THE STRATIGRAPHY OF THE POTOMAC GROUP IN MARYLAND.[1]

CONTENTS.

INTRODUCTION.

The recent controversy regarding the age of the Potomac formation, which has been precipitated as the result of the conflicting evidence presented by the palæobotanists and the vertebrate palæontologists, suggests the necessity of determining the

[1] The investigations have been carried on under the auspices of the Maryland Geological Survey and the Woman's College of Baltimore.

sequence of the Potomac deposits, together with the horizons from which the fossils have been derived, if the questions at issue are to be finally settled. The authors of this paper have been engaged upon the investigation of these relations during the past year, and believe that much of the difference of opinion is due to the lack of knowledge regarding the stratigraphic position of the beds which have yielded the various plant and animal remains. They desire at the outset, however, to express their obligations to their predecessors in the field, without the results of whose work their own investigations would have been seriously retarded, if not rendered entirely abortive. The great volume of data which the palæobotanists have presented to us during the past few years, and the more meager evidence of the vertebrate palæontologists, have been of signal service in interpreting the stratigraphy of the Potomac formation. It is a pleasure to witness to the splendid achievements of Professors Ward, Fontaine, and Newberry, in the study of the fossil floras, and of Professor Marsh in extricating from poorly fossiliferous beds the important vertebrate remains which he states he has in store for us. The junior author of this paper has also made collections of the flora and fauna which will be discussed by him in a subsequent contribution.

The conclusions reached by those who have studied these two classes of organic remains may be briefly stated as follows: The palæobotanists, largely upon the discovery of dicotyledonous types of plant life, claim the Cretaceous age of the Potomac group, while Professor Marsh upon the evidence of the vertebrate remains, particularly of the Dinosauria, is as firmly convinced of the Jurassic age of the deposits.

It seems to the authors that the difficulty lies in the fact that each side has assumed too largely the unity of the Potomac group and has not sufficiently regarded the possibility of its representing more than a single formation. A marked exception to this is found in the late work of Professor Ward who has discovered several distinct stages in the fossil floras—a discrimination which is of much importance in determining the

stratigraphic relations of the higher portions of the Potomac deposits.

It is the conclusion of the authors, founded upon a detailed stratigraphic study of the Potomac group, that all the beds which have afforded dicotyledonous types of plant life are above those which have yielded the vertebrate remains, and, moreover, that a marked unconformity exists between the two series of deposits. The evidence for this conclusion will be brought out in the succeeding pages.

DESCRIPTION OF THE DEPOSITS.

The several formations into which the larger unit of the Potomac group has been divided are as follows:

Lower Cretaceous - -	(Raritan Formation) (Patapsco ")	Potomac
Upper Jurassic (?) - -	(Arundel ") (Patuxent ")	Group

THE PATUXENT FORMATION.

Name and areal distribution. — The Patuxent formation receives its name from the Patuxent River in the basin of which deposits of this horizon are found typically developed. As the basal member of the Potomac group the Patuxent formation occupies a position near the landward margin of the Coastal Plain, although the higher members of the series frequently overlap it and are found resting upon the crystalline rocks of the Piedmont Plateau to the westward. The Patuxent formation has been traced as a narrow, broken belt from Cecil county across Harford, Baltimore, Anne Arundel, and Prince George's counties to the borders of the District of Columbia.

Leading features of the deposits. — The deposits of the Patuxent formation consist mainly of sand, at times quite pure and gritty, but generally containing a considerable amount of kaolinized feldspar, producing a clearly defined arkose. Clay balls are at times distributed in considerable numbers through the arenaceous beds, which in places contain lenses of gravel, sometimes

with cobble stones. Frequently the sands pass over into sandy clays and these in turn into more highly argillaceous materials which are commonly of light color, but at times become lead-colored, brown or red, and not unlike the variegated clays of the Patapsco formation. Those arenaceous materials which lie adjacent to ferruginous clays are not infrequently indurated by hydrous oxides of iron, forming ferruginous sandstone. The more arenaceous deposits are commonly cross-bedded, and the whole formation gives evidence of rapid deposition.

The strike of the beds is in a general north-northeast south-southwest direction, corresponding to the eastern border of the Piedmont Plateau. The dip of the strata, so far as can be determined from the narrow exposures which have been obtained, is probably between thirty and forty feet to the mile. The irregular character of the sedimentation, together with the small areal extent of the deposits, renders it very difficult to make any satisfactory measurement.

The thickness of the Patuxent formation is rather variable, but, so far as has been determined, has not been found to exceed 150 feet, although it may be considerably thicker at some points.

Characteristic local sections.—The deposits of the Patuxent formation outcrop, among other places, in the valley of the Little and Big Patuxent rivers, having been reached in the iron-ore openings which have been made at many points in the overlying Arundel formation. An excellent section is found in a cutting on the Baltimore and Ohio Railroad a short distance to the south of Contee. At the latter locality the coarse gravelly phase of the formation is well developed, and is unconformably overlain by the iron-ore clays of the Arundel formation. At the southern end of the cut the gravels have become cemented near the contact with the Arundel into a considerable ledge of conglomerate, by the leaching into them of the hydrous oxide of iron from the overlying deposits.

