ART. XVII.—*The Upper Devonian Delta of the Appalachian Geosyncline* ;* by JOSEPH BARRELL.

PART III. THE RELATIONS OF THE DELTA TO APPALACHIA.

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INTRODUCTION AND SUMMARY.

THE descriptions of the significant formations and the interpretations given in the first part upon the delta and its relations to the interior sea follow present well-known paths of geologic thought, but the search eastward and northward for the original boundaries involve interpretations which are much less customary,—interpretations in fact which are contrary to those which have prevailed. A preliminary consideration was therefore necessary in the second part on the factors controlling the present limits of the strata and the lack of relationship to the original boundaries. This has prepared the ground for the development of the conclusions, resting in part upon evidence, in part upon theory, as to approximately what those original limits were, as shown in fig. 1.† The subject leads up also to the relations of the delta to Appalachia and the information which is given thereby as to the character of that ancient land.

Briefly, the lines of argument are as follows: The marine fauna of the interior sea shows a connection eastward around Appalachia and implies a far extension, possibly to the south, but more probably to the north, of strata long since broadly uplifted and eroded. The character of the sediments and the rate of thinning at the present margins point to the same conclusion of a northward extension. The same lines of evidence

* Continued from this Journal (4), xxxvii, pp. 87 to 109, 1914.

† Published on p. 430, part I, Nov. 1913, and on p. 89, part II, Jan. 1914.

show that on the east not only did the strata once extend many tens of miles, but that the sources of erosion were not nearby. The evidence contained in the formations of the Green Pond Mountain outlier shows that the Upper Devonian deposits were there of fluvial origin and of materials brought from a distance. The structure as well as the composition point to the present syncline being a mere fragment of the original deposit, downfolded and downfaulted, and thereby preserved from erosion. The Green Pond Mountain axis was consequently not an isolated bay but its sediments were originally a part of the general Paleozoic mantle thinning to the eastward and in that direction were commonly of coarser texture. In the Upper Devonian it was part of a broad piedmont gravel plain, a continental bajada of low grade skirting the mountains of Appalachia; a gently inclined and graded plain, sensitive to climatic and diastrophic changes.

Following this part on the character and original limits of the Upper Devonian sediments, is given a discussion of the volume and sources of the material. It is concluded that Appalachia was not confined to the limits of the present continental shelf. The shelf in fact is to be regarded as in considerable part an aggradational terrace built out in post-Jurassic time. The foundations of Appalachia are buried some thousands of feet beneath it, extend beyond it, and doubtless slope gradually for an unknown distance toward and beneath the basin of the Atlantic Ocean. In Upper Devonian times the mountains which rose above these foundations stood on the eastern side of the Appalachian system.

INDICATIONS GIVEN BY THE STRATA OF FORMER EXTENSION.

Faunal Relationships and the Possible Seaways.

According to Schuchert, the Upper Devonian faunas of the Appalachian geosyncline show a connection with the Atlantic province and in his Paleogeography he has located a strait across northern New Jersey as the channel of ingress.* The existence of an Upper Devonian seaway in this locality, however, seems impossible. In the first part was developed the evidence showing that the Upper Devonian of this region must be regarded as continental in origin. Furthermore the sediment appears to have come from lands in this direction. In the search for an available connection with the north Atlantic faunas we must look for a passage around either the southern or northern end of Appalachia. A southern route would not be a direct one for the migration of North Atlantic

* Bull. Geol. Soc. Am., xx, p. 545, pl. 77, 1910.

faunas. Eastern uplands supplying waste seem to have existed as far south as the latitude of Virginia and a more southwestern passage would have apparently made it easier for southern or interior faunas to invade southwestern New York. The postulation of a northeastern route, on the other hand, has the objection that Upper Devonian strata are unknown in the Upper St. Lawrence valley. Moreover, the Middle and Upper Devonian deposits which exist in Gaspé are all or nearly all of continental origin, except at the base of the Middle Devonian. This evidence or lack of evidence does not exclude, however, the possibility of the existence in the Upper Devonian of a shallow seaway over the Saint Lawrence valley or even farther northwest, mantling the margin of the Canadian Shield.

The Gaspé sandstone of Middle Devonian and early Upper Devonian age shows thick outcrops eroded toward the north. The crucial question here is whether the sediments came from the north or south. If from the north, then a Middle Devonian sea could not be supposed to have existed in that direction. If from the south, the Gaspé sandstone, like the Catskill of Pennsylvania, may have been a delta deposit built from the south and facing a shallow sea to the north. Above an unconformity, the Bonaventure formation, latest Devonian and earliest Mississippian in age, on the eastern shores of Gaspé, is regarded by John M. Clarke as a shore conglomerate. In view of the crustal disturbances which affected the Maritime Provinces in the Upper Devonian, such a sea seems as likely to have entered from the north, the region of little disturbance, as from the east or south, the region of orogenic and igneous activity.

The Devonian seas extended much farther, in some cases at least, than the remaining outcrops indicate. The agglomerates connected with the intrusions of the Monteregian Hills show on St. Helen's Island, opposite Montreal, fossiliferous masses of Helderbergian and Oriskanian limestones. The highest local rocks are Ordovician, and the nearest outcrops of these Devonian horizons are more than a hundred miles distant. The mixing of inclusions in the volcanic pipes has carried material some thousands of feet upward from the pre-Cambrian base and mixed it with other material carried several thousands of feet downward from formations now completely removed from the region.*

The accidental preservation of these fragments through such unusual means suggests how widely certain seas may

* Chas. Schuchert, *Am. Geologist*, xxvii, 245-253, 1901. H. S. Williams, *Trans. Royal Soc. Canada*, 3d Ser., iii, Sec. IV, 205-246, 1910. Robert Harvie, *Trans. Royal Soc. Canada*, 3d Ser., iii, Sec. IV, 249-299, 1910.

The evidence of this locality and its important bearing on the principles of paleogeography were called to the writer's attention by Professor J. A. Bancroft.

have extended beyond the present outcrops of their strata in cases where the strata do not show internal evidence of the proximity of a shore. On the other side of the argument, although several masses of Lower Devonian age have thus been preserved, none from the Upper Devonian has been found.

As similar testimony from another region, attention should be called to the observations by Weller regarding the accidental preservation of a late Upper Devonian fauna in a fissure in Silurian limestone near Chicago.* The nearest known Upper Devonian strata occur 80 miles north and 130 miles west, but even these beds appear to be somewhat older than the filling of the fissure. The nearest place where Devonian strata form the surface rock is probably under the heavy drift in north-western Indiana.

The Laurentian province was not involved in the vigorous Upper Devonian mountain-making. Nor were these movements marked by a wide withdrawal of seas from the more quiet areas. Over such a region as that north of the St. Lawrence valley shallow ocean water may have spread consequently to a considerable distance. The strata, if they once existed, have not been preserved by infolding nor by the downfaulting which has protected remnants of some older Paleozoic formations within the Laurentian Plateau; but such facts as those cited show the possibility of the extension of shallow seas over lands not subjected at the time to uplift; and the later obliteration of the sedimentary evidence upon regional elevation followed by prolonged erosion.

Professor Schuchert has pointed out to the writer, however, that in the late Silurian the bay faunas of that time appear to have been distinct from each other in New York and in the Maritime Provinces. Of the latter region, however, but little is known. A more declaredly marine facies appears furthermore in the Great Valley Province of the Appalachians, suggesting that the sea lay in that direction, a strait opening either across New Jersey or farther south; but that no connection is probable through the Saint Lawrence Valley. He has called attention, however, to the Monroe problem of Grabau, the strata near Detroit holding a fauna seemingly unrelated to the other faunas of the period, and which may have entered from the north. Although Schuchert and the writer are agreed as to the general improbability of waterways crossing the trends of mountain structures in times of orogenic activity, there seems to be no incompatibility of their crossing after long periods of erosion, and due to broad warpings or local down-sinking. Such relations are especially possible when they

**Jour. Geol.*, vii, 483-488, 1899.

antedate the chief period of mountain building. Successive periods of orogenic activity seem in general to extend and weld together axes of movement which were previously more or less separate. A mountain barrier in the Upper Devonian in this region is therefore not evidence against a transverse strait in the late Silurian provided the faunas of the latter period indicate its probability.

