

# THE SEDIMENTARY BELT OF THE COAST OF BRAZIL

ORVILLE A. DERBY

Rio de Janeiro, Brazil

## INTRODUCTION.

- Location of the belt.
- Early references.
- Division into Cretaceous and Tertiary.
- Doubts regarding the division.

## DISCUSSION OF FOSSILIFEROUS LOCALITIES.

- The Sergipe district.
- The Pernambuco district.
- The Parahyba district.
- The Rio Grande do Norte district.
- The Pará district.
- The Bahia district.
- The Maranhú district.
- The Ilheos district.
- The Arolhos district.
- The Alagoas district.
- The interior districts.

## SUMMARY.

From a geological point of view the coast of Brazil can be divided into two principal sections according to the character of the highlands that either abut directly on the beach or at a moderate distance from it rise above the low costal plains, composed of sand flats and tidal- and fresh-water marshes, which are evidently of comparatively recent origin. In the southern section, extending from Cape Frio to the southern limit of the republic (this section might without impropriety be extended to the northern limit of the La Plata estuary) and embracing about one-third of the entire coast line, these highlands are composed of ancient metamorphic and eruptive rocks which are presumably of Archean or early Paleozoic age.<sup>1</sup>

<sup>1</sup> The only known exception is a comparatively short stretch of coast near the Porto de Torres, close to the northern boundary of the state of Rio Grande do Sul, where sandstones and eruptives of late Paleozoic or early Mesozoic age (Permian or Triassic, presumably the latter) abut on the coast.

In the northern section from Cape Frio to the southern mouth of the Amazonas (perhaps also the northern limit of Brazil) the highlands on or immediately back of the coast are, for the most part, composed of horizontal, or approximately horizontal, sedimentary beds of sandstone, shales, and clays, and more rarely of limestone. This coastal belt of sedimentary rocks is usually quite narrow, and nowhere does it extend more than a few scores of kilometers from the coast. In the comparatively few and short stretches of coast where it is lacking—as at Cape Santo Agostinho and near Tamandaré in the state of Pernambuco, Bahia and Ilheos in the state of Bahia, and several points on the coast of Espírito Santo and Rio de Janeiro between the mouth of the Rio Doce and Cape Frio—it appears probable that it has been denuded away rather than that it was originally lacking. Its elevation is usually under one hundred meters, but in one district at least (near Alagoinhas in the state of Bahia) it is known to rise to an elevation of about 400 meters.

Although frequent references to local occurrences of this sedimentary belt are to be found in earlier writers,<sup>1</sup> the first geological contribution of value relating to it was made in 1850 by Allport (5), who described the occurrence of fossiliferous beds at Bahia containing carbonized wood, cyprids, fish and reptile remains, and fresh-water mollusks that were referred to the Cretaceous age. The first general account of the belt was, however, given in 1870, by Hartt (4) who had personally traced it from Cape Frio to Pernambuco. After discriminating the recent consolidated beaches or stone reefs, which are so frequent on this coast and so liable to mislead the geologist, Hartt

<sup>1</sup> In 1811 Feldner, a German engineer in the employ of the Brazilian government, made explorations for coal in this belt, which were based on the occurrence of fragments of carbonized wood in the neighborhood of Bahia. Spix and Martius (1) briefly described some of its outcrops of Bahia and near Ilheos, considering those at the former place as of recent formation and those at the latter as equivalent to the European *Quadersandstein*. The identification in the latter case was evidently based solely on lithological resemblances, and in the former on fossils supposed to come from its rocks which were evidently confounded with those of the consolidated beach, or stone reef, later described by Hartt (4) and Branner (11)—a not unnatural error. Pissis (3) in 1842 mapped quite accurately the Bahia basin as extending down the coast to beyond Marahú, but, misled by shells from the above-mentioned consolidated beach, or more probably and less excusably by the shell-heaps on the island of Itaparica described by Rathbun (9) which he erroneously attributed to the section at Monserrate Point, he determined the formation as Tertiary.

referred the beds of the sedimentary belt proper to the Cretaceous and the Tertiary; the former represented by several detached and somewhat disturbed basins of the fossiliferous sandstones, shales, and limestones; the latter, by more widespread and continuous undisturbed (except perhaps by vertical movements) beds of soft sands and clays which clearly overlie the fossiliferous ones. The recognized fossiliferous (Cretaceous) basins were on the Abrolhos islands (with indeterminate plant and fish remains, and associated with eruptive rocks that are not known elsewhere in the belt), at Bahia and vicinity, near Maroim, Propriá, and Santa Luzia in the state of Sergipe, and, based on information that was afterward proved to be reliable, near Pernambuco and Parahyba. Of these basins, those of the Abrolhos and Bahia are of fresh (or brackish) water origin, the others being marine. From the Mariom district a number of typical Cretaceous fossils were obtained and described, but for the other localities no critical study of the fossils was made. Aside from lithological differences, Hartt's principal criterion for discriminating the Cretaceous from the Tertiary, which had not afforded fossils, was the somewhat disturbed position of the former while the beds referred to the latter are undisturbed.