One of the most comprehensive sections of the Patuxent formation is at School House Hill, Baltimore county, about three-quarters of a mile northwest of Lansdowne on the Baltimore and

Ohio Railroad, where a gulch, known as "Deep Ditch," on the southern side of the hill, has opened up one of the finest sections of the Potomac group. The Patuxent, Arundel, and Patapsco

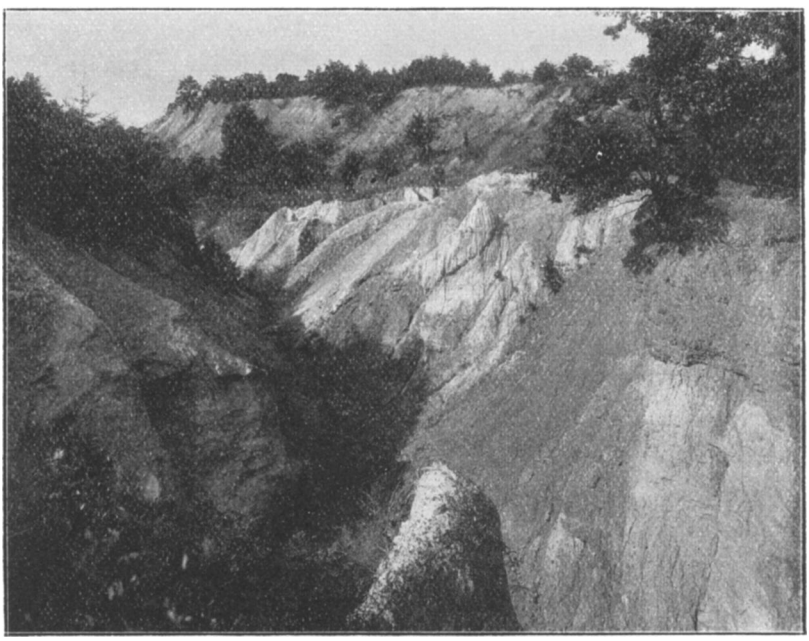

FIG. 1. View at School House Hill, Baltimore County, showing Patuxent sands overlain by Arundel clays.

formations are all exposed at this locality. The section is as follows:

SECTION AT SCHOOL HOUSE HILL, BALTIMORE COUNTY.

Patapsco.	Argillaceous sands more or less iron-stained, with variegated clays, and with ferruginous crusts; ash-colored, lignitic and somewhat indurated toward the base; silicified coniferous and cycacean trunks. - - - - -	10 ft.
Arundel.	Slightly indurated, ferruginous ledge containing abundant impressions of monocotyledonous plants. - - -	1 ft.
	Drab-colored clays, with beds of lignite, containing "brown" and "white ore," exhibiting impressions of ferns; dinosaurian teeth; ferruginous ledge at base. - - -	50 ft.

Patuxent.	Compact, yellowish, reddish, and variegated sands, locally carbonaceous; brown clays containing flakes of iron ore (hydrous oxide); lead-colored clays with fragmentary plant remains; ferruginous ledge containing pipe ore. - -	30 ft
	Compact jointed clays of great variety of color, red, lilac, and white predominating; "paint rock" and lenses of coarse gravel containing balls of clay and silicified coniferous wood, passing into - - - - - - -	20 ft
	Cross-bedded sand, slightly carbonaceous - - -	10 ft
	Total thickness, - - - - - -	121 ft

The slope of the hill is thickly covered with a wash composed of highly ferruginous sand charged with broken crusts of ironstone.

Another section of much interest is found near Federal Hill Baltimore city, where the Patuxent sands are apparently directly overlain by the Patapsco formation, lenses of the Arundel formation having been observed occurring in their proper stratigraphic position in the immediate vicinity. The section at Federal Hill, somewhat generalized, is as follows:

SECTION NEAR FEDERAL HILL, BALTIMORE CITY.

Raritan.	Sand and ferruginous sandstone containing silicified coniferous wood - - - - - - -	5 ft. 0 in
	Carbonaceous clays containing flakes of "white ore"	1 ft. 4 in
Patapsco.	Variegated clays with ironstone crusts - - -	34 ft. 6 in
	"Short" blue slickensides clay with logs of lignite and occasional fern impressions - - -	7 ft. 6 in.
	Fossiliferous "slaty clay," with ferns, cycads, conifers, monocotyledons and dicotyledons - - -	7 ft. 10 in.
	Indurated ferruginous layer containing "paint rock"	0 ft. 6 in.
Arundel.	Represented in immediate vicinity by lenses of lignitic clay with nodules of "white ore" and its derivatives - - - - - - - -	0 ft. 0 in
Patuxent.	White sand - - - - - - - -	7 ft. 0 in.
	Coarse sand with clay-balls - - - - -	4 ft. 0 in.
	White clay - - - - - - - -	5 ft. 0 in.
	Indurated gravel - - - - - - - -	4 ft. 0 in.
	Total thickness - - - - -	76 ft. 8 in.

Many other occurrences of the Patuxent formation might be cited both to the north and south of Baltimore, but enough have already been given to show its character and relations.

Fossils.—Very few traces of organic remains have as yet been found in the Patuxent formation. Those which have been obtained consist of lignetized coniferous wood, and various indeterminable vegetable fragments, among which no traces of dicotyledonous forms have been observed. A silicified coniferous trunk has been found *in situ* at School House Hill. One cycad trunk is also reported to have been seen in place in these beds. No animal remains have yet been with certainty detected.

THE ARUNDEL FORMATION.

Name and areal distribution.—The Arundel formation receives its name from Anne Arundel county where the deposits of this horizon are well developed. It has been traced as a broken belt all the way from Cecil county to the borders of the District of Columbia, and occurs as long narrow belts that extend in a general northwest-southeast direction forming a low angle with the border of the Piedmont Plateau.

