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J. C. Branner.

The Oil-Bearing Shales

OF THE

Coast of Brazil.

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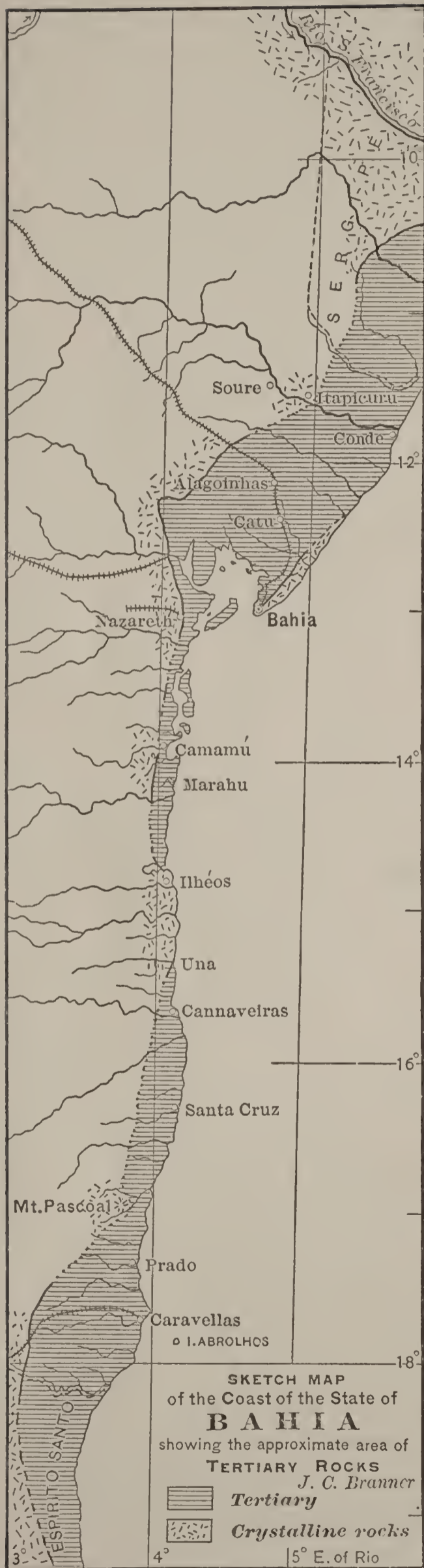
BY JOHN C. BRANNER, STANFORD UNIVERSITY, CAL.

(Canadian Meeting, August, 1900.)

SHALES rich in oil are found at several places along the coast of Brazil. The material has been prospected at several places, and samples have been examined and reported upon by competent authorities. So far as I am acquainted with them, these oil-bearing beds are of Tertiary age. A glimpse at the distribution and character of the Tertiary rocks of the region should give us some idea of the possible distribution of these oil-bearing shales. Tertiary rocks skirt the northeast coast of Brazil from the northern part of the State of Espirito Santo almost or quite to the Amazon valley. Here and there this narrow strip is cut in two by the encroachment of the sea, and the underlying gneisses, granites or other crystalline rocks are exposed upon the beach. In other places, the Tertiary belt widens out until it is 80 kilometers or more in width. Fig. 1 is a sketch-map of a part of the coast-area referred to.

Along the coast from Prado, in the State of Bahia, northward to Natal, there is a line of bluffs from 15 to 90 meters high, interrupted here and there by stream-valleys. As seen from the sea, these bluffs are rather conspicuous and highly colored yellow, brown, red, white, black, and purple. These colors are often so mingled as to give the beds a mottled or parti-colored appearance. Fig. 2 shows a characteristic bit of the coast in the State of Parahyba do Norte. In some places, especially in the southern part of the State of Sergipe, and in the northern part of Rio Grande do Norte, the immediate coast is covered with sand-dunes. Here and there these sand-dunes have been carried inland over the top of the Tertiary beds, and the subsequent encroachment of the sea has exposed the Tertiary rocks again, where they form the bases of the bluffs. This is well shown in Fig. 3, from a photograph taken at Bahia Formosa, on the coast of Rio Grande do Norte.

FIG. 1.



The width of the Tertiary belt has been determined at several places. Owing partly to the fact that the landward margin of the beds is generally more or less ragged, and partly to the lack of good maps, these measurements must be accepted as only approximately correct:

1. From Porto Alegre, just south of Caravellas in southern Bahia, along the Rio Mucury to the Serra dos Aymores, 80 kilometers. This does not include the Abrolhos islands of the coast, which are also Eocene Tertiary.

2. At Ilhéos, Bahia, there are no sedimentary beds; the crystalline rocks appear on the shore.

3. At Camamú, 22 kilometers.

4. From Bahia to the western margin of the series near Nazareth, 50 kilometers.

5. From Bahia in the direction of Feira de Santa Anna, 82 kilometers.

6. Across the axis of the basin at Alagoinhas, Bahia, 80 kilometers.

7. From Aracajú to the Serra d'Itabaianinha, 80 kilometers.

8. Along the Rio São Francisco from its mouth to Propriá, 60 kilometers.

9. From Maceio to Cachoeira along the Alagôas railway, 33 kilometers.

10. At Pedra do Conde,

south of Tamandaré 0 kilometers; granite is exposed on the beach.

11. At the mouth of Rio Formoso, State of Pernambuco, 3 kilometers.

12. At Cape Santo Agostinho, Pernambuco, 0 kilometers; granites and porphyries on the beach.

13. At Pernambuco along the Great Western of Brazil railway, the granite is exposed $\frac{1}{2}$ kilometer above Macacos; 7 kilometers.

14. On the Central de Pernambuco railway the inland margin of the Tertiary is about kilometer 10, two kilometers above Tigipió. On the Recife ao São Francisco railway the Tertiary beds are not exposed, the first recognizable beds being crystalline rocks at Cabo, kilometer 31.