In his expedition to the Amazonas in 1870, immediately after the publication of his book, Hartt dispatched two of his assistants, of whom the present writer was one, to Pernambuco to examine the fossiliferous locality reported near that place. The result was a small collection from the limestone rock of the small river Maria Farinha, a few miles north of the city, which were described by Mr. Rathbun (6), who referred them to the Cretaceous, without, however, finding any forms decidedly characteristic of that age. In 1875 Hartt personally visited the locality, accompanied, among others, by Dr. J. C. Branner, and secured a large and varied collection for the Geological Commission of Brazil, of which he was chief. In the following year Branner made a careful examination of the Sergipe basin, where a large collection was also made. In the same year the present writer obtained through a friend, a few blocks of highly fossiliferous limestone from the river Pirabas (by error this name was given as Piabas in the notes furnished to Dr. White (10) for his monograph on the Brazilian fossils), just south of the southern mouth of the Amazonas, containing a number of species

identical with those of the Pernambuco basin. Some years later he was shown fragments of fossiliferous limestone from near Mossoró, in the state of Rio Grande do Norte, that indicated the existence of another similar marine basin in that region; and recently Branner (12) has shown that a fresh-water formation similar to that of Bahia occurs along a considerable part of the coast of the state of Alagoas to the northward of the city of Maceio.<sup>1</sup>

Gonzaga de Campos (15) has recently shown that the fresh-water formation of Bahia extends southward along the coast to Marahú, where it is associated with marine beds containing a fauna similar to that of Sergipe, while unpublished observations by Ennes de Souza and the present writer show that another basin of the same character exists farther southward in the neighborhood of Ilheos.

The approximate interior limit of this sedimentary belt in the section from the state of Espirito Santo to Rio Grande do Norte has been given in several recent papers by Branner (12, 13, 14), but without attempting to discriminate the two members above indicated, which with our present knowledge is indeed an impossible task. The accompanying sketch map is in great part compiled from the various maps accompanying his papers. Throughout the section of the coast here represented to Cape St. Roque the higher lands lying back of the sedimentary belt are composed of very ancient metamorphic rocks, for the most part probably Archean, with their accompanying eruptives, though in a few places (Lower Jequetinhonha and Rio Pardo, Inhambupe near Bahia, and Serra de Itabaiana in Sergipe), unmetamorphosed beds, probably of early or middle Paleozoic age, are known to occur. Farther northward, in the states of Ceará, Piauí, Maranhão, and Pará, it is probable that they abut against or perhaps merge into, the high-lying beds of presumably Mesozoic age that form the table-topped hills and ridges so characteristic of considerable portions of those states. It is possible also that in the three latter states they will be found in close connection with late Paleozoic (Permo-Carboniferous) strata. Regarding these points, however, nothing is definitely known.

As above stated, the strata of this sedimentary belt fall on the

<sup>1</sup> The origin of the bituminous shale described by M. Bertrand (*Travaux et Mémoires de l'Université de Lille*, VI. Mem. 21, 1898) from Ceará is not certainly known.



upper series of soft sandy and clayey sediments that for the most part is without fossils and undisturbed by earth-movements of a character to affect the horizontality of the beds. So far as known to the writer, in no place have these two series been seen in actual juxtaposition, and an unconformability between them is rather assumed than actually proven. In each series there are beds, especially the sandy ones, that closely resemble each other, so that their discrimination is often a matter of doubt.

Following Allport, and Hartt, and the various paleontologists to whom their material was submitted, the lower series has been referred to the Cretaceous and the upper to the Tertiary. This classification has lately been questioned by Branner (12, 13, 14), who is inclined to refer to the Tertiary much that has hitherto been called Cretaceous. In his recent examination (the most complete and minute that has yet been made) of the coast from Natal, Rio Grande do Norte, to Caravellas in southern Bahia, he found that none of the physical characteristics (lithological character, coloring, inclination of the beds, etc.) can be depended upon for the discrimination of the two series, though he does not put in doubt their actual existence. In examining the paleontological evidence, he finds that unequivocal Cretaceous marine types have been found only in the Sergipe basin and at Parahyba, and that the general aspect of the faunas of the Pernambuco (Maria Farinha, Olinda, and Ponto das Pedras) and Pará basins is decidedly Tertiary rather than Cretaceous, and that the same is the case with the invertebrates of the Bahia fresh-water basin.<sup>1</sup>

These doubts of Dr. Branner are undoubtedly well founded, and in a recent excursion in the region about Bahia and Ilheus I fully sympathized with him in his difficulties in determining the dividing line between the upper and the lower series, and like him I referred to the latter a number of outcrops that formerly I should

<sup>1</sup> In the earlier of his papers embodying this view Branner refers these supposed Tertiary faunas to the Eocene, and quotes Dr. Gilbert D. Harris to the effect that the marine forms are probably not older than the Midway Eocene. In his latest paper (14), however, he mentions Cretaceous cephalopods from one of the Pernambuco localities, and quotes a letter from Dr. Smith Woodward to the effect that the vertebrates of the Bahia Basin suggest a doubt as between Jurassic and Cretaceous rather than between Cretaceous and Tertiary.

unhesitatingly have referred to the former. Such perplexities are not unknown in other regions where the difficulties of geological study are far less than in Brazil, and where the number of geological students to set about unraveling them is far greater. They are of great importance when attempts at areal geology are to be made, but for the region in question they may for the present be put aside. The really important questions for the moment are: Is the reputed division into an upper and a lower series a real one; and, if so, what part, if any, of the latter belongs to the Cretaceous?