In regard to the Hamilton epoch of the Middle Devonian, an Atlantic passage should be looked for however rather to the south of New Jersey, or else along the northwestern side of the Saint Lawrence axis. It is seen that there is no positive evidence as to either connection; the southern seaway would be the shorter to the *present* ocean, but in the latter part of this paper the evidence is presented which suggests that Appalachia was of considerable breadth and the Devonian Atlantic was not so near. Furthermore in the Upper Devonian the sedimentary evidence is more positive that marine connections could not have existed north of Virginia, probably not north of North Carolina.

This problem of the relationships of the fauna of the Che-mung sea and its connection with the Atlantic province is really not a vital part of the problem of the Upper Devonian delta and may be left in this indeterminate state. It has been dealt with so far as it is necessary to show that other connections could possibly have existed besides that which has been postulated as crossing New Jersey. The latter seems clearly disproved by the whole assemblage of evidence, and it is seen that an easier line of ingress may be conceived along the northwestern side of the Appalachian deltas.

Character of the Sediments of the Marginal Outcrops.

Where the edges of the upturned folds show strata many thousands of feet in thickness as in Pennsylvania, or where almost similar thicknesses of nearly horizontal beds remain in mountains of circumdenudation, as in the Catskills of New York, it is clear that in most cases the formations must have thinned out gradually beyond their present limits. The only exception is found on the borders of fault troughs. There a continual raising of the walls and a simultaneous settling of the basin permits a deep filling of debris at the very base of the block mountains. Such a condition records its evidence if the formations are of continental nature, by talus conglomerates and alluvial fans. If the fault movements are principally of profound subsidence rather than of uplift, as around the present-day shores of Greece, wave-formed conglomerates may be expected to mark the presence of the shores, passing outward rapidly into comparatively deep-sea deposits. In the formations

of the Upper Devonian of the Appalachian geosyncline, however, the sediments on the eastern outcrop are alluvial deposits of rather uniform nature. They are dominantly siliceous sandstones, argillaceous sandstones, some conglomerates of fine, well-worn gravel, and considerable shale. There is no sharp change near the present margin. The sediments therefore show no indication of an immediate source of erosion. If the size and abundance of pebbles in what there are reasons to believe were once continuous alluvial deposits be used as a means of estimating relative distances from the sources of erosion, it is to be noted that in the Skunnemunk outlier the coarsest pebbles of the conglomerate lie in the upper part of the formation. They are well water-worn, of quartzite, showing much previous transportation even here, and range from six to eight inches in maximum diameter. The average pebbles are about half this size. In the section of the Catskill rocks exposed from the town of Catskill to the summit of High Peak, 3660 feet elevation, it is the portion at 2000 feet and above to the mountain summit which shows notable conglomerate beds, the pebbles commonly ranging from 1.5 to 2.5 inches in diameter. The pebbles are largely quartzite. The southeastern outcrop in Schuylkill County, Pennsylvania, is more dominantly sandy, less conglomeratic. The pebbles there are of vein quartz and range from 0.5 to 1.5 inches in diameter. In the western outcrops conglomerates are very thin and fine-grained, or wanting. These observations are not along the same section and are incomplete, but they show something of the rate of disappearance of gravel at distances progressively greater from the source of supply. They suggest that even the easternmost outcrops are not close to that source.

The outlier known as the Rensselaer plateau deserves separate mention, although the age of the Rensselaer grit which constitutes it is not positively known and is more likely Middle rather than Upper Devonian. These sediments have been described in the first part of this article (p. 448), the metamorphism and the relations to the Taconic Range in the second part (p. 95). Although the sediments show by their character and variety that they are nearer to the sources of erosion than are those of the main area of the geosyncline, they do not show that the present limits of the Rensselaer formation hold any direct relation to the original boundary.

The previous statements have referred to the continental deposits of the eastern outcrops of the Upper Devonian. On the northern side of the basin the present limiting outcrops of both continental and marine nature show the principal relation in their sediments not to a nearby northern land but to sediments from the southeast and to Appalachia beyond. The

rocks are thin, even-bedded shales and sandstones traceable for long distances along their outcrops. They suggest for the greater part of the deposits the smooth floor of an open shallow sea. The dark mud-cracked shales of the Portage in central New York appear to be delta deposits developed because the subsidence was slower than the infilling, but the fine even grain of the sediments shows that even these are far from the sources of erosion and suggest that they once extended farther to the north.

Rate of Thinning at the Present Margins.

A method of attacking the problem of the original limits is found in the rate of thinning at the present margins. The data for determining this is, however, somewhat meager and not as accurate as is desirable for reliable results. It further rests upon the assumption that the thinning shown near the present margin continued uniformly to the original limits, an assumption which certainly is not exactly true, but which on the other hand serves as an approximation. The determinations check fairly well with the other indications and thus the arguments gain accumulative strength. The data of this nature are as follows:

The upper Devonian rocks in Pennsylvania and Maryland thicken in general from northwest to southeast. In Maryland the extreme easternmost outcrop is the thickest. Here therefore the axis of subsidence was to the east of the present eastern outcrop and later complete erosion has advanced westward beyond the line of maximum thickness. This may possibly be true in northeastern Pennsylvania also, but in Perry County on the Susquehanna, in central eastern Pennsylvania, a thinning exists toward the margin. Through Pennsylvania it seems probable therefore that the axis passes under the anthracite coal basins. This strikes east of the limiting outcrops in Maryland and agrees with the indications from that region as to the location of the axis. The eastern side of the original basin of sediments seems consequently in eastern Pennsylvania not to have been wholly destroyed. More carefully measured sections on the two sides of the coal basins are needed however to establish this view. The data supporting it rest at present, so far as known to the writer, upon the sections measured by Claypole in Perry County. He notes the difficulty of obtaining reliable measurements in this intensely folded and somewhat faulted district. Allowing for these difficulties as far as possible, he states that above Newport on the Juniata river the thickness of the Portage-Chemung rocks is 3300 feet. In the southernmost outcrop, some sixteen miles distant toward the

ancient land they measure but 1100 feet.* The Catskill rocks are given by Rogers as 6000 feet thick at the Susquehanna Gap above Harrisburg and Claypole gives this figure for the whole of Perry County.† A large part of the thinning of the Portage-Chemung to the southeastward is doubtless due to the passage of beds into the Catskill facies in that direction as observed both to the northeast and southwest.

The sum of the Upper Devonian rocks in the northern part of Perry County as derived from these measurements amounts to 9400 feet. Sixteen miles south at the Susquehanna Gap it is 7200 feet. The amount of shortening due to folding on this line was measured by the writer from the sections by R. T. Chamberlin.‡ The base of the Catskill was used for this purpose and it was determined that 21.5 miles had been shortened to 16 miles, 75 per cent of the original length. Assuming that the thinning is accurately determined and not in part due to a greater pressure on the east during folding, it gives a rate of 2200 feet in 21.5 miles, approximately 100 feet per mile. This is a higher rate of thinning than is observed anywhere toward the west, on the western side of the basin. There the highest rate, as seen between the anthracite basins and the Allegheny front, is not more than 60 or 70 feet per mile. A higher rate on the eastern side of the basin is however quite possible, and since this is near the center of the basin the rate may have increased to a still higher figure farther east. A higher rate of thinning than 100 feet per mile is not demanded, however, by the other lines of evidence. This would bring the original margin approximately to a line passing through New York, Philadelphia, and Baltimore, the margin of the present Coastal Plain. If the crust was shortened 25 per cent by the later folding of this zone, it would bring the original limit to a present line 15 to 20 miles northwest. This is the position shown on the map, fig. 1 (p. 225). In a later part of this article it is shown that the sources of erosion were southeast of the margin of the present Coastal Plain from rocks whose foundations are now concealed. Consequently the sediments either approached to the region of the present Coastal Plain or there was in the Upper Devonian a more or less broad neutral zone between the regions of erosion and deposition.