15. At Parahyba do Norte on the Conde d'Eu railway, 30 kilometers.

16. At the Rio Grande do Norte the Natal a Nova Cruz railway does not cut square across the Tertiary, but runs southward parallel with the coast and on Tertiary beds for most of its length. It crosses the Matahú river on the gneiss, so that the Tertiary varies in width here from 15 to 50 kilometers.

At Bahia, Tertiary beds are let down by a fault behind a narrow strip of crystalline rock which, northeast of that city for many kilometers, separates them from the ocean.

In my work upon the stone and coral reefs of Brazil, a trip was made on foot along the beach from Pernambuco to Maceio, in the State of Alagôas. This trip afforded an excellent opportunity for seeing the best exposures of these rocks to be found in the country.

The series to which the oil-shales belong is exposed in many places about Cape Santo Agostinho, Rio Formoso, Tamandaré, Abreu de Una and Maragogý; but at these places the unweathered shales were not found.

Going south from Pernambuco, the oil-bearing shales were first found upon the beach just south of the mouth of Rio Maragogý, $9^{\circ} 3'$ S. latitude, in the State of Alagôas. At this place they are uncovered at low tide and extend seaward for a few hundred meters, forming a wave-cut bench. They are also exposed in the bank above the reach of high tide. The beds are more or less wrinkled, and a small syncline is plainly shown

upon the bench at low tide. The dips observed are 10° S. 71° W., and 6° S. 31° W., magnetic. The shales all dip landward and beneath the red and mottled beds exposed in the cliffs or line of hills that follow along close to and parallel with the coast at this place.

Between the mouth of Rio Maragogý and the village of São Bento, at a *venda* called Camáxo, the sea has cut into a bed of heavy conglomerate rocks that underlie the shale beds. Immediately south of these conglomerates, black shales are exposed at low water. These shales contain many finely broken plant-remains. The dips of the shales at this locality vary as follows: 9° S. 60° W., 4° S. 80° W., 4° S. 33° W., 10° S. 50° W., all magnetic.

It is noticeable in all these cases that the dips carry the rocks downward toward the hills that follow the coast-line.

At Japaratingá, just south of the mouth of a small stream, low tide exposes conglomerates, sandstones and shales, dipping S. 80° W. The exposure extends seaward about 300 meters from the beach.

In front of Pitinguí ($9^{\circ} 7'$ S. lat.) shales are exposed at low tide dipping 9° N. 70° W. and 7° due west. Just north of Pitinguí, however, a red cliff rises to an elevation of something like 90 meters.

There is another interesting exposure of the shales at a place called Barreira do Boqueirão, between one and two leagues north of Porto das Pedras. Here the sea has cut into the foot of one of the red hills and has exposed about 7 meters of mottled, gray and red sandstones. The shale is visible to the south of this exposure, partly covered by soil and vegetation from the hills above. The shale where exposed is about 2 meters thick, but it is possible that it has a thickness of 3 or 4 meters. Along the shore the exposure is about 100 or 150 meters long. The dip varies considerably both in amount (10° to 15°) and direction; but for the most part the dip is inland and toward the red hills of the coast. The hills above this particular place are about 60 meters high.

At the mouth of the Rio Manguába (sometimes called Rio Porto Calvo), in the edge of the town of Porto das Pedras (S. lat. $9^{\circ} 10'$), these beds are exposed again at the ferry. Here the rocks are mostly sandstones; but they are of the same