Dr. Branner apparently does not put in doubt an affirmative answer to the first of these questions, and this, therefore, can be summarily put aside. In regard to the second he expresses serious doubts, which, however, seem to have varied from time to time; and this makes it desirable to discuss the question, locality by locality.

The fossiliferous beds of all the numerous Sergipe localities examined by him are unhesitatingly set down by Branner as Cretaceous, and the overlying non-fossiliferous ones are referred to the Tertiary, apparently on the same stratigraphical and topographical criteria that were used by Hartt and others. Some of the species are admitted by him to present a decidedly Jurassic aspect, and on referring to Dr. White's memoir we find that their number (nine) is somewhat in excess of that (seven) cited from the Pernambuco beds to establish their Tertiary age. Curiously enough, the beds containing the greater number of these species of Jurassic aspect are the same that carry the greater number of the species common to the Pernambuco and Pará beds which Branner would refer to the Tertiary, and the most decided Jurassic form of all (an Ammonite) is from a bed that is referred to the top rather than to the bottom of the series which is given as presenting a considerable vertical range. The most characteristic Cretaceous forms are the Ammonites, represented by fourteen species, of which only three occur in the three localities most abundant in other mollusks. If, therefore, by the chances of collection, only these localities had been examined, and if these few Ammonites had been overlooked, a doubt regarding the Sergipe basin as between Jurassic and Cretaceous might have been raised on the same ground as that raised between Cretaceous and Tertiary for the Pernambuco and Pará basins. Some of the other localities,

however, present a well-characterized Cretaceous fauna, which, as a whole, can be taken as typical of the marine Cretaceous of the Brazilian coast region, although it is to be noted that only five species are positively identified as occurring elsewhere.

In the Pernambuco district the principal locality is Maria Farinha, which has furnished seventy-three species of invertebrate fossils which, in the opinion of a number of prominent European and American paleontologists, present a more decidedly Tertiary than Cretaceous aspect. Of these species two are Echinoids, of which one is referred to a characteristic Cretaceous genus (*Toxaster*) and the other to a new genus, which is therefore unavailable for correlation. Of the seventy-one mollusks, the single Cephalopod and four of the sixty-eight Gasteropods are referred to species known outside of Brazil. These are: *Nautilus sowerbyanus* d'Orb., *Volutilithes radula* Sow., *Nerinea inaugurata* Stoliczka, *Euspira pagoda* Forbes, and *Turretella elicita* Stoliczka. Branner, on the basis of a study by Dr. Ralph Arnold, questions the identification of the second and fifth of this list, and cites the first two as characteristic Tertiary (*sic*) forms. Even if these doubts be admitted, there would still remain two Cretaceous against two Tertiary forms, whereas White gives four Cretaceous against no Tertiary forms. In any case, the evidence from known species is weak and may very properly be considered as inconclusive for either reference, though note should be taken of the presence of the characteristic Cretaceous genera *Toxaster* and *Nerinea*.

The evidence for Cretaceous age to be drawn from a comparison with the Sergipe fauna is somewhat stronger, though still less conclusive than could be desired. Six species, including one of those above mentioned (*Euspira pagoda*), are identified as common to the two regions. When it is considered that the Pernambuco and Pará faunas, whose correlation no one seems inclined to contest, have only twelve (or fifteen including three doubtful forms) species in common, this showing is not so unfavorable as might at first sight appear, and affords at least a stronger presumption in favor of the Cretaceous than any I have yet seen cited in favor of the Tertiary age.<sup>1</sup> This presumption is greatly strengthened by Branner's state-

<sup>1</sup> The list of Tertiary forms presented by Branner in his latest discussion of the subject (*The Stone Reefs of Brazil*, p. 15) includes, besides the two cited above given by

ment that he saw in the possession of a gentleman at Pernambuco specimens of Cephalopods that he calls Cretaceous, from the limestone of the island of Itamarica, close by Maria Farinha, and that he himself collected on the same island one of the most characteristic of the Maria Farinha fossil shells.<sup>†</sup> As no good reason has yet been presented (from my personal knowledge of the district I doubt that any can be presented, for presuming that there are two widely distinct fossiliferous formations in this vicinity, it is reasonable to assume that the lack of strongly characteristic Cretaceous types in the collection submitted to Dr. White for study was due to the chances of collecting, and that, if the island of Itamarica had been thoroughly explored, the general aspect of the Pernambuco fauna would have come out with much greater similarity to that of Sergipe. The other Pernambuco localities, Olinda and Ponta de Pedras, have been shown by Branner to be clearly correlated with that of Maria Farinha, and therefore need not be discussed here.