Leading features of the deposits.—The deposits consist of a series of large and small lenses of iron ore-bearing clays which occupy ancient depressions in the surface of the Patuxent formation. These clays as most typically developed ("blue charcoal clays" of the miners) are drab colored, tough, and frequently highly carbonaceous, lignitized trunks of trees and limbs lying horizontally strongly compressed and frequently charged with or enclosed by carbonate and sulphide of iron. Sometimes these trunks are encountered in an upright position, with their larger roots still intact. Scattered through the dark clays are vast quantities of nodules of iron carbonate, at times reaching many tons in weight, and known to the miners as "white ore," "hone ore" or "steel ore." In the upper portions of the formation which have been exposed to atmospheric influences the carbonate ores have sometimes to considerable depth changed

to hydrous oxides of iron, which the miners recognize under the name of "brown" or "red" ore. Under these conditions also the originally drab-colored clays containing the carbonate

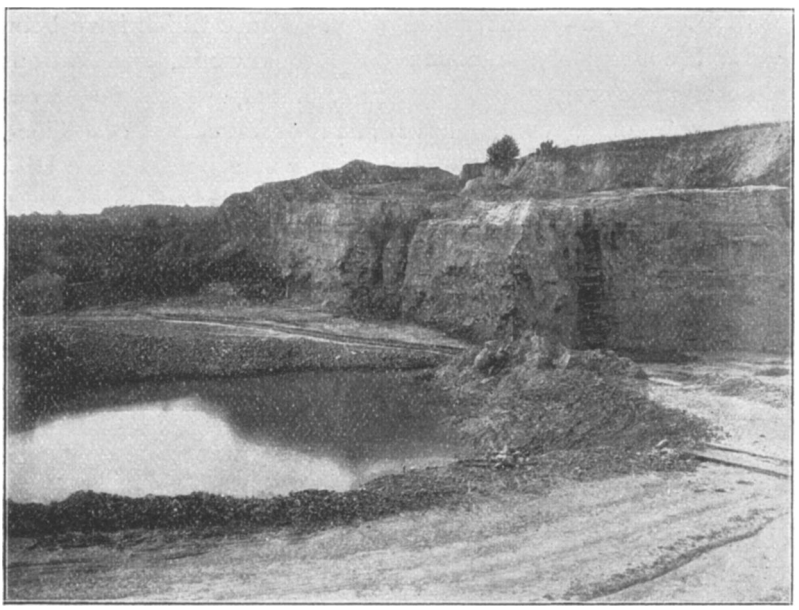

FIG. 2. Section at Reynold's Mine, Anne Arundel County, showing Arundel clays overlain by Patapsco formation.

ores have suffered a like chemical change, resulting in red or variegated clays. Where these clays chance to contain but little lignite the iron ore may consist almost entirely of these oxides.

The peculiar relations which the Arundel formation presents to the other members of the Potomac group render it difficult to say much regarding the strike and dip of the deposits, although the fact that they lie exposed in depressions upon the surface of the Patuxent formation renders it probable that these features do not differ materially from that observed in the other formations.

The lenses vary greatly in thickness, and from their character are at times lacking in portions of the country. The esti-

mates which were made of the thickness of the largest lenses observed render it probable that they attain at least 125 feet.

Characteristic local sections.— One of the best sections is found at Reynold's Mine on Piney Run, Anne Arundel county, one mile south of Hanover. It occurs on the western flank of the so-called "Elk Ridge" in a heavy lense constituting its axis and largely conditioning its existence. The section at Reynold's Mine is as follows:

SECTION AT REYNOLD'S MINE, ANNE ARUNDEL COUNTY.

Raritan.	White and light brown sand and gravel containing crusts of iron-stone	10 ft. 0 in.
Patapsco.	White, varigated argillaceous sands, "fuller's earth," clay and paint clay, with paint rock at the base; silicified coniferous and cycadean trunks.	10 ft. 0 in.
	Ferruginous ledge, more or less conglomeritic	0 ft. 3 in.
Arundel.	Drab colored compact laminated clays containing beds of lignite and bearing fern impressions; nodules, flakes and ledges of "white ore," slightly plant bearing	70+ ft.
	Total thickness	90 ft. 3 in.

Another important section is found at Muirkirk, Prince George's county, where also the iron ore clays have been extensively worked for many years. The Muirkirk section exposed at the "Old Blue Bank" on the Tyson estate is as follows:

SECTION OF "OLD BLUE BANK" MUIRKIRK, PRINCE GEORGE'S COUNTY.

Raritan.	Sandy gravel	4 ft.
Patapsco.	Mottled gravelly loam; silicified coniferous and cycadean trunks	12 ft.
Arundel.	Massive blue clay containing "white ore;" bones of Dinusauria at base	20 ft.
	Highly lignitic lens with "charcoal ore"	2 ft.
	Tough, "dry," blue clay with "white ore"	15 ft
Patuxent.	White sand	10+ ft.
	Total thickness	63 ft.

FIG. 3. Arundel formation showing nodules of "white ore" at Reynold's Mine, Anne Arundel County.

Many other characteristic local sections might be given, since the Arundel formation has been opened at numerous points for iron ore. Lenses have been observed among other places at the head of Elk River neck in Cecil county, in the vicinity of Joppa, Harford county, on Stemmers Run, Baltimore county, at Locust Point, Baltimore city, and at numerous localities in Anne Arundel and Prince George's counties.

Fossils.—Animal and plant remains have been observed at several localities in the Arundel formation. The Muirkirk area has afforded much the largest number. It was in this section that the vertebrate and cycadean remains of the Potomac group were first discovered by Mr. Philip T. Tyson. Later Professor O. C. Marsh of New Haven made extensive collections at this locality and upon this material based his conclusions regarding the age of the Potomac group. The vertebrate fossils consist largely of Dinosauria.

The plant fossils consist of ferns, conifers and monocotyledons. No dicotyledonous forms have yet been recognized.

THE PATAPSCO FORMATION.

Name and areal distribution.—The Patapsco formation is so called from its typical occurrence in the valley of the Patapsco River. It extends entirely across the state from the Delaware border to the Potomac River, and throughout this distance is one of the most important members of the Potomac group. It has a much larger areal extent than either of the two formations before described, and in places overlaps them, resting directly upon the crystalline rocks of the Piedmont Plateau.