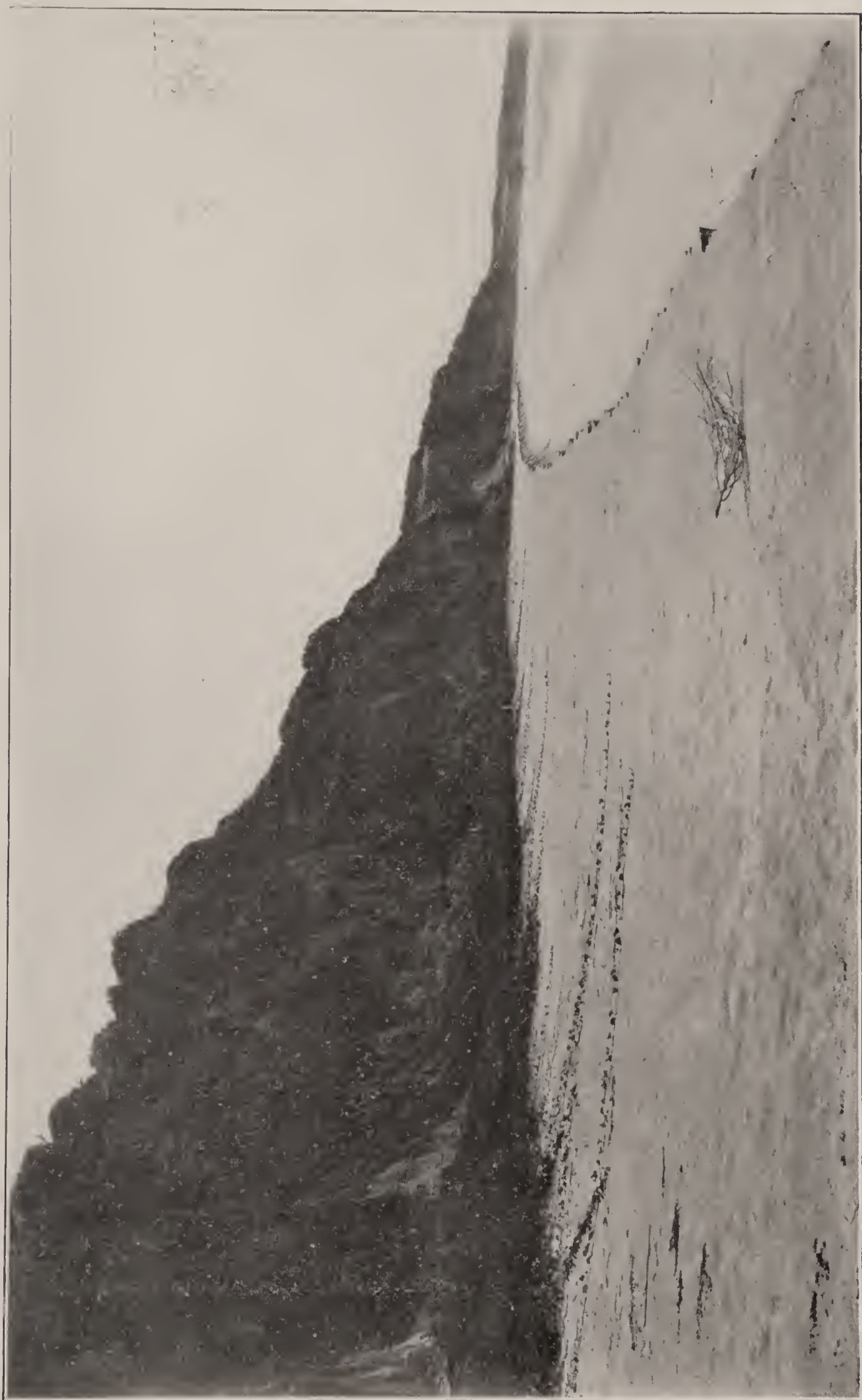
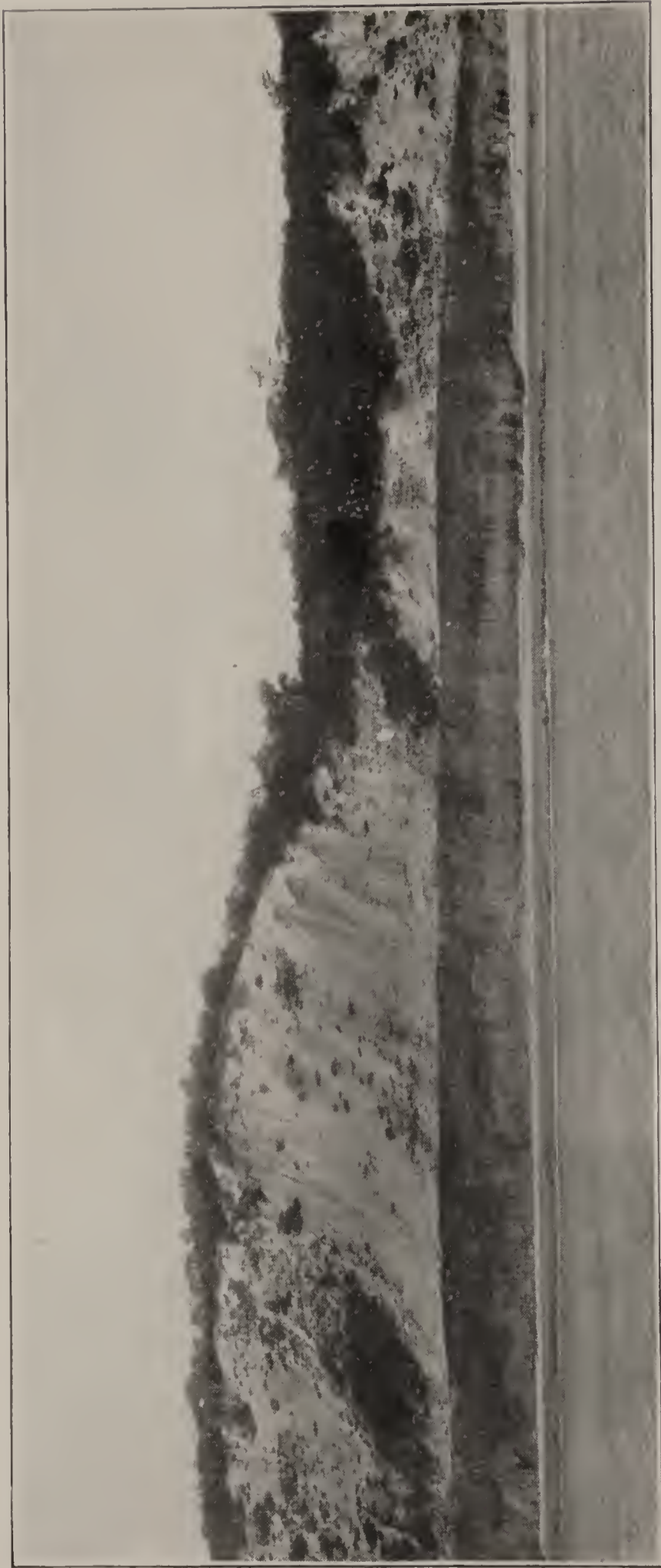


FIG. 2.

The Red and Mottled Cliffs, 3 kilom. N. of Trairão, State of Parahyba do Norte.

FIG. 3.



Bluffs, 200 feet High, Capped with Sand, at Bahia Formosa, State of Rio Grande do Norte.



FIG. 4.

The Gray Unaltered Sediments at the Base of Morro de Camaragibe, Merging into the Highly-Colored Beds of the Hill-Tops.
Wave-Cut Terrace of Oil-Shales in the Foreground.