The Parahyba locality, being set down by Branner as unquestionably Cretaceous, need only be noted as another example of the collector's chance—in this case a particularly happy one, as only three recognizable fossils were obtained. It seems reasonably probable that this and the Pernambuco localities will eventually prove to be remnants of a single original basin.

The Mossoró or Apody basin, in the state of Rio Grande do Norte, is very imperfectly known. My recollection of the impression given several years ago by the casual inspection of fragments of limestone with imperfectly preserved fossils is that the fauna

White as characteristic Cretaceous forms, five others that have not as yet been found in other localities, either in Brazil or elsewhere, and belonging to genera which might be either Cretaceous or Tertiary.

<sup>†</sup> Another fossil from the same locality is referred to a species occurring in the fresh-water beds of Bahia—a rather singular combination, which is repeated at Ponta de Pedras, where this and still another characteristic fresh-water form are reported in association with a well-characterized marine fauna.

With reference to the discovery of Cephalopods (*Ammonites* ?) in the limestone of Itamarica, it may be remarked that this and Branner's discovery of fossils at Parahyba seem to confirm an instinctive feeling that I have long had, that wherever fossiliferous limestones are found in this sedimentary belt their fauna will be found to present a more characteristic Cretaceous aspect than that of the arenaceous and argillaceous beds. From several chance remarks it seems that Branner had the same impression.

would eventually prove to be similar to that of the Pernambuco beds.

The Pará basin (9, 10) has furnished fifty-two species of mollusks (Lamellibranchs and Gasteropods), and as these were obtained from a few loose blocks picked up at a single point at the mouth of the Rio Pirabas, it is to be presumed that the fauna is a much richer one. Indeed, Kraatz-Koschlau (16) states that corals, echinoids, and reptiles also occur, but as yet nothing is known of their character. With one doubtful exception (*Pteria linguiformis* Evans & Shumard), all of these species are as yet unknown outside of this Brazilian coast belt, although six are cited by Ortman (Branner, 14) as closely resembling Tertiary species from Patagonia. Twelve (or fifteen including three doubtful forms) are identified as occurring also at Maria Farinha, and seven (including two found also in the Pernambuco basin) in Sergipe. The general aspect of the fauna is stated by good authorities to be decidedly Tertiary, but, so far as I can learn, no distinctively Tertiary genera or species have been cited from it, whereas the occurrence of several species that are found also in Sergipe affords a reasonable presumption that, with more extensive collections, characteristic Cretaceous forms are liable to turn up. As already remarked, a chance collection made from certain of the Sergipe localities might readily have been equally equivocal in general aspect, owing to the deficiency of representatives of characteristic Cretaceous genera.

The evidence of a correlation between the Pará and the Pernambuco faunas is somewhat stronger, in a positive sense, than that of the Pará and Sergipe ones, due to the presence of a greater number of species in common; and is decidedly stronger in the absence of characteristic Cretaceous forms. This last argument for a Tertiary age will, however, break down if Branner's casual identification as Cretaceous of the Cephalopods seen at Pernambuco be accepted as final.

One of the most interesting localities of the whole sedimentary belt is that of Marahú, about 60 miles south of the city of Bahia, since here the marine and fresh-water fossiliferous members of the series are found in close juxtaposition. This locality will be discussed below, and only the marine fossils will be mentioned here.

A small collection brought from there by Gonzaga de Campos (15) represents an earthy limestone bed and one of calcareous mudstone, both being quite similar in appearance to some of the beds of the Sergipe basin. The limestone has afforded a pectinoid shell apparently identical with *Neithea quadricostata* Sow., which is a very characteristic form of the Sergipe limestone, and a small echinoid. The fossils from the mudstone represent species of *Cucullaea*, *Cardium*, *Corbula*, *Crassatella*, *Isocardia*, and *Tellina*, closely resembling, if not identical with, the representatives of these genera in the beds of similar material of the Sergipe basin. Although no critical comparison of the species could be made, there can be little doubt that the marine beds at Marahú represent substantially the same geological horizon as those about Maroim, in the state of Sergipe.

With regard to the fresh, or rather brackish, water deposits of the neighborhood of Bahia and other parts of the coast belt, Branner's doubts of the correctness of their reference to the Cretaceous seem to have been based, in the first instance, on the modern aspect of the mollusks that occur in them, being afterward somewhat modified, though not entirely withdrawn, by Woodward's statement, above referred to, that the vertebrate fossils are of Mesozoic types. In his latest reference to the subject (14) he suggests that possibly the vertebrate and molluscal elements of the fauna may belong to two distinct formations which have not been defined and separated from lack of proper stratigraphical and paleontological work, and notes appearances that suggest an unconformability between beds of two separate ages. Dr. I. C. White, who has also visited the typical locality at Monserrate Point, informs me that he also noted an appearance of unconformability that may possibly explain the apparent disaccord of the two fauna-elements.