Leading features of the deposits.—The deposits of the Patapsco formation consist chiefly of highly colored and variegated clays which grade over into lighter colored sands and clays, while sandy lenses of coarser materials are sometimes interstratified, which are occasionally indurated and at times form "pipe

ore." The clays are in places dark colored, massive and more or less lignitic. At times they are laminated ("slaty") and bear large numbers of leaf impressions. Fossiliferous flakes and nodules of "white" and "red ore" also occasionally occur. The sands sometimes contain much decomposed feldspar, and rounded lumps of clay are also found. The sands are frequently cross-bedded and give evidence of rapid deposition. Workable beds of "paint rock," as the highly ferruginous clays are termed, are found at many points, usually near the base of the formation.

The strike of the formation has a general north-northeast south-southwest direction, following the eastern margin of the Piedmont Plateau. The dip of the beds is somewhat less than that of the underlying formations, the deposits of the Patapsco formation transgressing the older strata, and as a result often come to lie directly upon the crystalline rocks to the westward.

A very marked unconformity is found between the deposits of the Patapsco and underlying formations. The thickness of the formation is estimated to reach fully 200 feet.

Characteristic local sections.—In addition to the several characteristic sections which have been already given, in which deposits of the Patapsco formation are found represented, the highly important locality of Cedar Hill in the area of Timber Neck in Anne Arundel county is also described. The section is on Licking Run one mile southwest of Hanover and is as follows:

SECTION AT CEDAR HILL, ANNE ARUNDEL COUNTY.

Raritan.	Reddish sands, somewhat gravelly, containing "pipe ore"	12 ft.
Patapsco.	White, red and brown sands, more or less argillaceous, containing clay pellets - - - - - -	20 ft.
Arundel.	Drab colored pyritous clays with beds of lignite; pellets, nodules and flakes of carbonate of iron ("white ore")	100 ft.
	White clay (in bed of Licking Run) - - - - -	5 ft.
	Total thickness - - - - - -	137 ft.

Another interesting section is found on the opposite side of Licking Run in Reynold's "Spring Drain" mine, where the basal member of the Patapsco formation consists of a ledge of

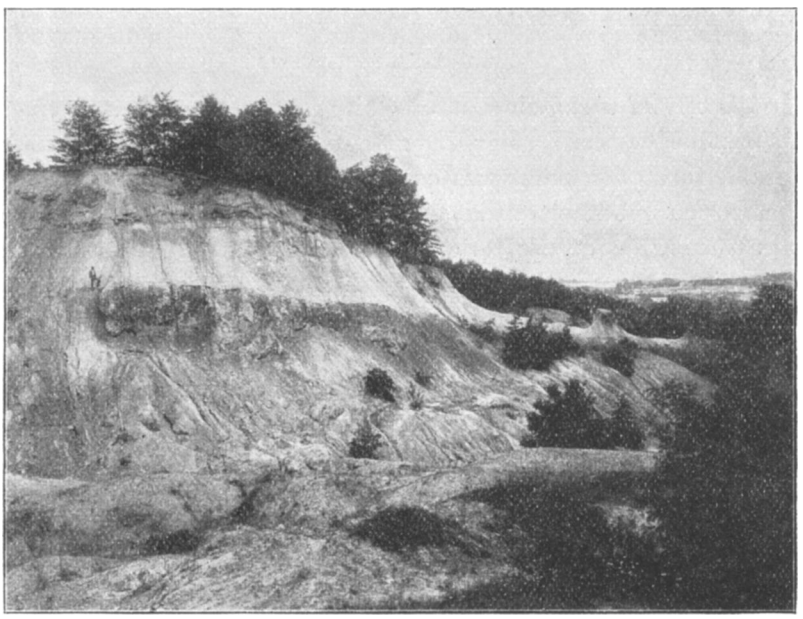

FIG. 4. View of Timber Neck, Anne Arundel County, showing Arundel, Patapsco, and Raritan formations.

ferruginous conglomerate and is found lying unconformably upon the Arundel iron ore clays below. Innumerable sections of the Patapsco deposits are found in other mines and along the streams, railroads, and highways which cross this region.

Fossils.—The fossils which have been found in the Patapsco formation consist chiefly of plant remains. A few poorly preserved molluscan shells have been observed but no study has yet been given to them. No dinosaurian remains have yet been with certainty detected.

The plant remains consist mainly of ferns, cycads, conifers, monocotyledons and dicotyledons. The dicotyledonous forms are not uncommon and according to Professor Lester F. Ward

who has made a very exhaustive study of the flora from this horizon, represent among their number a few archaic types, while others approach quite closely to modern types of vegetation.

THE RARITAN FORMATION.

Name and areal distribution.—The Raritan formation receives its name from the Raritan Bay, New Jersey, where the deposits of this formation are typically developed. The name was given by the senior author of this paper in the annual report of the state geologist of New Jersey for 1892 although the term Raritan clays had been somewhat loosely used for deposits of this age by earlier writers.

The Raritan formation extends as a constantly narrowing belt from northern New Jersey into Maryland and disappears by the transgression of the upper Creteaceous formations near the borders of the District of Columbia.

Leading features of the deposits.—The deposits of the Raritan formation consist of sands and clays, the former largely predominating in the upper portion of the formation. The sands are frequently very pure and white but at times, especially in the lower portion of the formation are more or less colored and indurated by hydrous oxide of iron which produces the characteristic tube-like structure which is known as "pipe ore.' The indurated beds are well exhibited at Rocky and Stony creeks on the south side of the Patapsco River, and at White Rocks in the immediate vicinity. The latter locality afforded the name of "Albirupean" which was applied by Professor Uhler to the upper portions of the Potomac group.