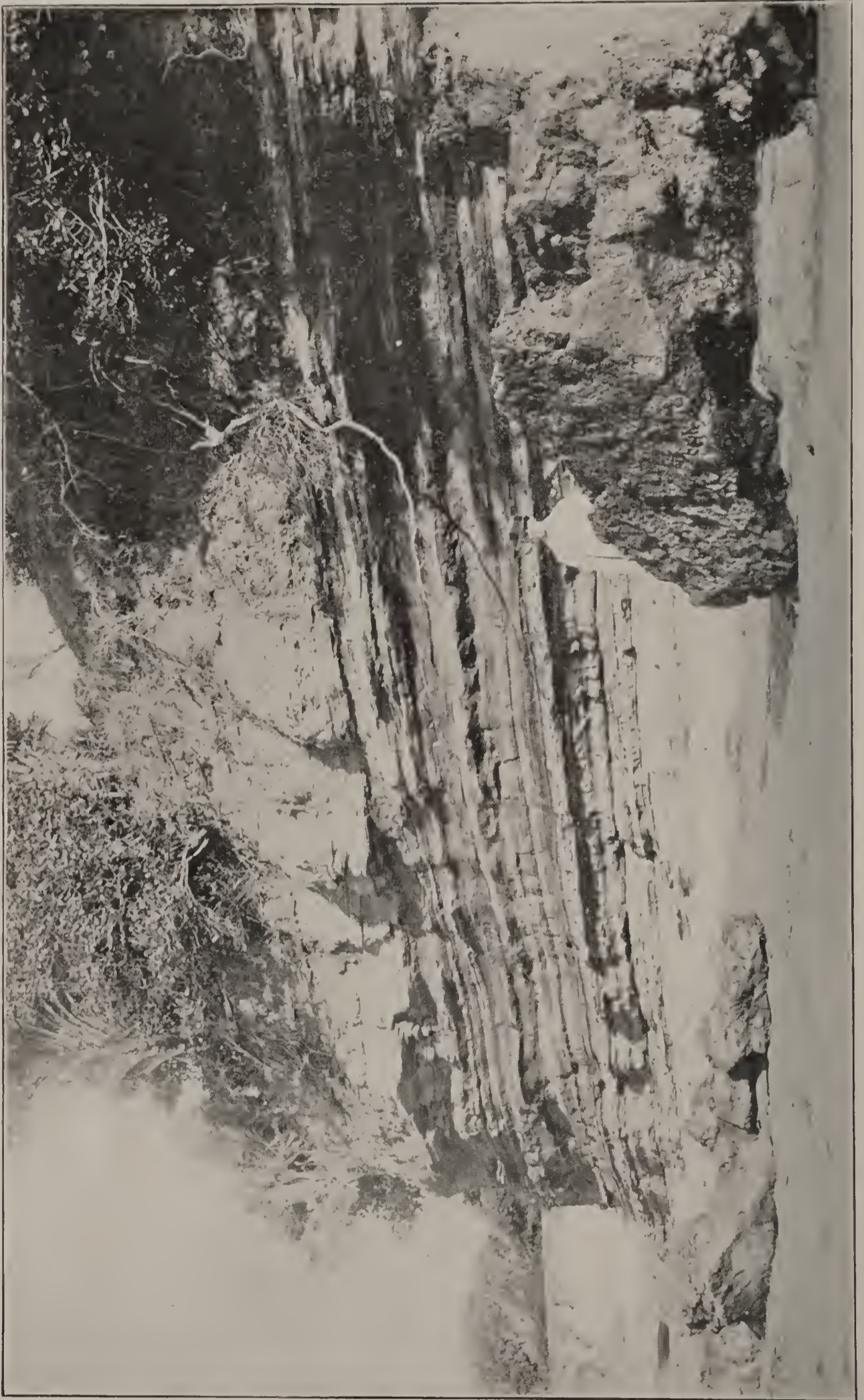


FIG. 5.

The Oil-Shales, 2 kilom. South of Morro de Camaragibe.

series, and the shales are interbedded with them. The dip is southwest about 3° or 4° .

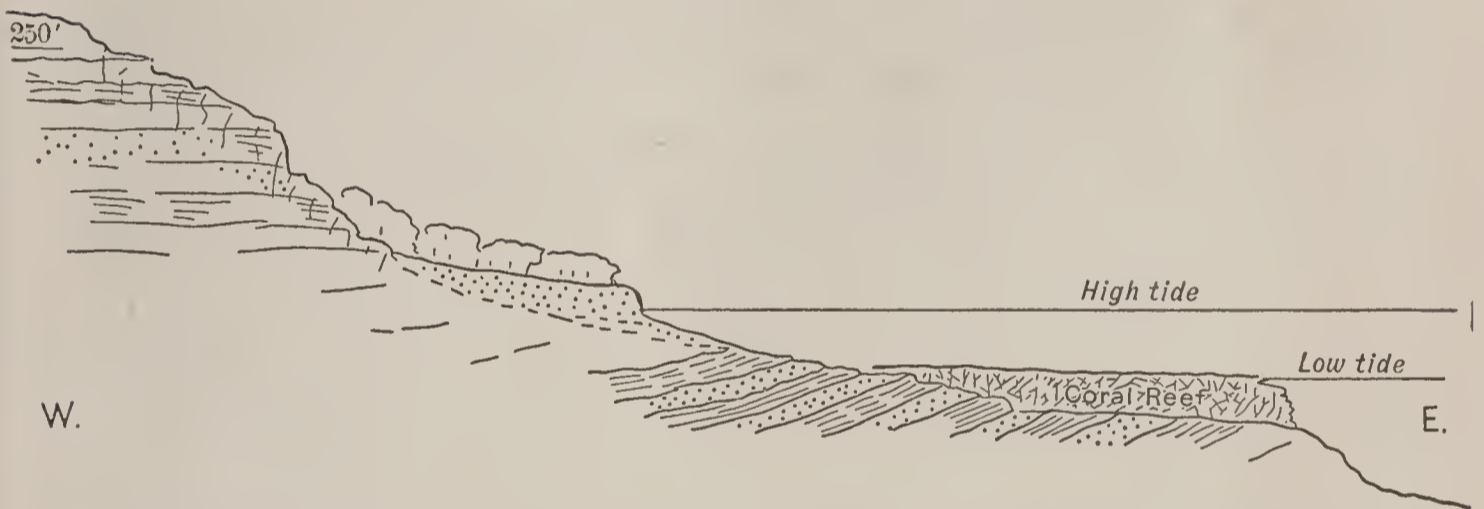
In the bottom of the embayment south of Marcenerio, the shales are exposed at low water, with a coral reef overlapping them, as shown in the section, Fig. 6.