In a recent visit to Bahia the typical section was examined with these doubts in mind. The stratification is very confused, layers of conglomerate, sandstone, and shale being mingled in a most perplexing manner and disturbed by a number of minor folds. The molluscan remains occur in thin layers and detached lenses of limestone, and in no case were they found in immediate association with the vertebrate remains. They were, however, found both above and below one of the lines that best simulates an unconformable contact,

and in one lens they were associated with plant remains, in the characteristic form of jet, which is of frequent occurrence in the layers containing fossil vertebrates. In short, the re-examination of the section with this point especially in view convinced me that it represents a geological unit. At the other locality, near Pojuca station, where mollusks occur, Mr. Mawson, a very competent and painstaking observer, reports (10) vertebrate and molluscan fossil from the same layer of only a few inches' thickness.

In view of these observations, the hypothesis of an admixture, through careless collecting, of fossils from two distinct formations may be safely put aside, and as the molluscan fauna is a comparatively characterless one, but little weight should be given to it as against the well-characterized Mesozoic forms of the vertebrate fauna.

The strictly fresh-water faunal elements of the Bahia basin are not sufficiently widespread, either in horizontal or vertical range, to characterize the formation as a whole, and it seems probable that, instead of being in a strict sense a fresh-water basin, it was rather an estuary or semi-detached arm of the sea in which deposits characteristic of fresh, brackish, and salt water might be laid down in different parts (or at different epochs in the same parts) and in close connection, or rapid alternation, with each other. A widespread and characteristic feature is the terrestrial elements represented by plant and dinosaurian remains. The former are represented by scattered fragments of carbonized wood, usually in the form of more or less pulverulent lignite in the sandstones and of jet in the shales.

Throughout the district the beds with recognizable fossils are overlain by soft sandstones, which, when they show plant remains or are distinctly inclined, have been referred to the Cretaceous, and in the contrary case to the Tertiary. As Branner has pointed out these criteria are unsafe ones, and doubtless some errors have been committed. My own impression is that in most cases these errors will prove to have been in the sense of placing the limit between Cretaceous and Tertiary too low down, rather than, as Branner seems to think, not low enough. The plant-bearing beds are often horizontal, or apparently so, over considerable areas, and if, as may readily happen, no plant remains are observed in such areas, they may erroneously be referred to the Tertiary. Indeed, it is by no means

certain that a horizontal position, even when general, is a sure index of Tertiary age, although this hypothesis has, for this region, a strong presumption in its favor. Thus far the only known fossils in the beds referred to this age are the leaves of *Ouriçanguinhas* from the high tableland (400 meters) back of Alagoinhas, which has been referred to the Pliocene (17, 18). As all the species are described as new, it is possible that they may prove to be somewhat older. Between this horizon and that of the fossiliferous beds discussed above there is almost certainly one (and there may be several) geological divisions to be established; but where the dividing line, or lines, between them—that is to say, between some horizon, probably not the extreme upper one, of the Cretaceous and a horizon of the upper Tertiary—is to be drawn must remain a subject for future study. Branner's protest against drawing it at the top of the known fossiliferous beds is a timely one, and his reserve in the matter of indicating another position for it is significative of the difficulties of the subject.

From Bahia southward for a considerable distance along the coast sedimentary beds similar to those about the bay have been reported from a number of points, so that it is tolerably certain that the formation is, or was formerly, continuous from Bahia to the region of Marahú which has recently been examined by Gonzaga de Campos (15), and more cursorily by myself. The former reports, in addition to the marine beds already mentioned, a sandstone with carbonized wood which he compares very properly with the similar strata about Bahia. The relative position of the marine and fresh-water beds could not be positively determined, but he was inclined to think that the former overlie the latter. Without being positive on the subject, it seems to me that the contrary will prove to be the case. These beds scarcely rise above tide-level and can be well seen only at extreme low tide, so that a proper examination of their numerous widely separated localities involves many days' labor. The soft part-colored sandstone most in evidence in the region is apparently without fossils and apparently horizontal, and for these reasons Campos referred it to the Tertiary, and assumed that the "turfa"<sup>1</sup> deposits

<sup>1</sup> The so-called turfa of Marahú is, in part, a peculiar light (sp. gr. 0.92), non-schistose, bituminous substance of earthy aspect and yellow color, containing about 70

that have made the place famous, and that were mainly under water at the time of his visit, also belong to that age. The occurrence of fossil leaves of modern aspect in the turfa seemed to him to confirm this view.