The bearing of lithologic evidence from the Green Pond Mountain outlier is considered in the next section, but such discussion as deals with the thinning of the strata may be given here. The marginal Upper Devonian outcrop in New York

* Second Geol. Surv. Pa., vol. F-2, pp. 71, 164, 1885.

† Loc. cit., pp. 34, 36, 244, 316.

‡ The Appalachian Folds of Central Pennsylvania, Jour. Geol., xviii, 233, 1910.

and Pennsylvania opposite the outlier has a thickness between 5000 and 6000 feet. The Upper Devonian in the outlier is estimated as still 2500 feet thick and an unknown portion has been eroded at the top. If the original thickness of the Upper Devonian be assumed here as only 2500 feet, and the formation regarded as part of a general mantle of sediments, it gives a thinning of about 3500 feet in 28 miles after folding. Assume this to be 35 miles before folding and the thinning comes to 100 feet per mile; the same figure as from Perry County, Pennsylvania, 150 miles southwest. This, it will be noted, is a maximum estimate. More probable figures for the rate of thinning near the present outcrops would be 80 feet for each mile of original distance. This may have steepened to a higher figure near the margin.

The rate of thinning at the northern margin, where the rocks are not much folded, may be approached from another standpoint: that of the dips in the successive formations. In southern New York the upper Devonian beds are known to thin from east to west, the Portage beds, for example, thinning westward from 1500 feet to 1200 feet in fifty miles, from long. 77° to 78° . This, therefore, is on the farther side of the geosyncline. The rate of thinning to the north is, however, more difficult to determine since the same bed is not exposed over great distances in that direction and gentle folds slightly warp the strata. In the higher strata, however (the basal Mississippian), the regional dips are to the southwest at an average of about 20 feet to the mile. In the Middle Devonian the dips average in direction 20 to 30 degrees nearer south and at average inclinations of from 30 to 50 feet per mile. These figures give between long. 76° and 78° a thickening of the Upper Devonian to the south-southeast, at a rate of from 20 to 30 feet per mile. In western New York south of Lake Erie, G. D. Harris gives data* from which it may be computed that the rate of thickening of the Middle and Upper Devonian together is 36 feet per mile to the southeast. Data given in the Warren, Pa., folio, however, make this seem somewhat high. These results serve as checks to the contour lines of the structure map accompanying the present paper, which are primarily based on measured or estimated sections and indicate a marginal rate of thinning of 22 to 23 feet per mile. It is possible that the thinning may have been accentuated beyond the limits of the present outcrops. It was not, however, the direction from which the sediments were dominantly derived, and from the absence of diastrophism in that direction a smaller rather than a larger rate of thinning in the portion now eroded might as readily

* Notes on the Geology of Southwestern New York, Amer. Geol., vii, 164-178, 1891.

be postulated. Thinning at the rate of thirty feet per mile would carry the margin of the Upper Devonian to the northern shore of Lake Ontario over Ordovician rocks, and over the southern part of the pre-Cambrian now exposed in the Adirondacks. A rate of 20 feet per mile would carry the margin some thirty miles farther north. The regional dip of the base of the Lower Devonian would project such a marginal extension upward high over the pre-Cambrian as now exposed. The present elevated position of the pre-Cambrian in that region cannot date back to the Devonian, so that this degree of extension of the Devonian strata meets with no structural difficulty.

Evidence from the Green Pond Mountain Region.

The discussions on the original limits of the Upper Devonian, based on the evidence of the margins, have been of the nature of an extrapolation, determining the rate of changes at the margin and projecting them to their limits. To give confidence to such conclusions they must be supported by independent lines of evidence. One of the strongest of these is found in the sediments of the Green Pond Mountain outlier, downfolded and downfaulted into the pre-Cambrian rocks twenty-five miles southeast of the marginal outcrop of the Catskill formation. The present isolation of the syncline and the different character of many of the formations within it have led a number of geologists to the opinion that this was a separate basin of deposition. In regard to this view, however, Kümmel and Weller state :

“Darton and Walcott have held that the rocks of this region, at least those subsequent to the Cambrian limestone, were deposited in an inlet separated by a land area on the west from the great sea, which lay still further west. We have observed no facts in the New Jersey area which necessitate this assumption. On the contrary, we believe that the weight of evidence there favors the view that these formations were formerly continuous with the corresponding beds in the Kittatinny valley and northwestward. Recognizing, however, that the evidence in New Jersey is not decisive, and not having had an opportunity of examining critically the field in New York, we are unwilling to oppose the conclusions of these workers, although from what we have seen we are inclined to believe that the facts are capable of a different interpretation from that of Mr. Darton. In any event, there can be no doubt but that the seas in which these beds were formed had a much wider extension than the present area of the formation.” *

A discussion of the stratigraphy as given below suggests that the conclusion of Kümmel and Weller may be more positively

* The Rocks of the Green Pond Mountain Region, Ann. Report New Jersey Geol. Surv. for the year 1901-1902, p. 40.

held, and that the differences in the rocks are such as are to be expected under the view that they were deposited nearer to the sources of erosion, but existed in continuity with synchronous sediments laid down in Pennsylvania. Grabau also has recently urged the view regarding the continuity of the Silurian rocks of this axis with those to the west.*

The history of the region must be traced from the Silurian. Early in the Silurian the Green Pond conglomerate was laid down with a thickness of 1200 to 1500 feet.

"This consists of coarse, silicious conglomerate, interbedded with and grading upward into quartzite and sandstones. The pebbles of the conglomerate range from one-half to three inches in diameter, and are almost entirely white quartz, but some pink quartz, black, white, yellow and red chert, red and purple quartzite, and a very few red shale and pink jasper pebbles occur. The white quartz pebbles have frequently a pink tinge on their outer portion. At Gould's quarry large masses of the underlying limestone are included in a conglomerate, which is believed to be the basal layers of this formation.

"The matrix is comprised of quartz sand, is vitreous in texture and generally of a dull red color, but white, gray and greenish strata frequently occur, particularly in the basal portion, so that the formation is not so exclusively red as implied in most of the earlier reports."†

The Shawangunk conglomerate and sandstone, in similar stratigraphic position, outcrops twenty miles northwestward, is 1500 to 1600 feet thick, but is without the red color,—consisting of cleaner, whiter sand and smaller quartz pebbles. This contrast suggests either that the Shawangunk has been subjected to the greater sorting due to wave action and contrasts with a fluvial origin of the Green Pond conglomerate, or that the latter corresponds to the red upper portion of the Silurian sandstone to the west, the basal portion being absent in the Green Pond axis.

The evidence shows that in neither the Green Pond axis nor to the west is the material of local origin. An enormous quantity of rock and from a considerable area has been destroyed to supply this mass, the pebbles consisting dominantly of white quartz-vein material from crystalline formations. Considerable transportation has been necessary in order to segregate it from the vastly greater quantity of finer grained and softer rock with which it was associated, a transportation to which the rounded form and resistant character of the pebbles bear witness. Furthermore, except to some degree at the unconformable base, local boulders are not encountered

* Early Paleozoic Delta Deposits of North America, *Bull. Geol. Soc. Am.*, xxiv, 477-479, 1913.