The dips observed are 10° N. 39° W., and 13° N. 57° W., magnetic; about 185 meters south of this place the dip is 12° N. 25° W.

At the Barra do Passo or Barra do Camaragibe there is one set of exposures north of the mouth of the river off the town, and another a league south of there at a place called Morro de Camaragibe or Barreira do Morro.

On the beach in front of the town of Barra the shales dip inland toward the town at an angle of from 70° to 10° , and

FIG. 6.



Geological Section at the Bottom of the Embayment S. of Marcenerio, Showing the Shales Dipping Landward and Overgrown with Coral-Reefs.

plunge beneath the hills back of the town. A section at this place would be something like Fig. 7.

The exposures on the cape just south of the Camaragibe at the Barreira or Morro de Camaragibe are unusually good, especially at low tide.

The cliffs are from 75 to 90 meters high. The upper beds are the well-known red, yellow and mottled beds of the coast; while at the base of the bluffs and uncovered at low tide are the shales and sandstones dipping landward. The lower beds form a wave-cut terrace about 150 meters wide. At the northern exposure of the bluffs on the beach are many large boulders of pink granite, apparently washed from a basal conglomerate underlying the series exposed on the hills. Some of these

water-worn granite boulders (see Fig. 8) are about a meter in diameter. The sandstones at the base of the bluff contain also rolled lumps of clay. The angle of the dip of the beds is usually low, (from 5° to 10°). Several pits have been sunk about and south of the cape by an English company that

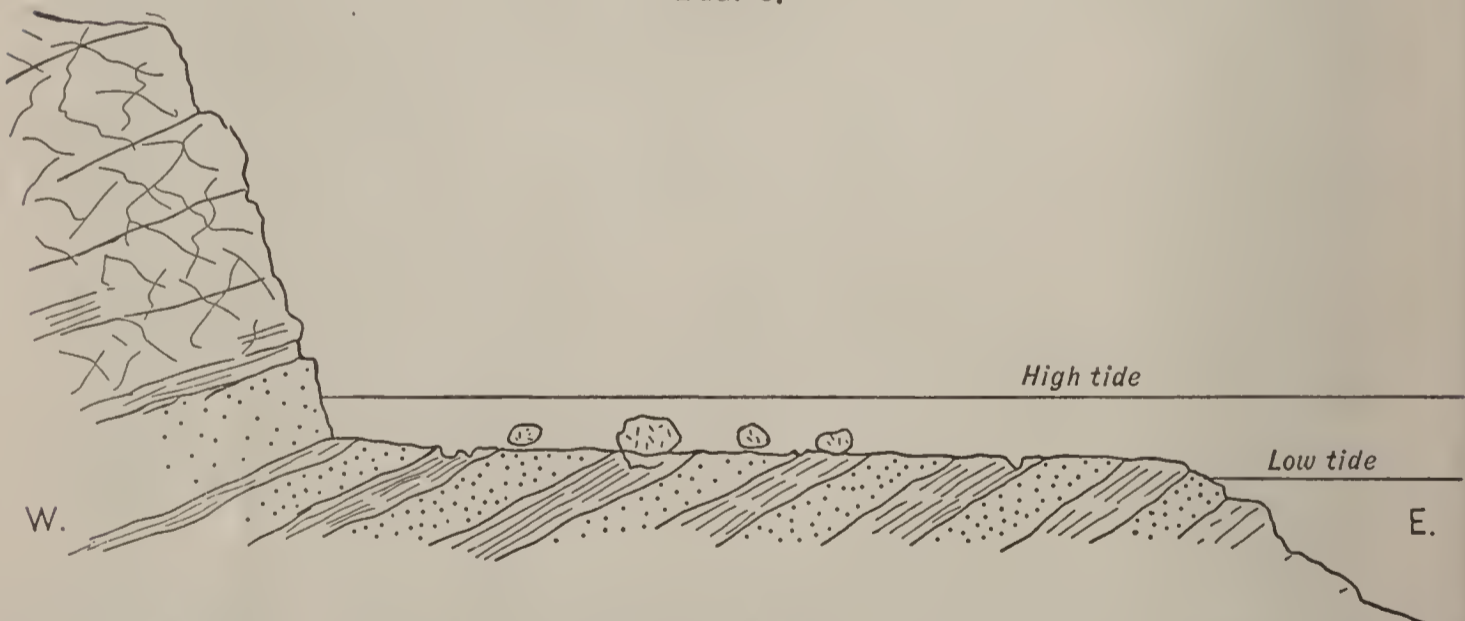
FIG. 7.



Section through Passo de Camaragibe, Showing the Shales Exposed Between Tides, and their Relation to the Mottled Beds in the Hills back of the Town.

prospected these shales some 10 or 12 years ago. Many of the shale beds contain large quantities of fragments of plants, so finely pulverized that no recognizable forms were found. The exposures in the bluffs here show in a satisfactory manner that the mottled and highly-colored beds exposed in the cliffs

FIG. 8.



Section at the Morro de Camaragibe, Showing Wave-Cut Shelf of Shales, with Boulders of Granite. Dip somewhat exaggerated.

along this coast are the weathered parts of the Eocene beds.

Fig. 4 is from a photograph taken from the wave-cut platform of shales on the seaward side of the hill. The beds shown in this picture have a marked dip, and the portions of the rock at the base of the hill are gray and unaffected by

the weather. Following the beds with the eye, one can trace many of the strata high up into the mottled and parti-colored beds that form the tops of the hills. To one near at hand, the transition from the unweathered to the weathered beds seems to be very gradual; but to one standing a hundred meters away from the face of the bluff there seems to be a well-defined line of demarkation between the gray beds below and the highly-colored ones above. This coloration affects all the rocks of the top of the bluff down to an elevation of about 4 or 5 meters above tide-level. In the observations made on the spot I find this note: "I see absolutely no difference between this cliff and hundreds of others I have set down as Tertiary."