At the time of my visit a boring had been made into the turfa beds and, the pit excavated in them being freed from water, a number of interesting features that escaped Campos' observation could be seen. A gentle flexure has brought above tide-level, at the oil-works, a series of shale beds which are covered by heavy beds of soft sandstone that participated in the flexure. The shales were penetrated by the boring to the depth of about 30 meters, but, as the record was not at hand no accurate account of it can be given. At the top, above the beginning of the boring and immediately underlying the sandstone, is a bed, 4 meters thick, of marahuite containing fossil leaves. The boring penetrated clay shale with intercallations of rich oil-shale for a depth of about 20 meters, then a thin layer of sandstone, and stopped at the top of a second shale bed. As shown by fragments of the core that had been preserved, a lower layer of marahuite was met with somewhere in the midst of the shale series, which also carries fossil leaves, of which a small collection has been forwarded to Dr. David White. Cutting the shale beds and penetrating into the marahuite (where they become diffused as an asphaltic impregnation) are thin (1-2 centimeters) stringers of a coal-like substance which, so far as can be made out, is quite similar to the albertite of Nova Scotia. The marine beds of the district are reported by Campos at a distance of about 2 kilometers to the southward and eastward of this locality, and it seems to me tolerably certain that they underlie the shale beds. This

per cent. of hydrocarbons, 10 per cent. of fixed carbon, and 15-20 per cent. of ash which is peculiar in consisting in great part of alumina soluble in acids. Campos, who has made a careful study of it, showed that it has essentially the composition of the so-called Boghead coals which, as Bertrand has shown, consist of a fundamental yellow base with a secondary infiltration of asphalt. As employed at Marahú, the term also covers a dark-colored shaly material, which is a true oil shale in which the hydrocarbons are of a somewhat different composition and the earthy element of the ash is argillaceous. Both give a high yield of gas and oil, and in the attempts to work the material were used indiscriminately under the general name of turfa. Although the yellow material is perhaps a true boghead, it is sufficiently different from the ordinary type to merit a distinctive name, and it may be called Marahuite.

seems to be confirmed by an observation made by Campos about 8 kilometers to the northward, where he found a shale with carbonized wood overlying the marine limestone and underlying the Tertiary(?) sandstone. All things considered, I have little hesitation in identifying the shale series at Marahú (with the included marahuite) with the Cretaceous series at Bahia, and in including in it a large part, if not all, of the so-called Tertiary sandstone at the former place. It is to be hoped that other borings will soon be made in this interesting locality that will settle these doubtful points.

The metamorphic highlands lying back of the sedimentary belt at Marahú extends down to the coast a few kilometers to the south of the town and abut on the coast for a distance of about a score of kilometers. To the southward the sedimentary belt again appears in the neighborhood of the town of Ilheos. The shales and sandstones composing it closely resemble, both to the north and the south of the town which is on a point of crystalline rocks, those about the bay of Bahia, and this correlation is fully confirmed by a fine collection of fossils made some years ago by my friend Dr. Ennes de Souza, which I lately had an opportunity of examining. The characteristic features of this collection are the fossil ganoid fishes and fragments of jet, both of which are very characteristic of the formation at Bahia. Fortunately, arrangements have about been completed for having this collection studied by a competent paleontologist.

From Ilheos southward to near Victoria, in the state of Espirito Santo, the sedimentary belt is unbroken, except by valleys of denudation, but no outcrops that can be definitely referred to the Cretaceous are known, though it will not be surprising if much of the so-called Tertiary sandstone of this section of the coast should eventually prove to be of that age. In front of the southern portion of this section, at a distance of about 40 miles from the mainland, lie the Abrolhos islands, where Hartt (4) reports fossiliferous limestone, shale and sandstone which he compared with the strata about Bahia. No recognizable fossils were found, but plant impressions and markings resembling scales of teleostean fishes were observed. The beds are somewhat inclined and are overlain by a sheet of basaltic trap. Specimens of this rock collected by Dr. Branner have been examined by Dr. J. P. Iddings, who determined it to be an olivine-gabbro-

diabase. Similar rocks characterize a large region in southern Brazil, where they are presumed to be of Triassic age. As no signs of eruptive activity have been detected in the sedimentary belt of the mainland, it is possible that the Abrolhos outcrop may prove to be somewhat older than those above discussed. However this may be, it must be regarded as a remnant of the same costal sedimentary belt representing a considerable, perhaps the major, portion of it that has disappeared on the submerged border of the continent.

Branner (12) has described several outcrops of oil-shale on the coast of the state of Alagoas, in some of which he found plant remains, and in one a fossil fish identified with a species occurring at Bahia. There can be little doubt that these various deposits are to be correlated with those containing fossil plants and fishes at Bahia, Marahú, and Ilheos. Vague information relating to the northeast section of the coast between Pernambuco and the mouth of the Amazonas indicates that at various points similar deposits occur along it.

