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TYPES OF SEDIMENTARY OVERLAP*

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* This paper, under the title "The interpretation of stratigraphic series by the principles of sedimentary overlap," was awarded the Walker first prize by the Boston Society of Natural History in May, 1906.

Introduction

The sedimentary formations of the earth's crust fall readily into two great stratigraphic groups, the marine and the non-marine, which in their essential characteristics are strongly contrasted and which in the analysis of sedimentary series must be carefully differentiated. In spite of the practice to the contrary, stratigraphers will admit that only marine deposits are suited to furnish the record for a complete time scale, and that consequently the standard column of any region should be based on marine deposits only. Where, as is often the case, the column selected as a standard contains non-marine members, the column is imperfect as long as these are retained. Thus the standard Cretacic column of North America is impaired by the retention in it of the non-marine Dakota and Laramie formations, and until recently the standard Triassic section of Germany was practically useless, as it contained only one marine member. The substitution of an extensive series of marine members for the Bunter Sandstein and Keuper has given us a perfect standard of comparison, such as is hardly equaled by that of any other of the geological systems.

Non-marine sediments, however, while not serviceable as members of a standard time scale, are still of great stratigraphic importance, since they furnish us with records of physical changes not determinable from the deposits of the marine series; but as long as non-marine sediments were regarded as lake deposits only, their true significance was overlooked. Now that stratigraphers recognize that non-marine deposits are oftener than not of fluviatile or æolian origin, their real meaning becomes more and more apparent.

The two types of sediment are distinguished from each other not only by their fossil content, but also, and almost as easily, by their physical characters, especially the larger ones. The most striking difference of all lies in the manner in which the successive members of either series are related to each other. In the following discussion the distinguishing characters of the marine and the non-marine series will be separately treated in the order indicated.

Classification of Types of Overlap

The types of overlap of sedimentary strata may be classified as follows:

A. Irregular or discontinuous overlap.

B. Regular continuous or progressive overlap.

1. Marine.
   - *a.* Transgressive.
   - *b.* Regressive.
2. Non-marine.
   - *c.* Fluviatile.

Irregular Overlap

Under this term we may comprise all overlap of concordant sedimentary formations, of any type, which does not proceed regularly in a given direction. All overlaps of strata due to sudden inundations rather than regular invasions belong here; also overlaps due to temporary deposition from any cause, as æolian sediments. Generally this kind of overlap implies some erosion of the underlying concordant formations, thus producing a disconformity. A change of method of deposition may also produce this kind of overlap, as the overlap of the marine Paleozoics along the Front Range region by the non-marine Red beds.

Progressive Overlap

Under this term are included the types of overlap due to a regular progressive onward movement of the zones of deposition, whether the direction of that onward movement is landward, as in a regularly transgressing sea,* or seaward, as in a regularly retreating seashore, and the regular progressive spreading of zones of deposition, as in a growing subaerial fan or dry delta. The first two cases constitute the marine transgressive and regressive; the third the non-marine fluviatile type of progressive overlap. The lake delta may be considered as a local phase of spreading river deposits.

Progressive Overlap in marine Series

The subject of progressive overlap of marine strata may be conveniently discussed under the following headings:

1. Transgressive overlap.

* This is overlap as defined by Geikie. Text Book, 3d ed., p. 518.

2. Regressive overlap.
3. Compound regressive and transgressive overlap.

Transgressive Overlap

When the sea regularly advances upon an old land surface from which there is a continued supply of detrital material, a steadily advancing shore zone of pebbles or sand will be recorded in the sedimentary series which is forming in the transgressing sea. At any given stage in the process a shore deposit of coarse clastics, derived from the old land surface, will form for some distance out, grading seaward into a deposit of finer shore-derived material. In proportion to the distance from the shore the fineness of the material will increase, and at the same time material derived from organic deposits, such as coral reef sands or shell formations, will accumulate in the regions of purer water. With progressive slow advance of the sea, the supply of detritus being uniform,