† Kummel and Weller, *loc. cit.*, p. 9.

within it, nor is any change along the axis of the syncline to be noted which suggests that the sands and gravels were deposited in a narrow inlet, subject to lateral transportation of sediments and weak wave action.

The Green Pond conglomerate is overlain by the Longwood shales 200 feet in thickness and of red color, succeeded by the Decker limestone 50 feet thick, and carrying Cayugan fossils. Above the Decker limestone occurs the Kanouse sandstone (Newfoundland grit of the New Jersey report) 215 feet in thickness and carrying a mixed Oriskany-Corniferous fauna. The sequence is thus similar to that of the main Appalachian geosyncline but the beds above the Silurian conglomerate are thinner and certain horizons are probably missing. There is, however, no suggestion of local sediments from the walls of an estuary. On the contrary, the evidence suggests that the region lay nearer to the land of Appalachia and the bottom was less subject to subsidence. Hence thinner deposits of sediment were apt to be laid down and the material on the whole was coarser and less calcareous. Over such a zone the minor crustal oscillations are more apt to bring about temporary erosion followed by overlap. Certain beds above the Longwood shales appear to be absent in places.* In this region, Darton notes the difficulty of discriminating between overlap and overthrust, but states that on the northwest the Helderberg limestone rests directly on Cambrian limestone with no possibility of an intervening fault.† This suggests a pre-Helderberg warping of some extent, perhaps while the Green Pond conglomerate was still an unconsolidated gravel. In this region the Hamilton is represented by the Pequianac shale (Monroe shales of Darton), consisting perhaps of a thousand feet of dark, thick-bedded shale, somewhat sandy toward the top and containing a Hamilton fauna. According to Darton it also overlaps all of the preceding formations,‡ but the character of the sediment, like that of the preceding formations, does not indicate a local source. This is the last overlap known, as the Pequianac shale grades up into the Bellvale flags, a formation between 1600 and 2000 feet in thickness. The lower part of the Bellvale flags contain a Hamilton fauna. Plant beds of middle Devonian age are found in this formation, marine fossils fail in the upper portion, and it seems possible that here the continental phase of sedimentation began before the close of Hamilton time. So far as known there is no diminution in the thickness of the beds of the Hamilton group in passing eastward from the Delaware River, where

* Kimmel and Weller, loc. cit., p. 20.

† Geologic relations from Green Pond, New Jersey, to Skunnemunk Mountain, New York, Geol. Soc. Am., Bull., v, 391, 1894.

‡ Loc. cit., p. 392.

they measure about 2000 feet, but the strata there remain fossiliferous into Portage time.* The Bellvale flags grade in turn into the massive Skunnemunk conglomerate with an eroded top, but still 2500 feet in thickness in the deepest part of the syncline. The broader structural evidence indicates no local source for these conglomerates, since the fine grain and fossiliferous character of the Hamilton beds gives no suggestion of a mountain-walled inlet. No overlap suggests later deformation, and the Skunnemunk conglomerate was separated from the Green Pond conglomerate and the Archean by from 2500 to 3500 feet of Middle Devonian strata.

Although no local basin existed, the evidence indicates that continued upwarping of the land to the east exposed earlier quartzites to erosion, for the pebbles in the Skunnemunk are less abundantly white quartz, but principally of quartzite. As seen in the southern end of Bearfort mountain in New Jersey, the quartzite pebbles are dominant to the base. The section of Skunnemunk mountain, however, 27 miles northeast shows in the lower beds pebbles up to three inches in diameter, dominantly of white quartz, but with some pale pink and gray quartzite. The upper beds are much more abundantly conglomeratic, with quartzite pebbles as the dominant constituent and ranging in size up to eight inches. All are well rolled, prolate spheroids being the common form.

According to Kummel and Weller, many of these pebbles are lithologically identical with the quartzite beds in the Green Pond formation, and seem to have been derived from it. The writer has observed internal evidence, however, which points strongly to a different and somewhat distant source. The pebbles in the Green Pond conglomerate are overwhelmingly white quartz. At the time of the deposition of the Upper Devonian the Silurian conglomerate had not become buried over 3000 feet nor subjected to mountain-making movements. If it supplied the material for the upper formation the white quartz pebbles would have had at that time greater resistance and coherence than the sandstone matrix and should apparently have contributed more conspicuously to the overlying conglomerate. Furthermore, the quartzite pebbles of the Skunnemunk are well rolled, implying considerable wear before deposition, and the grain of the quartzite pebbles is fine and somewhat more vitreous than the matrix in the dominant beds of the Green Pond conglomerate. A more positive indication is derived however from color. The matrix of the Green Pond conglomerate is a purple-brown with tinges of deep red, the few lighter colored beds not being volumetrically important.

* C. S. Prosser, *The Devonian system of eastern Pennsylvania and New York*, Bull. 120, U. S. Geol. Surv., p. 12, 1894.

The original color of the Skunnemunk quartzite pebbles, on the contrary, was a grayish white to greenish gray, stained later to a purplish or pinkish white, lighter in color value than the matrix of the Green Pond conglomerate. The evidence for this conclusion is as follows:

The lower part of the Skunnemunk conglomerate contains beds of green flags and greenish conglomerates well shown west of Hanks Pond and along the carriage road leading to the summer residence of Mr. R. F. Cross. In this greenish conglomerate the quartzite pebbles, the same in texture and size as in the purple beds above, are grayish white or greenish gray. In the purple beds they are whitish pink or purple. The vein-quartz pebbles are white in all cases, though stained a little on the outside and on internal fracture surfaces. The larger quartzite pebbles, especially in the beds only slightly ferruginous, are pale in the center with a purple rind on the outside.

The logical explanation of these facts is based upon the observation that white vein quartz is not porous and hence does not stain readily by taking up solutions of iron in the ground water. Quartzites, on the contrary, show various degrees of porosity, from sandstones, the most porous of rocks, to vitreous quartzites, almost without porosity. Ferruginous solutions becoming oxidized in sands and gravels stain them yellow, as seen in the yellow gravels of the Atlantic Coastal Plain. This stain permeates the porous pebbles in direct ratio to their porosity. Subsequent diagenesis in the ancient formations has eliminated the water from the iron oxide and turned the yellow of limonite to the reddish brown or purple of hematite, which if diluted by the rock substance becomes pink or pale purple. In the Skunnemunk conglomerate, although the matrix is of about the same depth of color as in the Green Pond conglomerate, only a few pebbles attain this same depth of stain, most of them remain distinctly lighter, and some of the greenish, jaspery pebbles do not change in color except on the surface.

The Green Pond conglomerate, of the Silurian, rests unconformably upon pre-Cambrian gneiss and Cambro-Ordovician limestone, the basal Cambrian quartzite in New Jersey being very thin and in many places wanting. The material of the Silurian is apparently derived from deep erosion of these gneisses at some distance to the southeast, sufficient to permit the segregation and rounding by transportation of the white vein quartz which is a minor constituent of the gneisses.

In regard to the Skunnemunk conglomerate, of Upper Devonian age, the evidence shows that most of it was not derived from a local source; neither the pre-Cambrian gneisses,

nor the Green Pond conglomerate. On the contrary, quartzite formations resembling Cambrian quartzite where these are extensively developed, had become uplifted and subjected to erosion. Such a supply of material could not have existed short of some region now concealed by Coastal Plain deposits or the waters of the Atlantic ocean.