The clays are generally of very light color but at times become dark colored in the leaf-bearing zones. Beds of brown, black or earthy lignite, containing much pyrites, and occasionally amber (Cape Sable, Magothy River), have been observed at a few points. The clays are generally more or less arenaceous and grade over into the sandy deposits which largely characterize this formation.

The strike of the beds is in a generally north-northeast to south-southwest direction, corresponding to the Patapsco formation already described. The dip of the strata is probably

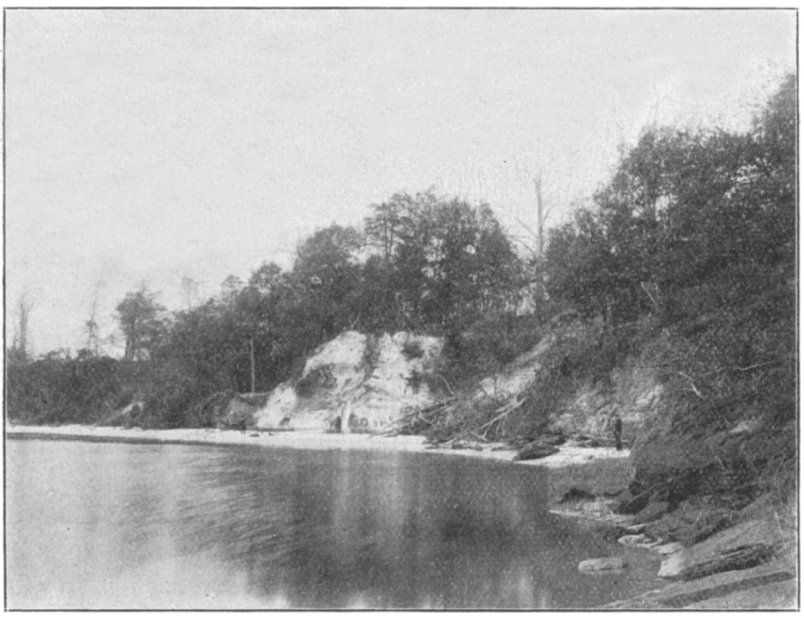

FIG. 5. Section of Raritan formation near Rocky Point above Round Bay, Severn River, Anne Arundel County, showing hard sandstone ledges at the right and white cross-bedded sands in the center.

slightly less than that of the underlying formation, and a slight transgression is noticeable to the northward.

The thickness of the Raritan formation in central Maryland is probably not far from 500 feet. It declines in thickness gradually to the southward where it finally disappears near the limits of the District of Columbia.

Characteristic local sections.—Very characteristic sections of the Raritan formation are shown in the bluffs of the Severn River in the vicinity and about Round Bay. On Rocky Point just above Round Bay an excellent exposure of the Raritan sands with the interbedded clays is exhibited, with a capping

of marine Cretaceous. The section at this point is as follows:

ROCKY POINT, ROUND BAY, SEVERN RIVER.

Matawan.	Black laminated sands highly weathered, producing a reddish and grayish motted appearance	10 ft.
Raritan.	Coarse, gritty sands with lenses of clay; the sand cross-bedded and often indurated, forming heavy ledges of ironstone	30 ft.
	Total thickness	40 ft.

Other excellent sections are seen on the Magothy River, on the Lower Patapsco and its tributaries, on Elk Neck, and near the mouth of the Sassafras River, in which very much the same characters are exhibited. The light colored sands are especially well developed on Elk Neck where they attain a very great thickness.

Fossils.—The fossils of the Raritan formation consist mainly of plant remains. Several brackish water molluscan shells have been obtained from the Raritan formation, farther to the north in New Jersey and it is not improbable that the same may be observed in Maryland when the deposits have been further studied. The fossil plants include dicotyledons of much more recent affinities than those of the Patapsco formation, the break between the two floras being very marked.

INTERPRETATION OF THE DEPOSITS.

The interpretation of the Potomac group involves the consideration of the sedimentation and structural relations of the deposits as well as of the entombed fossils, and each has an important bearing in the elucidation of the other. The conditions of sedimentation explain in no small degree the character of the fauna and flora while their features likewise throw light upon the physical conditions which existed during Potomac time.

Sedimentation and structural relations.—The sedimentation of this period can best be understood after an examination of

the physical conditions which prevailed during the time immediately preceding the opening of Potomac deposition. The results of recent work in the study of the physiography of the North

FIG. 6. Section below Round Bay, Anne Arundel County, showing Raritan formation overlain by Matawan formation.

American continent during the Mesozoic show that the eastern side of the country had been largely base-leveled, so that a long period of rock disintegration preceded the Potomac. With the advent of this period the land was tilted southeastward, and the increasing erosion brought about by this movement afforded the deposits of the Potomac group. That this movement was not continuous or persistent in the same direction is evidenced by the varying character of the deposits which have been already described. With the close of Potomac sedimentation a gradual transgression of the later marine formations across the margin

of the Potomac group took place, by means of which the higher strata were gradually cut off to the southward. The details of this transgression will be further explained in the subsequent pages.

The basal deposits of the Potomac group, which have been described under the name of the Patuxent formation, indicate in their arkosic character, their proximity to the ancient continent, the rocks of which had suffered extensive disintegration. These features so pronounced where the deposits lie adjoining gneissic or granitic rocks largely disappear where these rocks are poorly developed and where the deposits themselves were evidently laid down at some distance from the old shore line. Rapid deposition in shallow waters is seen in the cross-bedded character of the strata and their rapid change in character The appearance of clay balls, so widely disseminated at certain points, as above described, indicates the shallowing of the seas and the breaking down of pre-existing clay beds by wave action and the incorporation of the rolled materials by the later deposits.