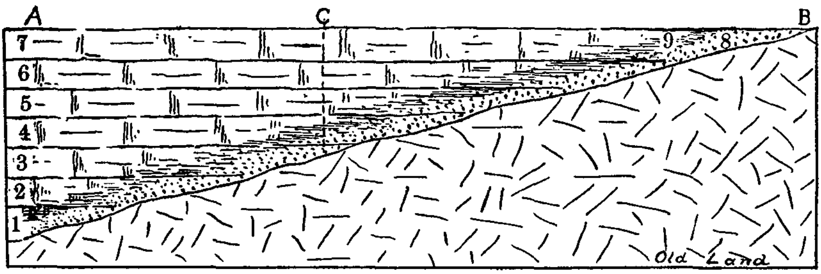

Figure 1.—*Diagram Illustrating Progressive (Transgressive) Overlap.*

the coarser shore clastics will be spread farther up on the old land, while at the same time the zone of offshore deposits will migrate in the same direction and approximately at the same rate as the shore itself. As a result, the offshore deposits of a later period will come to rest on the shore deposits of an earlier period, and if the transgression has been a uniform one, on a uniform old land surface, with a uniform supply of detritus, a vertical section of such a series of successive deposits will show an upward gradation from coarse to fine comparable to the similar gradation in texture of the deposit of a single period from the shore seaward. At the same time there will be a continuous basal bed of coarse clastics spread immediately above the old land surface within the zone of transgression, this continuous bed being made up of the shore ends of the successive units of the series formed during the successive periods of the transgression. The basal bed will be essentially a lithic unit, resting everywhere unconformably upon the old land surface, and it will be succeeded upward by strata of similarly uniform lithic character in most of the sections. But it is evident from a consideration of the mode of its formation that the age of different portions of this basal bed varies, becoming progressively younger in the direction of transgression. The following diagram will illustrate this principle:

The series of successive strata, 1 to 7, is deposited at *A* during the period of transgression of the sea from *A* to *B*, and therefore it constitutes the depositional equivalent of the time interval occupied by the transgression, which may be assumed to have proceeded at a uniform rate. It is evident that the basal sand or conglomerate bed 1–8 is not of the same age throughout, but rises in the scale progressively, until at *B* it is equivalent in age to bed 7 at *A*. The same thing is true of bed 2′–9, a finer bed which directly succeeds the basal bed, and which like it rises in age in the direction of transgression. It is clear that two sections of this series, taken the one nearer the shore than the other, as at *C* and *A*, will have the same lithic succession from the base upward; but section *C* will begin very much higher in the scale than section *A*, and the corresponding lithic units of the two sections will be of different age.

Application of the Principle of Transgressive Overlap in the Sedimentary Series

THE BASAL PALEOZOIC SERIES

General character of the overlap.—Wherever the Paleozoic rocks are found to rest unconformably on the pre-Cambrics, a comparison of sections shows a progressive overlapping of the successive formations, each of which rests, with a basal sand or conglomerate bed, on the eroded surface of the pre-Cambric old land. Some of the more typical examples of this may now be cited.

Newfoundland.—A comparison of the following sections from Trinity and Conception bays, Newfoundland, will show the character of the basal transgression. At Trinity bay, Smith sound, the Lower Cambric (Etcheminian of Matthew) is represented by 811 feet of fossiliferous shales, with some limestones carrying the *Holmia bröggeri* fauna. Almost 350 feet below the top of the Etcheminian is a brick red and pinkish limestone stratum, 27 feet thick, and rich in *Holmia bröggeri, Hyolithes princeps,* and other fossils. This is the Smith Point limestone of Walcott, which has been recognized in Conception, Saint Marys, and Placentia bays. In Conception bay, at Manuels brook, this limestone when found rests directly on the basal conglomerate, which has a thickness of 35 feet, and in its basal portion contains boulders of the underlying gneiss up to 6 feet in diameter; but upward it changes to fine sand.