The company that prospected this locality for oil-shales sank 6 pits south of the village of Barreira, one of which was 6 meters deep. The following are the determinations made by Mr. Boverton Redwood of the composition of the shales taken from the pits at this place:

Composition of the Camaragibe Shales.

Volatile. Per cent.	Non-volatile Combustible. Per cent.	Ash. Per cent.
30.55	9.45	60.0
24.8	4.3	70.9
27.1	12.2	60.7
25.5	2.2	72.3
7.8	2.9	89.3

Two kilometers south of the village of Barreira the shales form a wave-cut terrace, and the beds dip west at an angle of 10° . (See Fig. 5.)

Going south from this locality there are several kilometers of the red and mottled cliffs before one reaches the Barra de Santo Antonio. These cliffs are the beds above the oil-shales, or the weathered portions of the oil-shales themselves.

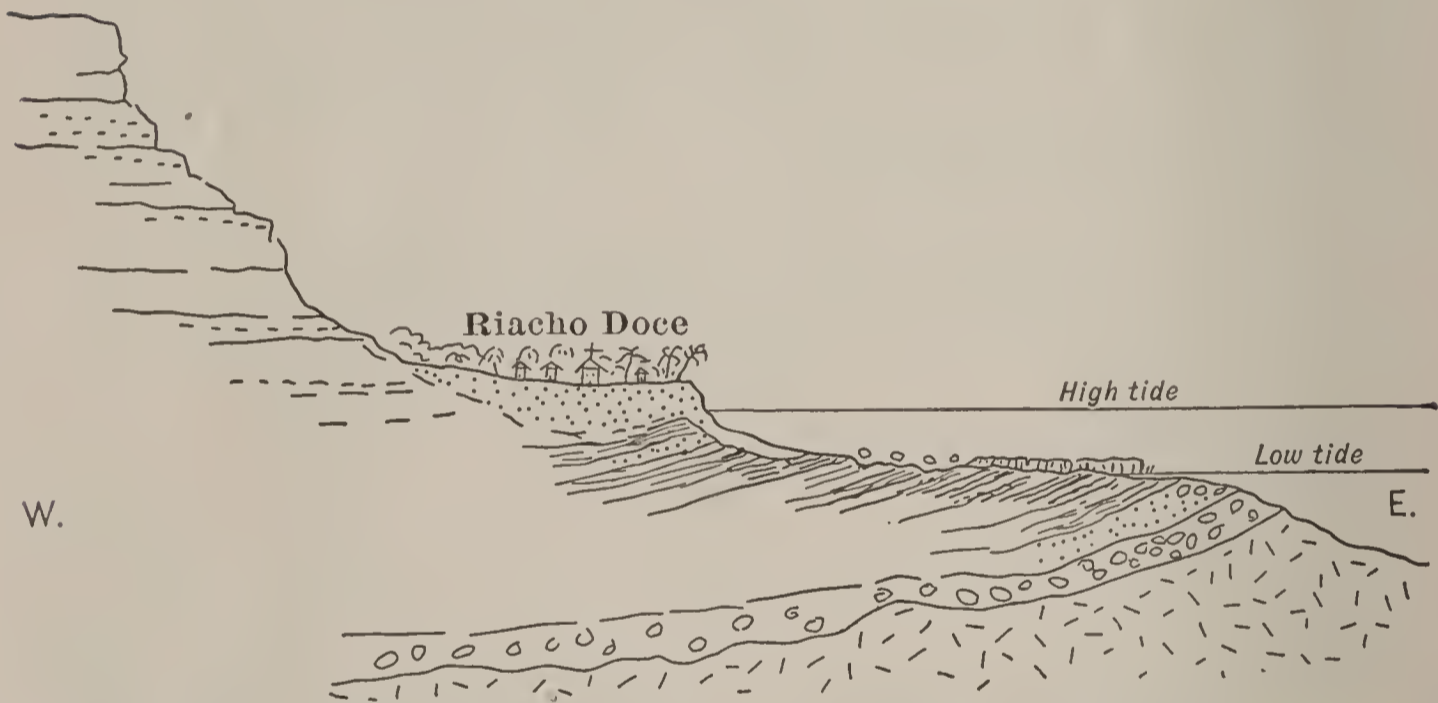
The bluffs are about 30 meters high, and the colors are variegated and most brilliant. Seen a distance, the colors seem to be due to the bedding of the rocks; but upon examination close at hand they are found to be due partly to structure and partly to weathering.

The next considerable exposures of the oil-shales south of Santo Antonio Grande are at Riacho Doce (S. lat. $9^{\circ} 36'$), and

between that stream and another small one known as Garça Torta.

The exposures at Riacho Doce are very much like the others mentioned above. Inland about half a kilometer from the beach is a steep-faced escarpment, 60 to 90 meters high, of highly colored beds; while on the beach itself are exposed shales, sandstones, and heavy conglomerates, containing large granite blocks. The dips taken on the beach at low tide vary considerably, showing that the rocks here have been much wrinkled. I noted also some faults and overthrusts. The general structure can best be shown by a section, such as is given in Fig. 9, which would answer for almost every one of the

FIG. 9.



Section at Riacho Doce, Showing the Relations of the Shales to the Conglomerates, and to the Cliffs West of the Village.

exposures seen. The heavy granite blocks indicate the near presence, at almost all of the exposures, of the granite which underlies them. The shales all overlie the heavy granite conglomerates.

The only fossils found in these rocks thus far are diatoms, plant-fragments and fish-remains. The diatoms so far as examined have no diagnostic value further than to show that the beds are of fresh-water origin, while the other plant-remains are so fragmentary as to be unrecognizable. The fish-remains have been kindly examined for me by Prof. F. A. Lucas of the U. S. National Museum, who finds them to belong to the genus *Diplomystus*—a genus already reported from the fresh-water

Eocene beds of Bahia,* where the fossils were collected by Mr. Joseph Mawson at Itacaranha, Plataforma, and Agua Comprida.