The close of the Patuxent epoch was evidently marked by a gradual elevation of the deposits and the trenching of the surface by streams, so that a series of broad, shallow valleys was formed While this was going forward, a landward depression of the continent border evidently took place, producing series of long marshes in the ancient valleys, in which sedimentation was slow and in which swamp vegetation flourished. The tough clays, filled with lignitic accumulation, in which the tree trunks are sometimes found erect, with their roots still intact, can hardly find a satisfactory explanation upon any other basis. It was in these ancient marshes that the iron was deposited. It is also probable that some connection existed between these marshes and the area of basic eruptive rocks of central and northern Maryland. It was in these marshes that the bones of Dinosauria became entombed which, with the evidences of dense vegetation, suggests a sub-tropical climate.

The marked line of unconformity separating the Patapsco

formation from the two basal members of the Potomac group points to elevation after the close of the Arundel epoch and to a prolonged period of denudation. A striking feature of this erosion is the greater resistance which the Arundel clays presented when compared with the deposits of the Patuxent formation. The partially eroded clay lenses which project above the common line of contact can readily be explained upon these grounds. It was over this uneven surface that the deposits of the Patapsco formation were spread, reaching far beyond their western limits until they rested directly upon the crystalline rocks of the Piedmont Plateau. Their materials, so largely arkosic in the vicinity of the feldspathic rocks (gneiss and granite), point to the rapid stripping off of the disintegrated surface materials, and their deposition along the continent border. To how large an extent subsequent disintegration has kaolinized these materials it is difficult to determine, but that they had been extensively weathered prior to their removal seems justified. The highly colored and variegated clays which were evidently formed in the quieter and deeper waters of the Patapsco epoch bear some relation to the great belts of basic eruptive rocks which lie to the west and north of them. This phase of sedimentation is much more marked in central Maryland where the rocks of this character are most highly developed and where the proximity to the eastern margin of the Piedmont belt is most apparent. It is also probable that these highly colored clays were in part derived from the weathered surface of the Arundel iron-ore beds.

The unconformity separating the Raritan from the underlying deposits is less prominent than that which has been above described at the base of the Patapsco formation, although the gradual thinning of the Patapsco along its western margin and the overlapping of the Raritan points strongly toward a structural break. The Raritan deposits also obliquely transgress the other materials of the Potomac group northward until in the Delaware valley they come to rest directly upon the crystalline rocks of the Piedmont belt. The thick deposits of sand and

clay indicate rapid deposition in shallow waters and the general continuity of the beds points to wider and deeper water areas. The close of Raritan sedimentation by the depression of the continent border and the gradual transgression of the deposits of the marine Cretaceous southward is a phenomenon of unusual interest.

The line of unconformity which separates the Potomac group from the later Cretaceous formations is so poorly defined in local sections that absolute unconformity could hardly be proved except by the evidence of this gradual southward transgression which finally cuts off the entire Raritan formation on the banks of the Potomac River.

This review of the conditions of sedimentation during the Potomac period and of the relations which the individual formations hold to one another and to the rocks above and below them points to the probability of the existence of extended areas of fresh and brackish waters along the eastern border of the North American continent during Potomac time. Just how these conditions could have been produced in all instances is not clear and speculation regarding them seems hardly warranted by the facts which are at present before us.

Correlation. — The correlation of the formations composing the Potomac group must rest largely upon the fossils which have been derived from them, although the physical history of the continent renders it possible to establish certain broad comparisons along the Atlantic and Gulf borders that are not without their value. The similarity of conditions during the deposition of the Tuscaloosa beds in the south is clearly indicated, and the corroborative evidence which palæontology affords in this connection will be presently mentioned.

As was stated in the introduction to this article the tendency of most authors hitherto has been to regard the Potomac group as a single stratigraphic unit and the discovery of fossils of known affinities within its beds to be conclusive evidence of the age of the entire series of strata. From what has been said in the preceding chapters it is evident that the Potomac group is made

up of a series of formations, containing clearly defined faunas and floras, and separated by marked structural breaks at various points. It is necessary, therefore, to correlate each division of the group upon its own merits, and not upon the floral or faunal relations of the underlying and overlying formations.

The absence of knowledge regarding the character of the organic remains entombed in the Patuxent formation renders it impossible to speak with definiteness regarding the age of this division. Its position beneath the Arundel beds and the physical relations which it holds to this formation render it probable that they must both be assigned to approximately the same position in the geological time scale. The Arundel formation has afforded a number of vertebrate forms, largely Dinosauria, which Professor Marsh regards as indisputable proof of the Jurassic age of the deposits. The fossil plants which have been hitherto found in this formation are altogether in harmony with this view. No dicotyledonous types have been observed, while the ferns, conifers and monocotyledons could, so far as at present known, be as well referred to the Jurassic as to a later horizon. The evidence afforded by the vertebrate fossils is unfortunately incomplete as but few forms have as yet been figured and described, although Professor Marsh states that he possesses a large amount of unpublished material which fully corroborates the views which he has promulgated regarding the age of these beds. Professor Marsh admits the equivalence of these beds with portions at least of the Wealden formation of Europe which most authorities refer to the Cretaceous. The final interpretation of the vertebrate fauna evidently involves, therefore, the determination of the upper limits of the Jurassic itself rather than the correlation of the Potomac group simply, and this article is hardly the place to discuss the merits of so broad a question. It is not impossible, however, that portions of the Potomac as well as the Wealden may antedate the oldest known marine Cretaceous, and for that reason as well as on account of the distinguished authority of Professor Marsh the Patuxent and Arundel formations are provisionally referred by the authors to the Jurassic. The discov-

ery of vertebrate remains of Jurassic affinities in these formations is not, however, sufficient grounds for the reference of the entire Potomac group to the Jurassic period.