If the correlation of the Smith Point limestone of the two sections is correct, and if the sections contain no unrecognized faults or erosion planes, we have here a case of progressive encroachment of the sea, apparently from the west eastward, though, of course, the basal gneiss of the Manuels Brook section may represent an old reef or island in the Cambric sea, which was gradually covered by encroachment from all sides. The difference in deposition, however, between these two points is about 300 feet of basal beds, the basal conglomerates of the eastern section being equivalent to the shales 300 feet above the base in the western section and not to the basal beds there. The following diagram illustrates this point:

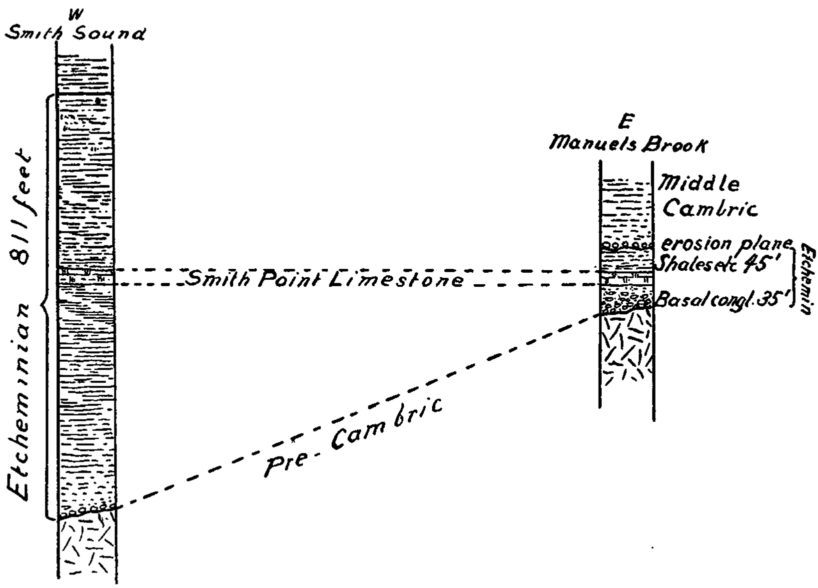

Figure 2.—*Comparison of Section at Smith Sound and Manuels Brook, Newfoundland.*

New Brunswick.—In this district the Cambric rocks have long been included under the general term of the Saint John group, from their typical exposure in the region about Saint John, New Brunswick. Matthew has subdivided the series as follows:*

	Feet
Division 3. (Bretonian) at Straight shore, Portland	700
Division 2. (Johannien) at Kings square, Castleton	1,000
Division 1. (Acadian) at Alms house, Simonds	650
Total	2,350

"The coarser sediments found at the base of the Saint John group are largely derived from those older rocks, chiefly the Huronian (Algonkian), and the line

* Illustrations of the fauna of Saint John group.

of division between it (the Saint John group) and the Huronian (Algonkian) is marked by conglomerates of mechanical origin which show no trace of the hardening process by which the Huronian conglomerates and breccias have been so firmly cemented."*

The Acadian represents the lower part of the Middle Cambric and begins with the Saint John quartzite, which is succeeded by the Protolenus zone, and this in turn by the Paradoxides zone. Beneath the Saint John quartzite is a series of red and green sandy shales 150 feet thick, below which lies the red basal conglomerate. Both the red shales and the conglomerate are referred to the Etcheminian or pre-Saint John terrane. This terrane is fully developed at Hanford Brook, Saint Martins, some 30 miles north of east of Saint John, where it is 1,200 feet thick. Here it begins with a coarse purplish red conglomerate 60 feet thick, which rests upon amygdaloidal greenstones of an older (Cold-Brookian) series, and passes upward into sandstones and flags some 300 feet thick, followed by a second conglomerate 35 feet thick, which in turn is followed by shales and sandy shales to the top of the series.

