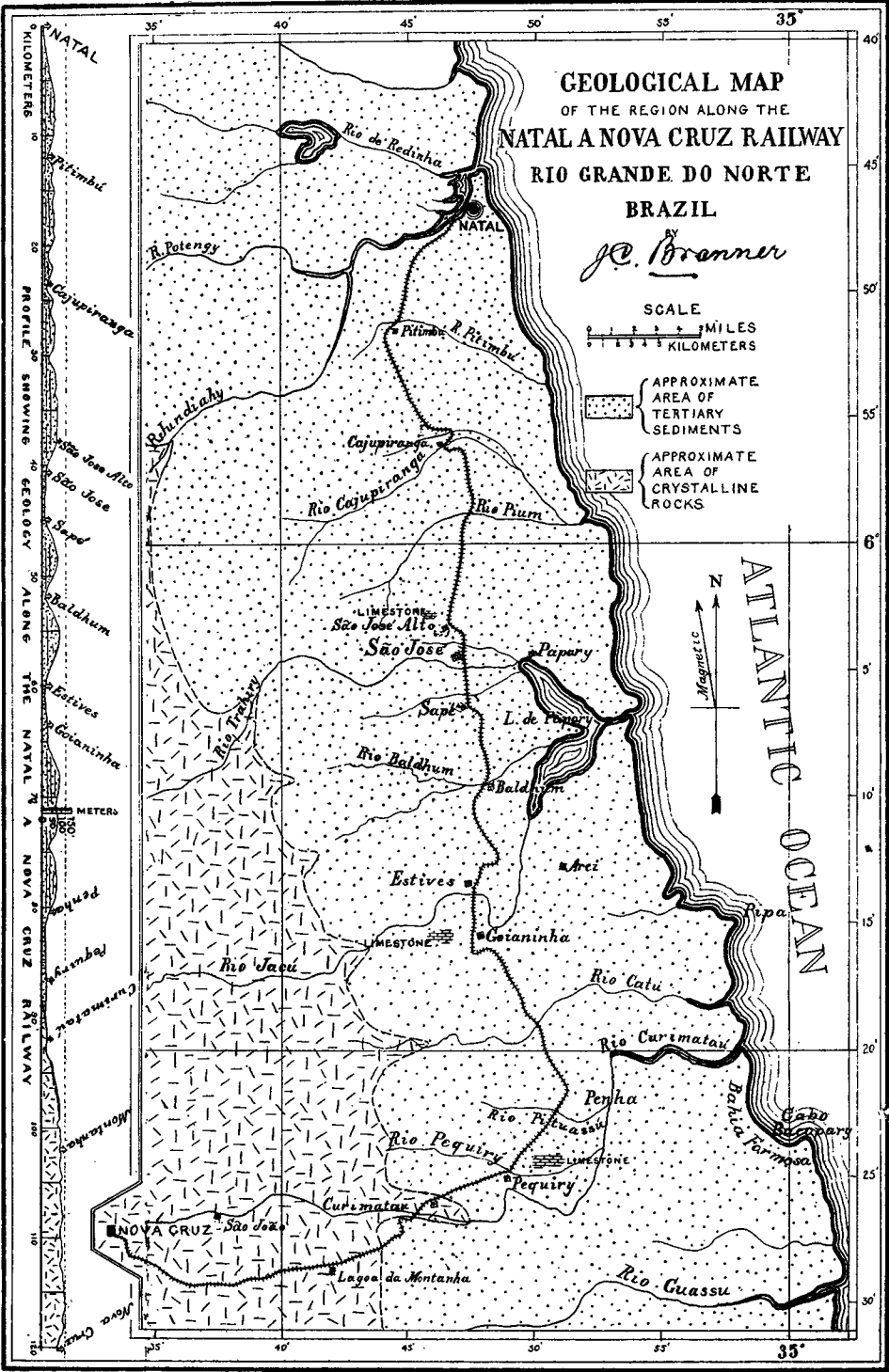
The lower part of the city of Natal stands on an alluvial flat, only a meter or two above high-tide level. This flat ends abruptly and sharply against the slope of the ridges, as if its materials had been deposited in water standing at that level against the hills. The "upper city" is on a hill of red Tertiary sediments that rises some twenty meters or more above high-tide level. The streams that cut across the region above or inland from the city are bordered by broad mangrove swamps, while the lowlands between the city and the sea is either mangrove or tide marsh or is covered with sand dunes.