A section made across country from the coast inland at almost any point shows the same geology, with only local variations. In some places the shales are thicker; in others they are entirely wanting.

The same company that prospected the oil-shales south of the Rio Camaragibe has dug several pits near the beach at Riacho Doce also. Boverton Redwood found the shales from this place to be richer in oil than those of Camaragibe district. The following table is taken from his report upon them:†

Composition of the Riacho Doce Shales.

No.	Volatile. Per cent.	Non-Volatile Combustible. Per cent.	Ash. Per cent.
1	34.9	1.1	64.0
2	46.3	19.5	34.2
3	26.9	8.1	65.0
4	32.8	14.6	52.6
5	25.4	10.5	64.1

A further examination was made by Mr. Redwood of the richest of these shales (No. 2). This contained 4.7 per cent. of sulphur, and upon distillation yielded 44.73 gallons of crude oil and 19.58 gallons of ammoniacal water to the ton. Mr. Redwood says further, in regard to these oil-shales:

“The presence of sulphur would not, however, be a serious drawback, if the crude oil were used as a liquid fuel, or as a source of gas for illuminating purposes. One ton of such oil would, if properly burned, afford rather more heat than two tons of good steam coal, and from each gallon of oil about 90 cubic feet of 60-candle gas could be produced.

“As regards the quality of the crude oil, it should be remarked that results obtained on the laboratory-scale of working are less satisfactory than those yielded when the shale is distilled on the manufacturing-scale in retorts of suitable construction. The difference is far greater in the case of the ammoniacal liquor, and a yield of probably as much as four times the quantity of sulphate of ammonia may be reckoned upon.”

* “On two deep-bodied species of the clupeoid genus *Diplomystus*.” By A. Smith Woodward. *Annals and Magazine of Natural History*, Jan., 1895., pp. 1–2.
 “A Contribution to the Vertebrate Paleontology of Brazil.” By E. D. Cope. *Proc. Amer. Phil. Soc.*, Jan., 1886, xxiii, 3–4.

† *Report on the Riacho Doce and Camaragibe Shale Deposits on the Coast of Brazil, near Maceio.* By Boverton Redwood and William Topley. (London, 1891.)

The parti-colored beds follow the coast southward from Riacho Doce to the city of Maceio and beyond.

At Maceio the lighthouse stands upon the summit of this same Tertiary plateau. The beds exposed in and about the city are all more or less mottled, and along the line of the railway that runs westward between the lake and the hills these strata are cut at several places. No fossils were found in these rock either at Maceio or along the line of the Alagôas railway. At the Instituto Archeologico e Geographico Alagoano, Dr. Costa Leite, the Secretary, showed me two fossil fishes, said to have been found at Fernão Velho, 14 kilometers from Maceio. The rock containing these fossils is a limestone concretion closely resembling that in which the fossil fishes of Ceará are found. Although the rocks at the base of the hills at Fernão Velho are yellow, cream-colored, and gray, that is, not so highly colored as the beds further up the hills, I am disposed to think that no importance should be attached to the reported origin of these fossils. The Ceará fishes have been carried all over Brazil, as curiosities; and it is quite possible that these specimens came from the Ceará beds, and, through some accident, have appeared at Fernão Velho, or have been reported from there by mistake.

The Tertiary series is crossed almost at right angles by the Alagôas railway. About a kilometer and a half east of Utinga station gray shales like those of Riacho Doce are exposed by the side of the railway. At several places along the line between Fernão Velho and Albuquerque are heavy beds of water-worn crystalline rocks, which I take to be the basal conglomerates of the Tertiary series. One of these exposures is immediately east of Cachoeira, where the conglomerate bed is about 10 meters thick. At kilometer 33 between Cachoeira and Albuquerque, the next station, the sedimentary series ends, and the railway west of these runs over granites and other crystalline rocks only. One cannot fail to observe the similarity of all these sections across the Tertiary, so far as their main features are concerned, though this one from Maceio to Albuquerque is much longer than the others.

Fig. 10 is an ideal section on the Alagôas railway. South of Maceio the Eocene beds are exposed about the shores of Lagoa Manguaba, on Rio Jiquiá and on Rio Cururipe, but I

do not know the western limits of the series in that direction except near the Rio São Francisco.

Where the shales are exposed about the east side of the Bay of Bahia they bear the strongest possible resemblance to the oil-bearing shales of Alagôas. I am not aware of any examination or attempted working of the oil-shales near the city of Bahia or on the island of Itaparica. Turfa beds, however, are reported from the northern part of the island of Tinharé, 40 kilometers south of Bahia, and from Rio Itahípe in south latitude $14^{\circ} 44'$.*

The turfa beds on Rio Marahú, just south of the Bay of Camamú, and 115 kilometers south of the city of Bahia, have been known for many years, and the material has been much ~~less~~ talked about in Brazil. Hartt says of this turfa:†

FIG. 10.



Ideal Section from Maceio to Albuquerque along the Alagôas Railway (35 kilom.), Showing the Eocene Sediments Overlying the Crystalline Rocks.

“The material burned readily when ignited in a candle, affording an abundant smoky flame. . . . The material appears to be merely a mud impregnated with bitumen, and as it appears to exist in large quantities, it would be very valuable for gas-making or the manufacture of kerosene.”

Hartt quotes from Mr. Nicolay to the effect that the Camamú series does not appear to be in any way connected with that of Bahia or with those of the south, unless, as has been reported, turfa is found in the Rio de Contas. This series, it is said, may be designated as follows:

“In a basin of gneissose rocks are bituminous schists, sands and marls containing fossils (fresh-water?), and, it is presumable, above that, the turfa.”

* Henrique Prager in the *Revista do Instituto Geographico da Bahia*, vol. iv, p. 429.