The information at present available regarding the unmetamorphosed geological formations of the coast of Brazil may be summarized as follows:

1. With the exception of comparatively rare and short sections, the whole coast from Cape Frio northward is formed, in its highland portions, by Mesozoic and Tertiary sediments, with which are associated eruptives of basic character at the Abrolhos islands.
2. In the southern section of the coast, from Cape Frio to the eastern shoulder of the continent at Cape St. Roque, these sedimentary rocks form only a narrow belt and abut against, or overlap, the margin of a shield-shaped mass of Archean(?) metamorphic and crystalline rocks, fringed in places (rarely along the Atlantic border region) by sharply inclined early Paleozoic strata. In the northern section, from Cape St. Roque northward to the mouth of the Amazonas, they in places extend far inland, occupying baylike indentations in the margin of the Archean (?) shield, or abut against older (?) Mesozoic (Ceará in the semicircle of sedimentary table-lands—Serras de Apody, Araripe, and Ibiapaba—that surround a minor shield in the central part of that state), or late Paleozoic (Piauhy, Maranhão, Pará, and northern Goyaz) strata that form the high

sedimentary table-lands of the Jaguaribe, São Francisco, Parahyba, coast rivers of Maranhão and Pará, and Araguaya-Tocantins basins.<sup>1</sup>

3. The oldest fossils known from this series present a preponderance of Cretaceous types, but with certain forms that standing alone would be referred to the Jurassic; the newest are of late Tertiary (Pliocene ?) types. The geological range is therefore from early(?) Cretaceous to Pliocene, thus embracing both Mesozoic and Tertiary strata.

4. Certain localities representing strata at or near the base of the series present faunas with a decidedly Tertiary aspect,<sup>2</sup> but with a small number of species that occur also in the typical Cretaceous beds. The geological horizon of the beds at these localities is therefore somewhat doubtful, but for the present the preponderance of evidence seems in favor of a Cretaceous age.

5. The typical fossiliferous Cretaceous beds are usually somewhat disturbed, whereas the typical Tertiary ones are undisturbed, except probably by vertical movements; and, in the absence of other evidence, this circumstance has been used as a criterion for discriminating the Mesozoic and Tertiary members of the series, but it is obviously an unsafe one. The assumption that the unconformability that doubtless exists is at the contact of the Cretaceous and Tertiary is a plausible one, but is unproven. The evidence of conformability or unconformability is frequently very obscure, and thus becomes practically valueless in rapid reconnaissance work.

Between the fossiliferous Cretaceous beds at the base of the series and the fossil leaf-bed near the top there is, in the Bahia section,

<sup>1</sup> These indentations are represented schematically by dotted lines on the map on p. 222. Cretaceous fossils are known from these table-lands from southern Ceará, eastern Piauí, and on the São Francisco below the great bend; and Permo-Carboniferous ones from the interior of Piauí, and on the Maranhão. The great bay embracing a part of the São Francisco valley follows quite closely a larger and older Eo-Paleozoic one that over a great part of that region occurred between the Archean (?) shield of Bahia and Eastern Minas Geraes, and a second (not entirely detached from the first) in Goyaz.

<sup>2</sup> Compared by Professor G. D. Harris, (14 p. 18) with the fauna of the Eocene beds at Midway, Ala. The resemblance is certainly a striking one, but, as above shown, its significance is greatly weakened by the recent discovery of a typical Cretaceous genus (Ammonites?) in the immediate vicinity of one of the localities affording this doubtful fauna, and presumably from a bed belonging to the same geological horizon.

a thickness of at least 200 meters (and probably considerable more) of strata that, thus far, have not afforded fossils, except unrecognizable fragments of carbonized wood in their lower part, so that there is no paleontological evidence as to where the division line should be drawn. At about 50 meters below the leaf-bed there is a change in the character of the rock, marked by a water horizon, which apparently indicates a break in the succession; but what its significance may be has not been determined. The beds below this horizon are somewhat more argillaceous than those above, and are more widespread, so that there is here an indication of unconformability by overlap. They are also more widespread than the beds below them that can be definitely assigned to the Cretaceous, but they are so like the upper arenaceous members of the latter series as to be inseparable from them without more study than has yet been given to the subject. These intermediate beds of the Bahia section may be presumed to represent the greater part of the so-called Tertiary of the costal region, and while there is a reasonable presumption that they will prove to belong to the early or middle parts of that age, it cannot be definitely proven that they are not upper Cretaceous.

6. The outlines, so far as they have been determined, of the various fossiliferous deposits of the costal region, and the character of their rocks and fossils, indicate that they were formed in estuaries, or partially closed litoral basins, in which marine, brackish, and fresh-water sediments might be laid down simultaneously in different parts; or alternately in the same parts. In view of this circumstance, much detailed study will be required to make out the details of the true succession of the different beds and their respective faunas. In the light of our present knowledge, the *apparent* succession is as follows, in ascending order:

*a)* A marine group, represented in Sergipe and at Marahú, well characterized by a Cretaceous molluscan fauna which in part shows Jurassic affinities.