Gravels as coarse and thick as those of the Skunnemunk formation are commonly developed skirting the larger mountain ranges, swept out by rivers and forming piedmont slopes. From the Himalayas they are swept southward in abundance 20 to 30 miles. In the basins of Asia from ten to forty miles is a common distance. In the valley of the Po, Bonney has noted that gravels with pebbles commonly 3 to 4 inches in diameter and more, reaching rarely 8 inches, are found after the river and its tributaries have flowed over from 35 to 50 miles of plain.* Gravels in some instances are carried much farther, even several hundred miles, but in such cases the pebbles are small and constitute a lesser proportion of the entire deposit. The well-worn and rounded character of the Skunnemunk gravel indicates that it had suffered a large reduction in size of pebbles and had been moved a considerable distance. The margins of the gravel plain may therefore be estimated at perhaps from 20 to 35 miles to the southeast of the Green Pond syncline, making the original limits of the upper Devonian deposits from 45 to 60 miles southeast of the present outcrops in Pennsylvania. Considering all the lines of evidence, especially the distance to an available source for the quartzite and the shortening of this distance due to later folding, the larger figure seems more probable than the smaller. Sixty miles during the final period of folding may well have been shortened to forty-five miles, so that this has been used as a minimum limit in locating the original margin in New Jersey and Pennsylvania. The distance to the northwestern edge of the crystalline floor concealed beneath the Coastal Plain is now about sixty-five miles, and from beyond this line it would appear that the greater portion of the quartzite must have been derived.

RELATIONS OF PIEDMONT GRAVELS TO CLIMATIC AND CRUSTAL MOVEMENTS.

Broad piedmont plains, such as those which skirt the east side of the Rocky Mountains and whose dissected surfaces form the High Plains, are in delicate adjustment to the grade of the rivers which built them. A climatic movement away from a state of semi-aridity toward a rainy and humid condition increases the hold of vegetation on the soil, decreasing the

* Rounding of Alpine Pebbles, *Geol. Mag.*, decade III, vol. v, p. 58, 1888.

washing of upland waste into streams, while at the same time the capacity of the streams to carry waste is increased. The rivers consequently load up by eating into the higher parts of the piedmont slope, the more readily because of the unconsolidated nature of the deposits; the river grade outside of the mountains is flattened and there is a transfer of coarser material to the delta or the sea. A conglomerate of climatic origin is the result, interbedded with normally finer grained deposits. A reverse climatic movement will build up again the higher parts of the slope, steepening the grade in this part and giving a minimum supply of waste to the delta until equilibrium between grade and climate is established. In general it may be said that climatic fluctuations of any nature will produce alternate terracing and filling in the upper parts of the piedmont plain; a synchronous alternation of thick and coarse with thin and fine deposits upon the delta topset beds, both on the land and extending to the shallow sea.

The repeated cutting and filling during the Pleistocene of the valleys crossing the High Plains seems, as W. D. Johnson has pointed out, to have been most largely of a climatic cause, and the same conclusion has been reached for the terracing in other regions by Davis and Huntington. The subject has been discussed more fully by the writer elsewhere, with some application to the Appalachian deposits of the Upper Paleozoic.*

The question arises, how such a climatic record may be discriminated from a somewhat similar record made as the result of crustal movements. The clearest distinction is in the relations of carbon and iron oxide as seen in the shale members of the delta deposits; an increase in the quantity of carbon marking a movement toward wetter or cooler climates, an increase in oxidation marking the movement in the contrary direction.

The results to the delta would be quite different if there were no storage of coarse siliceous waste in a piedmont slope between the mountains and the alluvial flats beyond. Then the movement toward a greater growth of vegetation would normally decrease the supply of coarse waste to the rivers and increase the deposit of carbon to the delta. Certain exceptions may, however, be imagined:—a climatic movement which would bring on glacial conditions in the mountains would carry coarser waste farther from them without deriving such from a piedmont slope and at the same time favor the storage of carbon in the parts of the delta which did not receive this waste. Alluvial gravels of ultimate glacial origin derived from a crys-

* Barrell: Relations between Climate and Terrestrial Deposits, Jour. Geol., xvi, pp. 162, 163, 363-384, 1908.

talline upland would, however, show a greater dominance of granite or gneiss cobbles over those of vein quartz as compared with gravels due to normal weathering and previously stored by rivers in a piedmont slope. The character of the silt in the two cases would also be different. Again, if vegetation had not evolved to that state where, under a favoring climate, it could bind the soil, a movement toward a cooler and wetter climate, even without glacial conditions, might lead to more rapid instead of less rapid erosion of the uplands. In that case, however, coarse and fine detritus would both be carried to the delta and clean formations of sand and gravel would not be conspicuous.

The more normal and probable relations of climatic fluctuations to mountain, piedmont, and delta which were first stated will be assumed to have existed during the later Paleozoic and the justice of that assumption tested by the degree to which its expected results accord with the observed stratigraphy of the delta plain and shallow sea. If the theory that pulses in climate are recorded in sedimentation be regarded as sound, it may then be used in two ways in the interpretation of the past:—the deposits of an ancient delta may contain a climatic record and at the same time testify to the former existence of a piedmont now destroyed as the result of orogenic movements and later erosion. It is from this standpoint that the subject enters into the present problem.

The Catskill red shales and gray sandstones are succeeded by the Pocono sandstones and conglomerates. The Pocono formation spreads across the state of Pennsylvania, but the beds in the east are coarser and thicker than farther west. Shale is much diminished in amount. Most of it is olive, though, especially in the western half of the state, considerable red shale occurs. Scanty coal seams show for their times and areas the presence of perpetual swamps. This Pocono sandstone plate is abruptly followed by the Mauch Chunk red shale and red sandstone; brilliant with ferric oxide, containing lime, gypsum and salt, with mud-cracked strata in place of coal. This formation closed the Mississippian period. The Pennsylvanian follows, inaugurated by the group of Pottsville conglomerates and sandstones with black shales and some coal, reaching a maximum thickness of about 1200 feet in Pennsylvania. This is succeeded by the coal measures. The whole series from the opening of the Middle Devonian reaches a maximum thickness in Schuylkill County, Pennsylvania, of more than three miles.

The red shale formations, the Catskill and Mauch Chunk, show transitions on the east into the overlying formations. The Pocono, on the contrary, passes abruptly at its top into the Mauch Chunk shale. Both the Pocono and Pottsville conglomerates

erates are made up dominantly of much water-worn white quartz pebbles, and their whole areas are characterized by a great dominance of siliceous over argillaceous contents. All of these features correspond to the theoretic results upon a broad piedmont slope of increasingly wide swings of the climatic pendulum which carried the world from Upper Devonian warmth and semi-aridity to Upper Carboniferous humidity and possible coolness. Such are the major changes through the later Paleozoic; changes which find parallels in the geosynclines of the Maritime Provinces of Canada and of north-western Europe. They form a crescendo leading from the Middle Devonian and terminating in the Permian, a period of mixed and unparalleled aridity and glaciation.

On these great climatic movements were superimposed the minor climatic rhythms and from them must be separated the effects of the crustal movements. In the continental interior, the region of shallow seas, the effects of diastrophism are more in evidence; an unconformity separating the Mississippian and Pennsylvanian and the latter exhibiting progressive overlap. The great thickness of the Pennsylvanian deposits of the south, measured by many thousands of feet, following the limestones of the Mississippian and the black shales of the Devonian, also testifies to great crust movements during the Pennsylvanian in those regions. The Pennsylvanian deposits of the Acadian and Boston basins seem also to imply orogenic movements of considerable magnitude in the north.