The Patapsco formation has afforded a rich flora in which dicotyledonous types are not uncommon. The fact that dicotyledonous forms have never been found elsewhere in rocks earlier than the Cretaceous is strong presumptive evidence of the Cretaceous age of these deposits; at the same time the fact that many other forms are identical or closely related to those of European horizons, generally referred to the Cretaceous, further substantiates this view. It is the opinion of Professor Ward, who has exhaustively studied the flora of this formation, that it is equivalent to the lower divisions of the Lower Cretaceous of Europe. Professor Ward has divided what the authors here recognize as a single stratigraphic unit into several zones, each with its characteristic plant forms, which, he states, give evidence of constantly progressive types in passing from the lowest to the highest members of the series. Whether these different zones represent a sequence of floras, or to a considerable extent local aggregations of forms under different physical conditions but of equivalent age, the authors are unable to determine, although they strongly incline to the latter view. The abundance of vegetation having a prominent cycadean element suggests a repetition of the mild climatic conditions which prevailed during the Arundel deposition.

The fossils of the Raritan formation are in the main distinct from those of the Patapsco and include a large assemblage of dicotyledonous types with much more modern affinities. Similar forms are found in the Tuscaloosa beds of the south, and it is the belief of Professor Ward that these deposits represent the Raritan formation in the north. The Raritan beds show strong floral affinities with the upper portions of the lower Cretaceous of Europe (Albian), and, according to Professor Ward, it is not impossible that the higher members of this formation to the north of New Jersey may even represent the basal portions of the upper Cretaceous as well (Cenomanian).

The Patapsco and Raritan formations have afforded no animal remains which are of determinative value; the fossil plants all point strongly to the lower Cretaceous age of the beds. So large an amount of evidence has been brought forward in support of this view by Professors Ward, Fontaine and Newberry, that the authors have no hesitancy in accepting their conclusions, and these two formations are therefore placed in the Cretaceous.

THE TAXONOMIC VIEWS OF OTHER WRITERS.

The earlier writers did not differentiate the Mesozoic deposits of the middle Atlantic slope into independent formations. For many years the basal clays and sands, which border the crystalline rocks of the Piedmont Plateau on the east, were considered the eastern equivalent of the red sandstones and shales with their enclosed coals farther west.

Professor W. B. Rogers, state geologist of Virginia, first sharply differentiated the eastern deposits from the western, and described the former under the name of the "Upper Secondary"[1] in his state report. In later articles Professor Rogers refers these deposits "at least in part to the horizon of the Upper Jurassic. Possibly we may find here a passage group analogous to the Wealden of British Geology."[2] On his geological map of the Virginias, and in his more recent publications, the deposits of the Potomac group are referred to as the "Jurasso-Cretaceous."

In the reports of Professor J. T. Ducatel, who was state geologist of Maryland between the years 1834 and 1841, comparatively little attention was given to the clays and sands at the base of the Coastal Plain series, and neither their stratigraphic nor taxonomic position was clearly defined. The reëstablishment of official geological work in Maryland by Philip T. Tyson,[3] who, as state agricultural chemist, published

[1] Geology of the Virginias. Report of 1840, p. 438.

[2] Geology of the Virginias, p. 712.

[3] First Rept. State. Agri. Chem., 1860, pp. 41–43.

his first report in 1860, led to a much fuller description of the Potomac deposits. He recognized two divisions in these basal strata, although his descriptions do not make it altogether clear that he understood their stratigraphic relations. He, however, differentiated the "Iron-ore Clays" which he described and mapped as distinct from another member composed of variegated materials ("a thick group of sands and clays of various colors"). He stated that this latter member in places abounded in lignite derived from coniferous plants, and in places contained beds of ferruginous sandstone. These deposits were referred with the sandy clays and greensand above them to the Cretaceous or Upper Secondary. In his second report, published in 1862, he referred the "Iron-ore Clays," on the supposed occurrence of fossil cycads in the beds, to the "Oolitic period."

In the "Memoir of the Geological Survey of Delaware,"[1] published by Professor J. C. Booth, the state geologist of Delaware, in 1841, the deposits which we are now considering were denominated the "Red Clay formation," and together with the "Greensand formation" above them classed as "Upper Secondary Deposits."

Professor H. D. Rogers, who published reports upon the geology of New Jersey in 1836 and 1840, described the deposits of that region as "Clays and Sands" without clearly defining their stratigraphic relations. Upon the organization of the second Geological Survey of New Jersey in 1854 under the direction of Wm. Kitchell, Professor George H. Cook began his extended investigations of the Coastal Plain series of that state. At a later period, as state geologist, he elaborated and classified these deposits in a manner that for many years met with wide acceptance. This classification is given in much detail in the *Geology of New Jersey* published in 1868.[2] The lowest of these formations is described by Professor Cook under the name of "Plastic Clays" and referred by him to the Cretaceous.

Little further attempt was made at the investigation of the

[1] Mem. Geol. Surv. Del., pp. 38–43.

[2] Geology of New Jersey 1868, pp. 249–257.

Potomac deposits until almost within the last decade. In 1885 Professor R. P. Whitfield, as the result of several years' study, published an important monograph upon "The Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey," in which several Lamellibranchs from the "Plastic Clays" of Professor Cook are described. While the investigations leading up to Professor Whitfield's report were in progress Professor William M. Fontaine, of the University of Virginia, began his elaborate study of the Mesozoic flora of Virginia. The published account of this work, however, did not appear until after the important stratigraphic study of Professor W J McGee, of the United States Geological Survey, which began a few years subsequently.