It is evident, then, that we have here an overlapping series, with a basal conglomerate in each case, that of the Saint John region, however, being equivalent, not to the basal bed of the Etcheminian series of the Hanford Brook section, but to the shales of the upper division of that series.

In Cape Breton island the Lower Cambric or Etcheminian strata were found by Matthew to have a thickness of 3,000 to 5,200 feet at Mira bay, on the eastern coast. Twenty miles farther west, on East bay (Bras d'Or lakes), only 500 feet of Etcheminian occurs. Both sections show a basal conglomerate resting on older rocks, succeeded in both cases by Middle Cambric strata, at the base of which an erosion interval is indicated in some other sections.

On the East Bengal road the lower Etcheminian is 3,200 feet thick, decreasing on the West Bengal road to 1,300 feet, and to 270 feet at Dugald brook, on East bay. The upper division likewise increases from 2,000 feet on the East Bengal to 1,700 feet on the West Bengal road, and to 230 feet at Dugald brook. The increase of the lower beds westward appears to be due to progressive overlap of the beds, while the greater thickness of the upper beds in the eastern section, when taken in connection with the heavy conglomerate which lies at the top of the series in the west, seems to suggest retreatal features of the type more fully discussed later on. Of course here, as in all the sections of disturbed areas, the possibility of the existence of faults and folds must be

* Matthew: Fauna of Saint John group, pt. 1, 1882, p. 87.

taken into consideration, since we can never be absolutely certain of the accuracy of the sections made in such regions. The general correspondence of the facts to the requirements of the theory seem, however, to suggest that the correlations as here given are correct.

In comparing the Myra valley section with the Lower Cambric strata of eastern Newfoundland (811 feet at Trinity bay, 80 to 100 feet at Manuels brook, or even the greater thickness of 1,200 feet at Hanford brook), the discrepancies are such as can not readily be accounted for by differential rate of deposition. In respect to the Trinity and Conception Bay sections, it has already been shown that the difference is in part accounted for by progressive overlap, and the progressive disappearance of the lower members. But this is not altogether the case, since there is a difference of nearly 300 feet in the beds above the Smith Point limestone. This, however, is accounted for in the Manuels Brook section by an erosion interval, as shown by the conglomerate at the base of the next succeeding Middle Cambric, the pebbles of this conglomerate being derived from the underlying Etcheminian. In the Smith Sound (Trinity Bay) section, however, deposition appears to have been continuous from lower to middle Cambric time, since no erosion interval is recorded. Walcott, moreover, correlates the basal 130 feet of the Middle Cambric of this section with the Protolenus beds of New Brunswick. If this correlation is correct, the eastern Newfoundland section represents only the upper part of the New Brunswicktown (Hanford Brook) section. The same reasoning would lead us to regard both the eastern Newfoundland and New Brunswick sections as representing only the upper part of the sections shown in eastern Cape Breton. This conclusion is, of course, based on the supposition that no very pronounced unrepresented interval occurs at the top of the Etcheminian in either the eastern Newfoundland or the New Brunswick section.

Northern Appalachian area.—In eastern Labrador and western Newfoundland Lower Cambric strata rest with basal conglomerates and sandstones (often arkoses) upon the gneisses and other pre-Cambric rocks. They pass upward into shales and limestones, of which over 1,700 feet are exposed at [redacted] bay, Newfoundland. The fauna of these beds is the typical Olenellus fauna of the Appalachian province. Upward these strata are succeeded by nearly 1,500 feet of limestones, with some shales and a quartzite near the base, all of unknown age, while above there is 400 feet of limestone carrying a lower Ordovicic fauna. At Canada bay, Newfoundland, 2,500 feet of conglomerates, shales, and igneous rock form the base of the Cambric series and are succeeded by nearly 3,000 feet of limestones, shales, and intercalated sandstones carrying the Olenellus fauna.*