At kilometer 3 the view over Rio Grande and the estuaries about Natal throw light upon the topographic history of the region. The water of the estuaries is bordered with mangrove swamps, and these swamps merge into flat lands which end abruptly against the rather steep slopes of the hills beyond. At kilometer 3 the railway is near the general level of the Tertiary plateau that forms the rather narrow belt along the Brazilian coast from Natal nearly to the mouth of the Rio São Francisco.

At Pitimbú (kilometer 12) the stream runs through a flat valley filled with a black, muck-like soil between steep hills.

From kilometer 15 to 19 the country is a somewhat rolling, but nearly flat, dry plateau, with a very scant vegetation.

The sand dunes that have blown up from the coast are visible from the railway at many places across the Tertiary plateau. Where the road approaches the coast they form a very striking feature of the topography—



GEOLOGICAL MAP OF THE REGION ALONG THE NATAL A NOVA CRUZ RAILWAY, RIO GRANDE DO NORTE

long ridges of light brown or yellow sand, often more than 30 meters high and several kilometers in length.

Stations on the Natal a Nova Cruz Railway

Kilometers.	Station.	Elevation.
		<i>Meters.</i>
0.00	Natal.....	11
8.50	Divide.....	70
12.00	Pitimbu.....	26
17.75	Divide.....	62
23.50	Cajupiranga.....	21
30.30	Rio Pium.....	35
34.50	Divide.....	80
38.00	São José Alto.....	75
41.00	São José Baixo.....	21
41.20	Bottom of valley.....	14
45.00	Sapé.....	19
48.50	Divide.....	81
52.00	Baldhum.....	19
55.00	Divide.....	93
60.00	Esteves.....	18
63.50	Goyaninha.....	24
68.00	Divide.....	90
74.20	Catú valley.....	37
78.00	Divide.....	74
80.20	Penha.....	42
82.50	Bottom of valley.....	15
86.60	Pequiry.....	26
92.00	Curimataú.....	30
102.00	Lagoa da Montanha.....	93
115.50	Summit.....	125
120.20	Nova Cruz.....	84

Between kilometers 15 and 20 these dunes, seen in the distance, look like low mountain ranges. Just before reaching kilometer 21 the road cuts down along the Tertiary red hills, crosses a narrow valley, and ascends another Tertiary ridge, whose surface is strewn with many lumps and pebbles of iron.

Cajupiranga (kilometers 23, 24) is only 12 kilometers from the coast. It is situated in a flat fertile valley, about 0.2 kilometer wide, between Tertiary hills.

Another long, narrow, and winding valley, known as the Pium, is crossed by the railway at kilometer 30. It is only about 100 meters wide, but drains into the ocean.

São José Alto (kilometer 38) is one of the highest stations on the railway. Limestone is said to be quarried a short distance northwest of the São José station, but no specimens of the rock from these quarries have