The facts which have been previously cited regarding the formations in eastern Pennsylvania seem, however, to correspond most largely to a climatic cause. The far-carried conglomerates and sandstones of the Pottsville associated with some black shales and coal; to a lesser degree the same relations in the Pocono, contrast with the absence of conglomerates in the Mauch Chunk, and the presence there of thick red shales and the marks of aridity. In the Catskill these features resemble the Mauch Chunk but conglomerates are not wholly absent on the east and the indications in the red shales are those of semi-aridity. The climatic control which explains these relations of conglomerates and shales also points strongly in consequence toward the former existence of a piedmont plain, now eroded, which during the Catskill and Mauch Chunk epochs became a storehouse of siliceous gravelly waste, which by the stronger rivers of the Pocono and Pottsville epochs was spread over the delta plain and given to the waves of the shallow sea. The amount eroded from the Piedmont slope was but a fraction of the volume of the whole deposit. It was that amount which was contained between the stable river grades before and after the climatic change. The

greater part of the piedmont remained unaffected save by crustal uplift, since it originated as a consequence of crustal downwarping in front of the mountains and all but its upper deposits were below any possible river base-level. The conglomeratic members of the Pocono and Pottsville are, however, hundreds of feet thick in eastern Pennsylvania, growing finer and thinner westward, but covering originally many thousands of square miles. Their volume implies, therefore, the former presence of a piedmont as wide and as high above sea level as has been indicated by the other lines of evidence.

The theory of the relations of climatic cycles to cycles in sedimentation converges to the same conclusion as the other lines of evidence regarding the former existence of a wide piedmont slope constituting an eastern side to the Appalachian geosyncline.

VOLUME AND SOURCES OF UPPER DEVONIAN SEDIMENT.

Of the volume of sediments deposited in the Appalachian geosyncline during Middle and Upper Devonian time, Willis states:

"If this mass with approximately the dimensions with which it was deposited in the sea, could be restored upon a sea-level plain of Appalachia, it would constitute a mountain range closely resembling in height, extent and mass the Sierra Nevada of California."*

The writer has computed from the data shown in fig. 1 (p. 89) the original volumes of sediment within an area bounded by lat. $39^{\circ} 30'$ on the south, 43° on the north, and from the original eastern margin to long. $80^{\circ} 30'$ on the west. Within this area the map by Willis indicates a volume of 55,000 cubic miles. The Middle Devonian comprises about one-fifth of this, leaving 44,000 cubic miles for the Upper Devonian. On the map accompanying the present article there is shown within these boundaries 63,000 cubic miles of Upper Devonian sediment, an increase of 43 per cent over the estimate by Willis. Allowing for the extension which the present writer has given to the north the present estimate becomes readily as much as 50 per cent greater than the previous. This is an impressive measure of the volume of the adjacent land which was eroded in Upper Devonian times. But it is a minimum measure, since that part of the rocks which was taken into solution was carried farther away, and of the mechanical sediments it represents only that part which was carried westward into the trap of the geosyncline.

* Paleozoic Appalachia, Md. Geol. Surv., vol. iv, Pt. I, p. 62, 1900.

An adequate geologic source for this volume of material must be sought. In part the sand and clay may have come from a distance of hundreds of miles, but the gravels and the feldspar sand indicate that much of it was from a nearby mountainous tract whose rocks were in large part of quartzites, gneisses and granites. The questions, therefore, arise,—how far away was the field of great erosion? From what direction were derived the Upper Devonian sediments? Did they come from New England and enter the geosyncline by way of the Catskill Mountain region, did they come from some other distant source, or were they poured in from a longitudinal land mass lying along the southeastern side of the geosyncline?

If attention were confined to those lands now above the sea and to the portion of the Upper Devonian rocks still uneroded, a derivation of the sediment from the northeast would be favored. There is in New England a broad region of metamorphic rocks and the Upper Devonian sediments still uneroded show further that subaërial conditions began to prevail first in eastern New York, gradually advancing westward and south-westward. A closer examination shows, however, that these facts are not real evidences of a derivation from the northeast. The strike of the New England rocks is southward under the submerged portion of the Coastal Plain. The Coastal Plain deposits rest on a surface which indicates profound erosion previous to Comanche time. The fact that the Coastal Plain in southern New England is diagonal to the structure and hides the older basement to the south indicates the lack of relation to the distribution of lands in Paleozoic time. The structure of that basement is the more significant feature.

The Catskill shore line advanced westward during the Upper Devonian past the axis of deepest and most rapid subsidence and encroached on the less rapidly subsiding sea bottom beyond. This is true in New York, in Pennsylvania, and in Maryland. If the sediment had been derived from the northeast the advancing shore line would, on the contrary, have been different from what is observed to be the case. The great zone of subsidence in southeastern Pennsylvania would have long remained as sea. The shore line would have trended east and west, advancing south, and a terrestrial phase in Maryland would have been deferred until the marine phase had entirely disappeared to the north. On the contrary, the Pawpaw-Hancock quadrangles show that the Catskill conditions in Maryland appeared in full force on the east, where lay the zone of greatest subsidence, before they encroached westward. The Catskill beds are also much thicker to the east, being given as 3800 feet in the eastern part of the Hancock quadrangle and thinning to 2000 feet within a distance of 15 to 20

miles northwest.* The delta in Maryland and southern Pennsylvania grew, therefore, from the southeast against and past the zone of maximum depression. From the southeast, consequently, the sediment was brought and in great volume. The appearance of the subaërial conditions first in eastern New York is adequately accounted for, first, by the more rapid subsidence of the basin in Pennsylvania; and second, the subsequent erosion there of its whole southeastern side, where terrestrial deposition must have prevailed before it reached the middle of the basin. After the subaërial conditions became established in eastern Pennsylvania as far as the region of greatest thickness the advance of the shore line was northwestward, contrasting with the initial western advance in New York.

The gradation in the coarseness of the sediments agrees with the indications of the shore lines. It is the eastern outlier which shows the only striking conglomerates. In the main areas the gray sandstones with fine-grained conglomerates dominate on the eastern side of the southern anthracite basin, far removed from the region of the Catskill Mountains. In Maryland the eastern outcrops show a less arenaceous nature than do the eastern outcrops in central Pennsylvania, but on the strike of the later folding they correspond to a more western part of the formation in Pennsylvania. A wider eastern zone may therefore have been eroded in Maryland, following the Permian folding. The sediment did not however come from the region of the present Southern Appalachians, since marine conditions prevailed longest in the south, the Catskill disappears in Virginia, and in Tennessee the Upper Devonian is represented merely by a thin black shale. In general the Paleozoic sediments of the Appalachian geosyncline do not show transportation along its axis from the north or south, but transference into it from a land parallel with it. The axis of upwarp and that of downwarp seem in fact to have been genetically related, as is so commonly the case in the present mountain chains.

The indications given by the directions of delta growth, thickness of the Catskill beds, and the gradations in their texture, are, therefore, that the sediment was brought in along the whole front of the geosyncline by more than one river and from the southeast as well as the east and possibly northeast. The result was a confluent piedmont plain and delta front building out a terrestrial coastal plain. More detailed study may be able to locate the several centers of principal delta growth.

* Stose and Schwartz, U. S. Geol. Surv., Folio 179, pp. 12, 13, 1912.

The rivers do not appear to have been great continental water-ways. Such are far apart in their mouths, corresponding to the size of their drainage basins. The bulk of the sediment of such rivers is mud and silt. They corrade their way across mountains at a low grade and would not be capable of building sloping piedmont plains. Furthermore the coarseness of the quartzite boulders in the Skunnemunk conglomerate is such that rivers probably did not carry them from the mountains more than 75 or 100 miles. For the sources of erosion we must look east and southeast from the geosyncline, toward a parallel and not far distant mountainous land.

Let the attention be turned next from the sediments to the terranes beyond which could have supplied them. The geologic maps show that within the zone once covered by the Devonian piedmont gravels, Cambrian and Ordovician rocks still remain over considerable areas, and evidence has been given that the pre-Cambrian ridges of gneiss east of the Schuylkill river were mostly mantled by younger formations up to Jurassic times. West of the Schuylkill the prevailing formations within the original Upper Devonian limits are Ordovician rocks. Even, therefore, if previous arguments had not indicated that this zone was a region of deposition, it could not be regarded as a field of supply for an appreciable portion of the sediment.