The investigations of Professor McGee upon the Potomac deposits were seriously commenced in the summer of 1885, and were participated in by Professor L. F. Ward, of the United States Geological Survey, and these gentlemen also coöperated soon after with Professor Fontaine. Some preliminary work had already been done by Professor McGee[1] in the previous year and the name "Potomac formation" proposed. Professor McGee continued his investigations of the Potomac formation during several years, and published a number of important papers regarding its stratigraphic features, the most comprehensive of these being entitled "Three Formations of the Middle Atlantic Slope."[2]

During this same period Professor P. R. Uhler,[3] of Baltimore, investigated the relations of the Potomac deposits in the Patapsco basin of central Maryland and proposed the division of these basal deposits into a lower member which he called the "Baltimorean," and an upper member which was designated the "Albirupean." In later publications[4] the term Potomac was accepted as the equivalent of the Baltimorean, and the "Alter-

[1] Rept. Health Officer, Dist. Columbia 1884–5 (1886), p. 20.

[2] Amer. Jour. Sci., 3d ser. Vol. XXXV, 1888, pp. 120–143.

[3] Proc. Amer. Phil. Soc., Vol. XXV, 1888, pp. 42–53.

[4] Md. Acad. Sci., Vol. I, 1892, pp. 185–202.

nate Clay Sands" placed at the top of the group as part of the Albirupean.

The senior author of this paper, in a study of the Coastal Plain formations of New Jersey, proposed in 1892 the name "Raritan formation"[1] for the "Plastic Clays" of Professor Cook, the term Raritan having been somewhat loosely used by several authors in earlier years in speaking of the clay deposits of this formation.

Mr. N. H. Darton,[2] of the United States Geological Survey, as a result of his study of the Coastal Plain in southern Maryland, differentiated a part of the sands at the top of the Potomac group as the "Magothy formation," which he considered might be equivalent to Professor Uhler's "Alternate Clay Sands."

The elaborate investigations of Professor Ward, which began as already described in 1885, have been continued to the present day. His exhaustive researches upon the fossil plants in the Potomac group have added largely to our knowledge of that formation. His most important publication[3] appeared in 1895, in which the Potomac formation is subdivided into a number of series, viz.:—

Albirupean Series,	Newer Potomac.
Iron Ore "	Older Potomac.
Aquia Creek "	
Mt. Vernon "	
Rappahannock Series,	
James River "	

The interest aroused in the age of the Potomac formation led to the collection by Mr. J. B. Hatcher under the direction of Professor O. C. Marsh[4] of the United States Geological Survey of vertebrate remains from the iron ore beds in the vicinity of Muirkirk, Prince George's county, Maryland. Upon the basis of these remains Professor Marsh has unequivocally referred the Potomac group of Maryland to the Jurassic. He has sub-

[1] Ann. Rept. State Geol., N. J., 1892 (1893), pp. 181–186.

[2] Amer. Jour. Sci., 3d ser., Vol. XLV, 1893, pp. 407–419.

[3] 15th Ann. Rept. Dir. U. S. Geol. Survey 1893–4 (1895), pp. 307–397.

[4] Amer. Jour. Sci., 3d ser., Vol. XXXI, 1888, pp. 89–97.

COMPARATIVE TAONGMIC TABLE.

		W. B. Rogers (state report)	W. B. Rogeers (later)	J. C. Booth	P. T. Tyson	G. H. Cook	R. P. Whitfield	J. S. Newberry	W. J. McGee	W. M. Fontaine	P. R. Uhler	N. H. Darton	O. C. Marsh	L. F. Ward
Cretaceous	Raritan	?	?		?	Plastic clays	Raritan clays	Amboy clays	?	?	Alternate clay sands	Magothy		Albirupean series
	Patapsco	Upper Secondary	Jurasso-Cretaceous	Red clay Formation (upper secondary)	Variegated clays and sands				Potomac	Potomac or Younger Mesozoic	Albirupean		Potomac (Jurassic)	Iron ore series Aquia Creek series Mt. Vernon series Rappahannock series James River series ?
Jurassic ?	Arundel										Potomac or Baltimorean	Potomac		
	Patuxent	?		?	Iron ore clays									
					?									

sequently placed all of the Coastal Plain deposits beneath the marine Cretaceous in the same geologic division.[1] Professor Marsh claims the more recent discovery of a large amount of vertebrate material which throws much light upon the age of the Potomac formation and which he proposes shortly to describe. The last contribution of Professor Marsh brought about an extended discussion regarding the age of the Potomac group which was participated in by Messrs. Gilbert,[2] Marcou,[3] Hollick, Hill,[4] and Ward.[5]

The important postumous work of Professor J. S. Newberry entitled "The Flora of the Amboy Clays"[6] is a valuable contribution to the geology of the New Jersey portion of the Raritan formation. This work, which was edited by Arthur Hollick, represents the results of many years of investigation on the part of the late Professor Newberry.

The conclusions of the authors of this paper, as set forth in the preceding pages, are formed upon an extensive study of the Potomac group both in Maryland and New Jersey, and are seen to be quite different from those advanced by their predecessors. The comparative table on page 505 exhibits in a graphic manner the taxonomy of the several writers referred to, as interpreted by the authors of this paper.

WM. BULLOCK CLARK,
ARTHUR BIBBINS.

GEOLOGICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
July 1897.

[1] Jurassic Formation of the Atlantic Coast, Amer. Jour. Sci., 4th ser., Vol. II, 1896, pp. 433–447; Science, n. ser., Vol. IV, pp. 805–816.

[2] Science, n. ser., Vol. IV, 1896, pp. 875–877.

[3] *Ibid.*, pp. 945–947; Vol. V, n. ser., 1897, pp. 149–152.

[4] *Ibid.*, pp. 918–922.

[5] *Ibid*, 1897, pp. 411–423.

[6] Monographs U. S. Geol. Surv., Vol. XXVI, Washington, 1895.