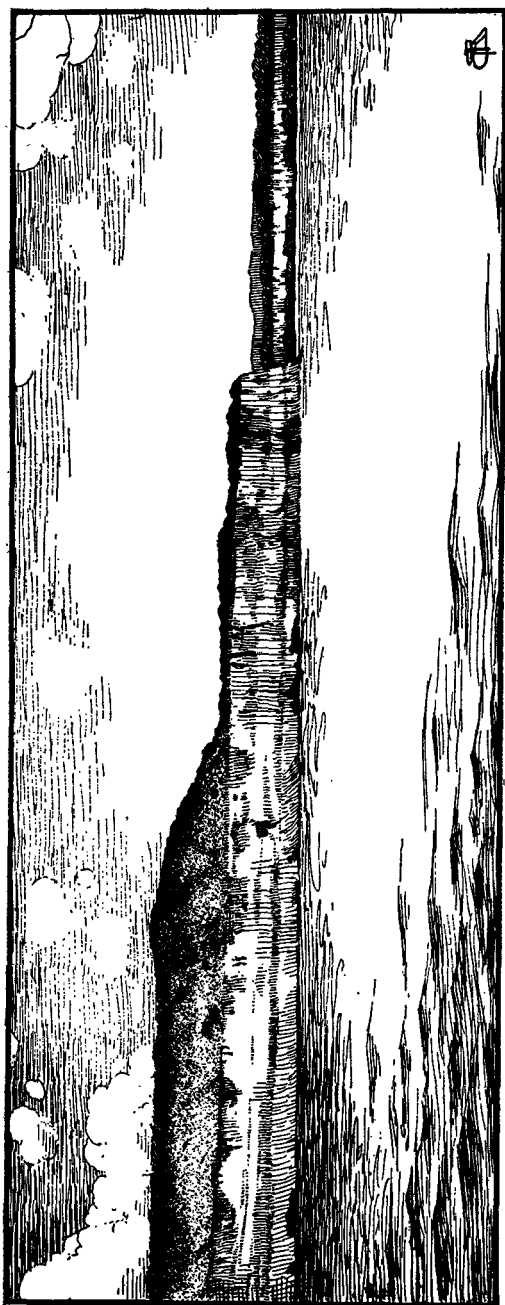


FIGURE 19.—Ancient Sand Dunes Capping the Bluffs at Pipa.

been seen. North of São José the plateau is flat. The country in sight is all Tertiary and is covered with a thin forest. The highest elevation reached by the railway on the divide between Cajupiranga and São José is 80 meters.

From the São José Parada one looks down on the Sapé valley—a wide and very flat valley with low hills here and there through it. Sapé station is on the east side of the low valley land. Through this valley flows the Trahiry river, but most of the valley, especially during the rainy season, is covered by a shallow freshwater lake or marsh 2 kilometers wide and known as Lagôa Mipibú. It is, however, a network of lakes and marshes rather than a single lake. It is said that the tides are not felt in this lake. At some places the topographic break between the valley floor and the hills is sharp and well defined; at others there is no great contrast, but the hill slopes and valley bottom merge gradually together.

Northwest from Sapé the hills are Tertiary, and seen from the valley appear to be flat topped.

After passing Sapé the railway ascends the Tertiary hills of horizontal beds, and, passing the watershed, descends to Baldhum (kilometer 52), where there is a long, narrow, flat bottomed valley only about 100 meters wide.

South of Baldhum the railway ascends another red Tertiary ridge (kilometer 59), from which one looks out over the broad open Estevão valley. Descending to the valley, at kilometer 60 there is a small lake at Esteves station, and the railway crosses Rio Jacú, a small, sluggish, winding stream, with several small lakes along its course.

Goyaninha station, at kilometer 63.5, is in a flat valley about 5 kilometers in width. Limestone is said to be found west of Goyaninha, at the foot of the hills. It was not possible for the writer to visit the locality, but through the kindness of Mr Samuel H. Agnew, the superintendent of the railway, some small specimens of the rock have been received from the quarry at that place. The rock contains marine fossils, but the specimens received are small and the fossils so fragmentary that it is not possible to identify them. They consist of gasteropods and bivalve mollusks. The rock is a very sandy limestone, straw colored and streaked with brown and red.

From the Tertiary hills beyond (south of) Goyaninha one sees in the direction of the coast the sand hills that have been blown inland. Behind and landward of these hills in the valley is a great lake between Tertiary hills. These hills south of Goyaninha form a remarkably flat plateau or *taboleiro*, having an elevation of 90 meters, and is covered with a very sparse vegetation, chiefly *mangabeira* rubber trees.

At kilometer 75 the hills are still Tertiary (?). At kilometer 79 the road descends westward from the plateau-cutting Tertiary (?) beds here and there until Penha is reached on the Rio Pituassú. A little beyond Penha the railway enters a broad, flat, marshy valley and, turning westward, follows up it for several kilometers.

A few kilometers south of Penha station and north of Rio Crimataú there are several limestone quarries. It is said that lime is made half a league east of Pequirý station. Mr Agnew kindly sent me samples of the rock from one of the quarries south of Penha and east of Pequirý. The specimens received contain no fossils. They are all of a light gray color and on analysis prove to be dolomites.

Analysis of Limestone from near Penha

L. D. Mills, analyst.

	I.	II.
Lime (CaO),.....	29.08	29.05 per cent.
Magnesia (MgO)	20.10	19.92 per cent.

Inasmuch as limestones and dolomites are common in the Cretaceous beds farther south, and as no limestones have been found in the beds of known Tertiary age, it seems probable that these limestones may be Cretaceous.

Looking south from Curimataú station, the Tertiary (?) hills have the appearance of a flat-topped plateau. At Curimataú station the railway first comes upon the gneiss, which is here exposed by stream erosion in this deep, broad valley. These rocks in place are visible at the railway station and also at the bridge over the river.