In northern Vermont the Lower Cambric consists of over 2,000 feet of limestones and shales with the Olenellus fauna, but the base of the series is not exposed. Southward, in the slate belt, the maximum thickness of the Lower Cambric is estimated by Dale† to be 1,400 feet, at Hebron mountain. The base is not exposed and the upper part is formed of quartzite and sandstone ranging in thickness up to 100 feet. Then follows 1,000 to 1,200 feet of Lower Ordovicic, the Middle and Upper Cambric series being apparently absent.‡ On the flanks of the Green mountains the basal Cambric beds are sandstone, resting unconformably on the pre-Cambric gneiss. These are the granular quartz of the Vermont geologists, which were long ago referred to the Potsdam on account of their position. The thickness of the quartzite is estimated at from 800 to 900 feet,§ and about 470 feet of the overlying Stockbridge limestone is also referred to the Lower Cambric.‖ This makes a total of 1,370 feet for the maximum of the Lower Cambric in the Green Mountains section. Compared with the Highgate Springs section, the base of the Green Mountains section seems to be considerably higher in the column, since in the northern Vermont section the basal beds are not shown. Walcott has suggested that the great mass of argillite east of the Vermont Central Railroad track in the Georgia section may be older than the limestone at the base of the section.¶ If this is the case, the Vermont section becomes more than double the thickness now assigned to it. In any case it is likely that the basal granular quartz of the Green Mountains is the time equivalent of the upper portion of the limestones of northwestern Vermont.

Southern Appalachian area.—The Hardyston quartzite of New Jersey represents the basal member of the series in the northern part of the southern Appalachians. It rests on the pre-Cambrics of the Highlands and varies from a few feet to over 200 feet, probably owing to the irregularity of the pre-Cambric floor.** It is often feldspathic and occasionally a conglomerate. It frequently grades up into the overlying Kittatinny limestone, which has an estimated thickness of from 2,700 to

* Murray: Geological Survey Rept. of Newfoundland, 1864.

† Nineteenth Ann. Rept. U. S. Geological Survey, pt. iii, p. 178.

‡ This appears to be true of the Middle Cambric in the northern Vermont region, though coarsely conglomeratic limestones with Upper Cambric fossils occur here. On the whole it seems that the northern Appalachian trough was dry land during Middle Cambric time, the sea returning only in Upper Cambric time.

§ Pumpelly, Wolf, and Dale: Monograph 23, U. S. Geological Survey, 1896, p. 190.

‖ Dale: Fourteenth Ann. Rept. U. S. Geological Survey, 1895, p. 541.

¶ Bulletin 30, U. S. Geological Survey, 1886, p. 19.

** Weller: Paleontology of New Jersey, vol. iii.

3,000 feet, and is mostly Cambric in age, though the upper beds carry an undoubted Beekmantown fauna. No Middle Cambric fossils have been recognized in this limestone, but an Upper Cambric fauna occupies at least the upper third, exclusive of the portion referable to the Beekmantown. In Pennsylvania a basal Cambric sandstone has been observed in a number of localities resting upon the pre-Cambrics. In the Cumberland valley this bed, known as the Reading quartzite, is probably near the horizon of the Hardyston quartzite, while the Cumberland limestone is in general the equivalent of the Kittatinny. The latter is separated, in New Jersey, by an erosion interval from the Trenton which follows it; its upper limit is therefore not of the same horizon everywhere. Whether or not the same is true of the Cumberland has not been ascertained. The basal sandstone is well shown at the Chickies (Chiques) rock on the Susquehanna above Columbia (Lancaster county), from which locality it takes its name. From the occurrence in it of Scolithes it was formerly referred to the Potsdam by Lesley.* At Emigsville a typical Olenellus was found in the sandstone.† Its thickness is estimated at 1,300 feet, though this may be excessive.‡ It is succeeded by 1,500 feet of limestones, the upper portion of which carry Ordovicic fossils.