† *Geology and Physical Geography of Brazil*. By Chas. Fred. Hartt. Boston, 1870. pp. 263-4. In quoting Hartt I have substituted *turfa*, the word used by the Brazilians, for the *turba* erroneously used by him.

Mr. Nicolay gives the following section of a shaft put down in the turfa district.*

Section of Shaft in Turfa District.

Ft.	In.				
20	0	.	.	.	Clayey and sandy shales.
3	0	.	.	.	Bituminous clay.
4	0	.	.	.	Ferruginous sandstone.
0	9	.	.	.	Shale with lignite.
0	9	.	.	.	Bituminous stratum.
1	6	.	.	.	Micaceous shale.
1	6	.	.	.	Shale with lignite and bitumen.
2	6	.	.	.	Shaly strata.
2	0	.	.	.	Bituminous strata.
12	0	.	.	.	Shaly rocks.
15	0	.	.	.	Bituminous strata.
45	0	.	.	.	Gneissose rocks.
<hr/>					
108 feet.					

Within a few years the oil-shale deposits of Marahú passed into the hands of a company controlling abundant means, and the most extravagant preparations were made to manufacture soap, paraffine, various kinds of oils, and I know not what. A town was built about the extensive factories; vast quantities of expensive machinery and supplies of every kind were imported from England; and the establishment started operations on a scale out of all proportion to the possibilities of the market. As might have been expected, the whole business collapsed within a few months, and much of the machinery is now rusting in the mud of the mangrove swamps, and the empty houses are being devoured by white ants. I believe this is the only effort that has been made to utilize the oil-bearing shales of Brazil. It is to be regretted that the business was not conducted in a more conservative manner, for after so colossal a failure other companies will hesitate to embark in any enterprise that attempts to utilize the oil-shales of Brazil.

It is worth noting, however, that the Brazilian government affords all the "protection" that any industry can reasonably ask in the way of high import-duties, and if it is found that these shales can be utilized, import-duties will be freely laid upon all the products that can be made from them.

* In giving this section I have altered the wording somewhat to express the evident meaning of Mr. Nicolay; he uses the words *schist* and *schistose* where *shale* and *shaly* are meant.

Résumé.—The oil-shales of the Brazilian coast are of Tertiary age, and the parti-colored beds exposed in the bluffs along that coast are for the most part the weathered portions of this same series. The Tertiary strata rest upon granites, gneisses and other crystalline rocks, with a bed of very coarse conglomerates forming the base of the series. The only known exception to this is in the Serra d'Itabaiana, in the State of Sergipe, where there is a series of Cretaceous beds with older beds between the granites and the Cretaceous, that appear to be Paleozoic, though no fossils have been found in them. The failure of the Maranhú Company was evidently due to extravagance and mismanagement, and cannot be regarded as a sufficient reason for condemning the oil-shales of Brazil as unworkable.

The total thickness of the Tertiary beds does not much exceed the total thickness of the mottled and parti-colored beds exposed on the coast—that is, from 30 to 90 meters (100 to 300 feet). This is shown by the fact that at many places the basal conglomerates are exposed, while at several points the crystalline rocks themselves are uncovered.

No oil-shales are now known in Pernambuco, Parahyba, Rio Grande do Norte, Sergipe or Espirito Santo; but they may be expected in any of those States within the Tertiary area.

POSTSCRIPT.

WHEN this paper was sent to the Secretary the oil-bearing beds referred to were set down as Cretaceous; and they are so classified in the pamphlet edition. This was done because the sediments of the Bahia basin had been accepted as Cretaceous without question since the publication of Hartt's book* in 1870. An examination of the paleontologic evidence, however, fails to reveal any satisfactory reason for this correlation. There are true Cretaceous beds in the State of Sergipe, just north of Bahia; but they are marine deposits, with a rich fossil fauna, and are not connected with the fresh-water beds of the Bahia basin. The marine sediments at Pernambuco, Maria Farinha, Itamaracá, Parahyba, Piabas, and other intermediate points along the coast, which were supposed to be Cretaceous,

* "Geology and Physical Geography of Brazil," by C. F. Hartt, Boston, 1870.

turn out to be Eocene Tertiary. Upon this subject I have asked the views of Dr. Gilbert D. Harris, of Cornell University, one of our best authorities on the Eocene, who writes:

"I can assure you most emphatically that neither in that work [Dr. White's report upon the Brazilian Mesozoic fossils], nor in our specimens [at Cornell University], nor in those I have seen in the United States National Museum from Maria Farinha, can I find a trace of any fauna other than the Midway Eocene."

An examination in 1899 of the geology of the coast, from Natal, State of Rio Grande do Norte, to the southern part of the State of Bahia, led me to the conclusion that the highly-colored beds of the coast (Pernambuco, Maria Farinha, Parahyba, Alagôas, etc.) were approximately of the same age as the fresh-water beds of the Bahia basin. If this is correct, then the Bahia basin is Eocene Tertiary, instead of Cretaceous. In calling them Tertiary, however, we are but going back to their earlier classification by Darwin* in 1841, by Pissis in 1842,† and to the age suggested by the *Entomostraca* described from Bahia by Professor T. Rupert in 1859.‡

The requisite corrections have been accordingly made in the text of the pamphlet edition of this paper, before the present republication of it.

* "Geological Observations," by Charles Darwin, 2d ed., p. 193, London, 1876.

† *Mém. sur la position géologique des terrains de la partie australe du Brésil, etc.*, par M. A. Pissis. (Présenté à l'Académie des Sciences, le 27 Juin, 1842.)

‡ *Quar. Jour. Geol. Soc.*, December 4, 1859, xvi., 266-268.

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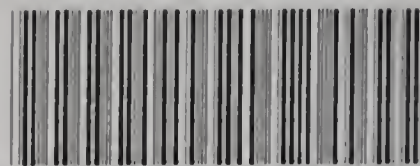
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