*b)* An estuarine group, represented about Bahia (including Marahú), Ilheos, and the oil-shale localities of Alagoas, with a well-characterized Cretaceous vertebrate fauna, which also in part shows Jurassic affinities, land plants and reptiles, cyprids, and rarely fresh-water mollusks.

c) A marine group, represented in Pernambuco, Pará, Parahyba (?), and Rio Grande do Norte (?), with a molluscan fauna showing strong Tertiary affinities, but containing several representatives of the fauna of group No. 1.

Unconformability (?).

d) Soft particolored sandstones and clays without known fossils, that practically cover the whole marine belt from Espirito Santo to Pará.

e) Soft red sandstones with intercalated clay layers containing fossil leaves of Pliocene (?) age, represented in Bahia and Sergipe (?) in a limited area to the northward of the bay-of Bahia.

7. To the southward of Cape St. Roque the Cretaceous coast-line was not very different from the present one, but lay in places somewhat farther inland, and in others somewhat farther seaward on the submerged border of the continent.<sup>1</sup> Later (if the Tertiary (?) beds prove to be marine) the coast-line swung considerably farther inland. To the northward of Cape St. Roque the Cretaceous coast-line was much more different from the present one.

#### BIBLIOGRAPHY

1. SPIX and MARTIUS. *Reise in Brasilien*. (Munich, 1823-31.)
2. ESCHWEGE, W. L. *Beiträge zur Gebirgskunde Brasiliens*, pp. 387-95. (Berlin, 1832.)
3. PISSIS, A. Memoire sur la position géologique des terrains de la partie australe du Brésil etc." *Mémoires de l'Institut de France*, Vol. X, pp. 398, 399. (Paris, 1842.)
4. HARTT, C. F. *Geology and Physical Geography of Brazil*. (Boston, 1870.)
5. ALLPORT, S. "On the Discovery of Some Fossil Remains near Bahia in South America. *Quarterly Journal of the Geological Society*, Vol. XVI, pp. 263-66. (London, 1850.)
6. RATHBUN, RICHARD. "Preliminary Report on the Cretaceous Lamelli-branches Collected in the Vicinity of Pernambuco, Brazil, etc." *Proceedings of the Boston Society of Natural History*, pp. 241-56. (Boston, 1875.)

<sup>1</sup> The absence of late Paleozoic and early Mesozoic strata in the coastal region of this section, together with the occurrence of Mesozoic (?) beds at the Abrolhos near the margin of the submerged continental border, suggests the hypothesis that from early Paleozoic to middle or late Mesozoic times the land area extended to near this margin, and that a transgression then occurred which established marine and estuarine conditions over a broad belt of which only remnants now remain.

7. RATHBUN, RICHARD. "Observações sobre á geologia: Aspecto da Ilha de Itaparica na Bahia de Todos os Santos." *Archivos do Museu Nacional*, Vol. III, pp. 159-83. (Rio de Janeiro, 1878.)
8. DERBY, O. A. "A bacia cretacea da Bahia de Todos os Santos." *Archivos do Museu Nacional*, Vol. III, pp. 135-58. (Rio de Janeiro, 1878.)
9. — "A Contribution to the Geology of the Lower Amazonas." *Proceedings of the American Philosophical Society*, Vol. XVIII, pp. 155-78. (Philadelphia, 1880.) *Archivos do Museu Nacional*, Vol. II. (Rio de Janeiro, 1877.)
10. WHITE, C. A. "Contribuições á palaeontologia do Brazil." *Archivos do Museu Nacional*, Vol. VII. (Rio de Janeiro, 1887.)
11. BRANNER, J. C. "Cretaceous and Tertiary Geology of the Sergipe-Alagoas Basin of Brazil." *Transactions of the American Philosophical Society*, Vol. XVI, pp. 369-434. (Philadelphia, 1889.)
12. — "The Oil-bearing Shales of the Coast of Brazil." *Transactions of the American Institute of Mining Engineers*, Vol. XXX, pp. 537-54. (New York, 1901.)
13. — "Geology of the Northeast Coast of Brazil." *Bulletin of the Geological Society of America*, Vol. VIII, pp. 41-90. (Rochester, 1901.)
14. — "The Stone Reefs of Brazil." *Bulletin of the Museum of Comparative Zoölogy*, Vol. XLIV, pp. 8-32. (Cambridge, 1904.)
15. CAMPOS, L. F. GONZAGA DE. *Reconhecimento geologico e estudo das substancias bitunino-sas de bacia de Rio Marahu, Estado da Bahia*. (São Paulo, 1902.)
16. KRAATZ-KOLSCHLAU, K. V. und HUBER, J. "Zwischen Ocean und Guama." *Memorias do Museu Paraense*, Vol. II. (Pará, 1900.)
17. KRASSER, F. "Konstantin von Ettinhaussens Studien über die fossile Flora von Ouriçanga, Brazilien." *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften*, Vol. CXII, pp. 1-9. (Vienna, 1903.)
18. BENNET, E. DE. "Contribution à la flore pliocène de la province da Bahia (Brésil)." *Bulletin du Musée de l'histoire naturelle*, pp. 510-12. (Paris, 1905.)