Passing next to a zone to the east of the last and beginning at the north, it is to be noted that the pre-Cambrian rocks of the Green Mountains are of comparatively small areas. As far east as the valley of the Connecticut and as far south as New York city, large areas of Cambrian and Ordovician schists remain. South and east of New York City the ocean and the deposits of the Coastal Plain largely conceal the older structures; but, beginning at Trenton on the Delaware River, the ancient rocks reappear between the Triassic and Commanche overlaps, constituting an exposure of gneisses and granites widening southwards through Pennsylvania into the Southern Appalachians. Near the Delaware state line, however, a few outliers of Cambrian quartzite and limestone still remain, and immediately west are large areas of metamorphosed Ordovician rocks. This exposed belt, about 25 miles wide, certainly suffered very considerable erosion in early Triassic and again in Jurassic times. There is no evidence that it was covered by Upper Devonian sediments, but neither could it have suffered much from Upper Devonian erosion. Thus, by a process of exclusion, for the zone of mountains which supplied this waste we must look farther to the eastward, at least as far as eastern Connecticut and the region now overlain by the strata of the Coastal Plain. This could have been

but the margin of the vast volume eroded; the land now hidden beneath the waters of the ocean must have been the chief source of supply. In Maine, New Brunswick, and Nova Scotia igneous activity is known to have prevailed in the Devonian. The rocks of these provinces and of Newfoundland, the latter structurally the eastern outpost of the continent, strike southeastward under the sea and toward the region from which presumably came the sediments of the Catskill formation. It would seem further that to such a zone beyond the margin of the Coastal Plain of New Jersey must we look to locate the source of the great volume of gray quartzites which supplied the pebbles of the Skunnemunk conglomerate. No adequate formation is known to the east upon the land, but pebbles of Cambrian quartzite, thought to have come from the east, are found in the Carboniferous conglomerates of Rhode Island and from that direction Woodworth thinks probably came the greater volume of material which filled the Rhode Island basin.

LACK OF RELATION OF APPALACHIA TO THE CONTINENTAL SHELF.

The Control by the Continental Shelf on Paleogeographic Maps.

The doctrine of the permanence of the continental platforms has been held rigidly by many American geologists. Starting in the past century with the recognition of the evidence that the continents have never been the beds of deep oceans, but have been flooded merely by shallow seas; the corollary was attached that consequently the beds of the deep oceans had never been land surfaces. Yet this is not a necessary consequence of the original proposition and has in reality no similar direct evidence to support it; except that basins must have existed sufficiently large in former ages to hold the ocean waters which were then upon the earth. But in the balancing of losses and gains to which the surficial water is subject, it appears probable that the gains have notably exceeded the losses through geologic time. To a somewhat greater degree than this the ocean basins can have increased in volume.

As evidence opposed to the hypothesis of an unchanging form of the ocean basins, many examples have been noted of extinct and living faunas showing their closest affinities on the opposite sides of present ocean basins, or isolated on oceanic islands. The affinities are so special in some cases that many even of the strongest adherents of the doctrine—that both continents and oceans have always been outlined in their present relations—admit some degree of connection of former lands. Yet where land bridges are not required, paleogeographic maps

have held rather closely to the present margins of the continental platforms. In the absence of evidence of a former extension of the land beyond these margins this procedure is no doubt the wisest and without it as a point of departure each different map would represent guess work and not science. But undue importance finally becomes attached to a conclusion for which there is only negative evidence. Thus it has been customary to regard the land of Appalachia, which through the Paleozoic shed sediments westward into the geosyncline, as confined to the area of the present continental platform, although from Nantucket to North Carolina the submerged shelf to the hundred fathom line is but approximately 75 to 80 miles in width.

Breadth of Appalachia implied by the Volume of Sediments.

The present investigation tends to limit the fields of erosion during the Upper Devonian to those ancient terranes now hidden beneath the Coastal Plain and the sea, leaving a width of not more than 125 miles opposite Pennsylvania to supply the great volume of sediments. In fact, if it be assumed of such a marginal region that half of its width shed its waste eastward into the Paleozoic Atlantic, it leaves a maximum width of but 60 miles, to have yielded the sediments which in the Upper Devonian alone were greater in volume than the entire Sierra Nevada. Over New England the available zone within the limits of the continental platform was much wider, but reasons have been given for believing that a large supply of the Upper Devonian sediment of Pennsylvania and Maryland came from the east and southeast.

If the present margin of the continental platform has held approximately its present place since the Upper Devonian, as many paleogeographic maps imply, it means, allowing for a certain breadth of shelf at that time, that Appalachia must have been still further restricted in width. As a quantitative test of such a view assume Appalachia from Rhode Island to Virginia to have been a mountain system 100 miles wide. Consider it an isosceles triangle in vertical cross section, and giving as much waste to the east as to the west. The Upper Devonian sediments between lat. $39^{\circ} 30'$ and 43° and east of long. $80^{\circ} 30'$, approximately the limits of the map, fig. 1, are computed to have had an original volume of 63,000 cubic miles. Neglecting the outlying portions, although these are of great thickness in West Virginia; assume that this sediment is equal to the volume eroded from the western side of Appalachia over a length of 500 miles, from southern Maine to the coast of southern Virginia,—the sediment thus converging into the geosyncline. The computation shows

that the crest of Appalachia would have had to be lowered five miles to supply this much of the Upper Devonian sediments. It is seen from the assumptions that this is a minimum estimate and might readily be increased fifty per cent or more. The easiest escape from these quantitative difficulties is to conclude that there is no relation between the Atlantic boundaries of Appalachia and the present coastal shelf. It would seem that the Upper Devonian slopes leading toward the geosyncline was probably as much as 100 miles wide instead of fifty miles as assumed and that the divide of the drainage was at least as far east as the present 100 fathom line southeast of Long Island and New Jersey. The eastern slopes of Appalachia in that case existed where now is deep ocean. The disproportion between the volume of the sediments in the geosyncline and the present area of the continent to the southeast emphasizes the query raised by Gilbert in 1892, whether Appalachia must not have extended into the present ocean basin in order to provide an adequate source for the Paleozoic sediments.*

The Shelf a Terrace of Post-Paleozoic Construction.

As another line of investigation bearing upon the problem, the nature of the continental shelf should be considered.

Ocean waves are known to have a perceptible effect to a depth of about 100 fathoms, planing away the shore and the higher parts of the bottom, carrying the products of fluvial and marine erosion outward to deeper water. The waves move material along the bottom and prevent the settling of the finest silt until the limit of wave action is reached. Beyond that limit the bulk of the material is rapidly deposited from suspension. In protected situations this depth becomes less and in many places is not over fifty fathoms. There is thus built outwards around the continents a subaqueous terrace, its top gently sloping to the depth of 100 fathoms or less, its front much steeper in comparison, and giving sharpness to the continental margin. The doctrine of the permanence of this line through geologic time implies that the constructional additions are insignificant. But the volumes of sediments which age after age have been poured into continental geosynclines must correspond to other volumes swept out to the borders of the ocean basins. Unless isostatic sinking under the load of sediment compensated progressively for the outbuilding of the terraces, the continental shelves, if ancient lineaments, would have widened on the average by some hundreds of miles during the course of geologic time. If there is isostatic sinking it is

* Continental Problems, Geol. Soc. Am., Bull., iv. 187, 1893.

Professor Grabau also has called attention to this significance of the great volume of Paleozoic sediments.

not so pronounced as to mask the constructional nature of the terrace, as shown by the relation of its upper surface to wave action.* To what extent then are the continental terraces constructional features controlled by erosion and sedimentation, and what are the limits which isostasy places upon them? The answer must satisfy the evidence of both geologic and geodetic nature. It will depend to a considerable degree upon the prevailing conceptions on the rigidity of the crust, as measured by the area and thickness of load which may be piled up before sinking of the foundation begins to keep pace with further loading. In order to gain such an answer the writer has investigated the subject under a separate title.† The results derived from both geologic and geodetic evidence, contrary to

FIG. 5.