At Balcony Falls, Virginia, 300 feet of sandstones and slates, with a basal conglomerate bed, form the basal Cambric series (Chilhowee), throughout most of which fossils of the Olenellus series occur. At Monterey and along the Blue Ridge mountains over 4,000 feet of quartzites, sandstones, shales, and mottled limestones occur, containing the Olenellus fauna. These are overlain by the Shenandoah limestone, the lower part of which is Middle and Upper Cambric. At Harpers Ferry the Chilhowee series is subdivided as follows:§

	Feet
Shenandoah limestone.	
Chilhowee series:	
Antietam sandstone	500
Harpers shale	800 to 1,200
Weverton sandstone	100 to 900
Loudon formation—slates, sandstones, conglomerates, and limestone—maximum	800
Unconformity.	
Catoctin schist (Algonkian).	
Total Chilhowee	3,400

* Lesley: Second Geological Survey of Pennsylvania, vol. x, 1885, pp. 16-17.
† Walcott: Loc. cit.
‡ Bascom: Bull. Geol. Soc. Am., vol. 16, p. 298.
§ Harpers Ferry folio.

In the region about Knoxville, Tennessee, the Shenandoah becomes known as the Knox dolomite and has a thickness of 3,500 feet. Beneath it, southeast from Bays mountain, is from 8,000 to 9,000 feet of shales and limestones, with occasional sandstone members, which are especially prominent toward the base, where extensive conglomerates occur.*

The series comprises:

	Maximum thickness Feet
Knox dolomite	3,500
Nolichucky shale	550
Marysville limestone	550
Rogersville shale	220
Rutledge limestone	450
Rome formation (shales)	250
Rome sandstones	700
Beaver limestones	300
Apison shale	1,100
Hesse sandstone	500
Murray shale	300
Nebo sandstone	500
Nichols shale	800
Cochran conglomerate	1,600
Sandrock shale (with Starrs conglomerate lentils farther southwest)	1,000
Total Chilhowee	8,820

Farther to the northwest† all the formations between the Rome and the Knox dolomite are represented by the Conasauga shale series, with a thickness of from 600 to 800 feet. This may be a nearer-shore formation, and the diminished thickness from 1,280 (minimum) or 2,770 (maximum) to 600 or 800 feet may be due to a rise of the top of the sandstone member underlying, which, from lithic similarity, is here also called Rome. Owing to the non-exposure of the base, the exact relation of these beds to the underlying pre-Cambric land surface can not be determined. In western Virginia‡ all the members above the Rome formation are shown with slightly increased thickness. The lowest formation is the Russell sandstone, 1,400 feet thick, but without exposure of the base; so we do not know whether the Russell is a basal bed or whether the lower beds are concealed. Since these beds are along the strike of the strata, as shown in the Knoxville folio, it seems probable that they are of the same age, and that hence the equivalent lower beds occur in the embed of this region.

* Keith: Knoxville folio.
† Briceville folio.
‡ Rome, Tazewell, Bristol, Estillville, Morristown, and Briceville folios.

Southeastward from western Virginia, the Rutledge, Rogersville, and Marysville formations are replaced by the Honaku limestone, a siliceous limestone aggregating perhaps a thousand feet in thickness.

The foregoing sections demonstrate that the transgression of the Cambric sea, in which the strata now preserved accumulated, was toward the *northwest* in the southern Appalachians.

South central section.—In Oklahoma and Indian Territory the Wichita and Arbuckle uplifts have exposed the basal Paleozoics. Here the basal sandstone member, sometimes wanting, is the Reagan sandstone, varying up to 500 feet in thickness. It is succeeded by the Arbuckle limestone, over 4,000 feet thick, of which perhaps the lower 1,000 feet are Cambric.* The following basal section occurs in the Arbuckle mountains:

Ordovicic

Simpson Formation

	Feet
Greenish shales and thin crystalline and shelly limestones, interstratified with a number of beds of sandstone, one of which, near the middle of the formation, is from 100 to 200 feet thick. The lower division carries a fauna similar to the Chazy of New York and Canada, while the fauna of the upper division is closely related to that of the upper Stones River group of Tennessee and Kentucky and the Stones River formation of the upper Mississippi valley. Thickness......	1,200 to 2,000

Slight erosion disconformity and local deposits of pure sand.