After leaving Rio Curimataú the soil is pebbly for several kilometers; beyond this it is sandy. Then follow the Tertiary beds, and these are succeeded by crystalline rocks.

These crystalline rocks begin on the plateau about 5 kilometers beyond Rio Curimataú.

At Montanha station the rocks are granites and the land is gently rolling. Some quartzitic or cherty rocks seen at Natal on the cars are said to have come from kilometer 108, north of Montanha station. These rocks appear to be Paleozoic, but without farther examination or evidence nothing trustworthy can be said of their age.

About 1 kilometer north of Montanha, Tertiary (?) beds are visible. These are followed by granites, which are exposed here and there as exfoliated boulders and bosses. Farther on the Tertiary appears in patches again, and these in turn are followed by granites and gneisses, which continue to Nova Cruz (kilometer 121).

In the low grounds along watercourses and on some of the slopes the vegetation is thick and rank, but across the high flat Tertiary plateaus it is sparse, and in many places so much so that the ground is bare and hard and the landscape desert-like.

CONCLUSIONS REGARDING THE GEOLOGY OF RIO GRANDE DO NORTE

The facts of geologic interest in the section along the Natal a Nova Cruz railway are as follows:

1. The horizontal weathered Tertiary (?) beds common along the coast southward nearly to Rio de Janeiro form a belt from 15 to 25 kilometers wide through the region traversed by the Natal a Nova Cruz railway.

2. Marine fossils have lately been found in the beds near the base of the series west of Goyaninha, and they probably occur also in the limestones northwest of São José and south of Penha.

3. The fossiliferous limestones near Goyaninha are quite sandy.

4. Whether the upper beds exposed on the coast are the same as those yielding fossils inland is not known certainly.

5. The limestones south of Penha are, in part at least, dolomites, and lithologically resemble some of the Cretaceous limestones of the Sergipe basin.

6. These Tertiary (?) beds contain much iron, especially on the coast south of Natal, at and in the vicinity of Ponta da Pipa.

7. The Tertiary (?) beds thin out on the interior side, and their margin is a series of patches resting on the old crystalline series.

8. The sedimentary beds rest unconformably on crystalline schists and granites probably of Paleozoic age. These crystalline rocks cover the greater part of the interior of the state of Rio Grande do Norte.

9. The beds here spoken of as doubtful Tertiary may be Cretaceous at the base and Tertiary at the top; this is suggested by the geology of the adjacent state of Parahyba do Norte, as shown in the first part of this paper.

10. Weathering has affected the sedimentary beds along the coast in much the same way, whether those beds are of marine or freshwater origin.

11. Besides those mentioned at Goyahinna, one other occurrence of fossils has been reported in Rio Grande do Norte. In 1853 or 1854 Jacques Brunet, a French physician, while exploring the interior of Parahyba and Rio Grande do Norte, found fossil shells at Apody, on Rio Mossoró, in the northern part of the province.* Dr Burlamaque also reports limestone and chalk † sent from the same place by Brunet. The Apody beds are probably the Cretaceous (or Tertiary) limestone.‡

* Notícia acerca dos animais de raças extintas descobertos em varios pontos do Brazil. Pelo Dr F. L. C. Burlamaque. Bibliotheca Guanabarensis, Trabalhos da Soc. Vellosiana. 9 de Junho de 1885. Secção de Geologia, p. 19.

† Notícia acerca de alguns mineraes e rochas de varias provincias do Brazil, recebidos no Museu Nacional durante o anno de 1855. Por Dr F. L. C. Burlamaque. Revista Brasileira, Rio de Janeiro, 1858 (?), vol. ii, pp. 78-79.

‡ Rocks containing Cretaceous fossils were reported to have been found by Dr Continho on Rio Mossoró in 1886. Contribuições a Paleontologia do Brazil por Charles A. White. Archivos do Museu Nacional do Rio de Janeiro, 1887, vol. vii, p. 10.

12. The most striking topographic features of the region traversed by the railway are :

The enormous sand dunes on the plateau southwest of Natal.

The flat bottoms of the valleys cut in the Tertiary (?) sediment, showing a comparatively recent depression of the coast.

In many instances these valleys are still in process of filling up. The great Mipibú lake is in one of these depressed valleys.