FIG. 5. Section of the Coastal Plain and Continental Shelf through Richmond and Fortress Monroe, Va.; vertical scale multiplied by 26.

some recent statements, indicate that the crust now sustains in places loads represented by several thousand feet of rock over areas of several tens of thousands of square miles. Judged by this measure it is quite possible that the continental shelves may be in places constructional features built far outward and upward; changing what would otherwise be a gentler slope from continental platform to ocean basin into a pronounced subaqueous shelf and steeper distal slope.

In the light of this possibility, attention may be turned to the actual evidence and the inferences from that evidence as given by the Atlantic Coastal Plain and its extension in that part of the continental shelf southeast of Pennsylvania and Maryland. It is a region which has been free from folding since the Permian, from fracturing since the Middle

* Professor T. C. Chamberlin has discussed in current articles the significance of this surface of wave planation as showing a lack of control by diastrophism. See especially *Jour. of Geol.*, vol. xxi, pp. 523-533, 1913.

† To be published in the *Journal of Geology* under the title,—"The Strength of the Earth's Crust."

Mesozoic; and the rivers during later time have carried to the seaboard great quantities of sediments. Wells penetrating the water-bearing strata show that a progressive tilting has gone forward since the close of the Jurassic, depressing under the Coastal Plain the erosion surface of Jurassic age and elevating the Appalachians. The information is most complete in Virginia on an east-west section, shown in fig. 5, passing through Richmond and Fortress Monroe. These two localities are on the two sides of the emerged portion of the Coastal Plain and 72 miles apart. At Fortress Monroe a deep well entered the crystalline floor below the sediments of the Potomac group at 2246 feet below sea level. The fresh-water beds of the Potomac are given there as 1300 feet in thickness, much thicker than at the outcrop. Numerous wells near the margin show that the crystalline basement has erosional irregularities amounting to several hundred feet. Their influence is, however, practically eliminated on this section because of the great depth of the well and its distance from the margin of the Coastal Plain. No warping apart from the minor irregularities is indicated between Richmond and Fortress Monroe as shown on the structure section recently published by the Virginia Geological Survey.* The Potomac formations, because of their fresh-water nature, have been held by many geologists to have originated in an estuary. Of a seaward barrier there is, however, no evidence. They are seen to thicken as far east as there is any information and the exposed sediments are best interpreted as the landward side of a delta plain skirting the rising Appalachians and built from their waste.† The erosion from the rising side and the deposition on that which was sinking would tend to promote the tilting. The building outward of the continental terrace would, from the standpoint of isostatic adjustment produce the greatest sinking of the floor under the outer part of the terrace, for there the departure from isostatic compensation is greatest. Such a curve to the Potomac floor is furthermore shown by fig. 5 to be necessary in order to carry the floor beneath the foreset slope of sediments. The adjustments, however, might be by distributive faulting instead of the smooth curve which is shown. It might further be largely due to internal movements which work in the direction of enlarging the ocean basin, and the sediments in that case may keep the surface far above isostatic compensation.

From these several lines of argument it is to be concluded that the Atlantic continental shelf is a subaqueous terrace built

* Samuel Sanford: The Underground Water Resources of the Coastal Plain Province of Virginia, Bull. No. 5, fig. 6, 1913.

† For a fuller discussion of this view see Barrell, Criteria for the Recognition of Ancient Delta Deposits, Bull. Geol. Soc. Am., xxiii, 405-411, 1912.

out since the Jurassic and extending the platform toward limits set by the resistance of the crust. The normal slope from the Appalachians to the ocean basin would in the present period be a much smoother and more gently sloping curve, although quite probably above the present level of the crystalline floor, if surface agencies had not planed across the piedmont on the one side and built out the shelf on the other. The surface of the latter holds then no relation to the limits of Paleozoic Appalachia.

The Ocean Basins widened by Continental Fragmentation.

The preceding arguments lead to the conclusion that the ocean basin has advanced inland since the close of the Paleozoic and that the seat of a part of the ancient land is now deep ocean.

This is in accord with the views of Suess, who holds that the Atlantic and Indian oceans cut across the Paleozoic structures and indicate a breaking down of the continental platforms since those structures were made. It is known also that close faunal relationships have existed in the past between northwestern Europe and northeastern America, implying some path of migration. On the maps by American geologists such a bridge has been shown as a more or less narrow connection circling Davis Strait and utilizing Greenland and Iceland as piers supporting a narrow causeway between North America and Europe. The structural evidence which has been considered would seem to show that such connecting lands may have been broader and more like the areas of the adjacent continental platforms, of which they in fact formed then a portion: at times, flooded in part by shallow sea; at times, in part the seat of ancient mountains.

CONCLUSION ON APPALACHIA IN THE LATER PALEOZOIC.

The old-land of Appalachia during the Paleozoic tended to be a broad and mountainous upland. West of it was the trough into which much of its waste was poured. As in the Eurasian mountain system, when this trough collapsed it was underthrust. Appalachia was overthrust against it. The eastward-dipping folds and faults and the greater uplift and consequent erosion on the eastern side of the geosyncline were in response to this relation of anticlinorium and synclinorium and not to a thrust from the ocean. The ocean in fact need have had no more direct connection than it had in the Laramide overthrusting of the front ranges of the Rocky Mountains upon the Great Plains in the center of the North American continent, or the Neocene overthrusting of the Himalaya upon the plains of India.

The general conclusion to this article which perhaps is most impressive is that regarding the magnitude in breadth and in vertical relations of the ancient orographic elements and the

changes which each successive age has wrought. The record has been interpreted in terms of the great Tertiary mountain systems of Eurasia, consisting of their overthrust structures, piedmont slopes, waste-filled basins, and delta plains,—as the members of a greater system, each part bearing relations to the other. The fragmentary remains of late Paleozoic Appalachia and its waste which still exist, when pieced together in accordance with this pattern, rise to equal grandeur. An orogenic era began in Appalachia in the Devonian and spread as time went on. Great as was the Upper Devonian mountain building, it was limited and was only premonitory of the greater, wider movements of the Pennsylvanian. During the Upper Devonian the interior waters facing the southern Appalachians received only meager supplies of sediment. The crust was there at rest. But with the coming of Pennsylvanian times the mountain system lengthened to the southwestward and its curving arc finally embraced as far as Texas the interior continental basin into which it poured its waste. The Permian witnessed only the final collapse of the interior geosynclines and the inward march of the conquering mountains. The Appalachian revolution began in reality in the Middle Devonian, the first mountain bulwarks being thrown up on the far eastern side of the Appalachian system and to the north. There in Maine, New Brunswick, and Nova Scotia granitic intrusions and volcanic outpourings of Devonian age took place and in the nearby basins the waste resulting from uplift was laid down. The southern part of that system supplied the debris which filled the geosyncline in Pennsylvania.

Our knowledge of the Appalachians as a distinct mountain system begins with the opening of the Cambrian. The basal formations of the Cambrian, or late pre-Cambrian, thousands of feet in thickness, are geosynclinal deposits whose volume testifies to the destruction of great mountains to the east. Lesser movements took place at intervals and one of considerable magnitude at the close of the Ordovician. These, however, were relatively brief and minor orogenic manifestations. They were separated and obliterated by periods of prolonged quiet and erosion. They were more comparable in character to the movements of the Mesozoic and Cenozoic and do not rise to the prolonged growth and culmination of those greater revolutions which preceded and closed the Paleozoic Era. The latter, because of its completer record, has become known as *The Appalachian Revolution* and its earlier development in the Upper Devonian has been traced in this paper.

The Devonian mountains are gone, and where once they rose in defiant height their very foundations are broken and buried, but in remnants of formations born of destruction we may read the epitaph which records their greatness.