Cambro-Ordovicic

Arbuckle Limestone

	Feet
Thinly bedded shaly limestones, with sandy beds at the top, grading down into light blue and white limestone and cream colored to white crystalline dolomite, with occasional thin shaly strata and occasional siliceous and cherty beds. The age of the formation varies from Middle Cambric to Lower Ordovicic, including the whole of the Upper Cambric and the Beekmantown formations. "From the base of the formation upward to the top of the Middle Cambrian the rocks are composed of thin bedded and in part intraformational conglomerate and shaly limestones." This comprises several hundred feet, while the Upper Cambric includes about 700 feet of strata.† Ulrich holds that an erosion interval occurs at the top of the Middle Cambric, but the evidence given for that is not conclusive. In the upper 1,250 feet fossils of the Beekmantown horizon occur. Thickness..............................	4,000 to 6,000

* J. A. Taff and E. O. Ulrich: Professional paper no. 31, U. S. Geological Survey.

† C. N. Gould: Geology and water supply of Oklahoma. U. S. Geological Survey Water Supply paper no. 148.

Cambric.

Reagan Sandstone

	Feet
Calcareaus sandstones, thin bedded and laminated, grading downward into clays and greensands, with coarser sands lower down, which pass downward into quartzites and arkose conglomerates of poorly assorted granitic material. At the top of the sandstone and in the shaly and calcareous strata for several hundred feet above the sandstone (basal part of Arbuckle), fossils of Middle Cambric age occur. The thickness averages 300 feet, but varies from almost nothing to	500
Great unconformity, with irregular erosion surface.	
Granite and porphyry.	

The occurrence of Middle Cambric fossils in the Reagan sandstone marks the beginning of the time of sedimentation as Middle Cambric and probably as the early portion of that period. There is, then, an overlap from the southeast, where the basal sandstone and a considerable part of the limestone is of Lower Cambric age.

In the Ozark region the following section of the basal Paleozoic rocks is exposed:*

				Feet	Feet
Ordovicic	Lower	Potosi group.	Joachim limestone	0 to	150
			Crystal City sandstone	0 to	200
			Jefferson City limestone	50 to	250
			Roubidoux formation	70 to	225+
Cambric	Upper		Gasconade limestone	450 to	650
			Elvins formation	0 to	120
	Middle		Bonneterre limestone	200 to	500 ?
			La Motte sandstone	0 to	300

Great unconformity.
Archean granites and porphyry.

The La Motte sandstone constitutes the basal formation of this section and was formerly identified as Potsdam sandstone. It is frequently a coarse grit or conglomerate near the base, the pebbles being quartz or granite and porphyry, and in the Saint Francis Mountain region a conglomerate of porphyry pebbles lies at the base of the formation. Upward the La Motte becomes more thinly bedded and flaggy, and calcareous beds make their appearance, the transition to the overlying Bonneterre being gradual. The sandstone may disappear altogether, probably along

* Bain (H. Foster) and Ulrich (E. O.): The copper deposits of Missouri. Bull. no. 267, U. S. Geological Survey.

more elevated portions of the old land surface, which, being kept free, on subsidence, from sand accumulations, received directly the deposits of the limestones, which thus overlap the basal sand.

The Bonneterre beds are granular, highly magnesian limestones, often with chlorite in the basal portion. The contact with the underlying formation seems to be a gradational one, indicating continued subsidence, and therefore advance of the sea. The shaly portion contains *Lingulepis* cf. *lamborni*, together with some other fossils, which are regarded as fixing the age of this bed as probably Middle Cambric.

An erosion interval is believed by Ulrich to separate this formation from the next overlying Elvins formation, though the evidence is meager. It consists of an irregularity at the top and the presence of one or more beds of limestone pebbles. The Elvins formation is Upper Cambric, according to its fossils. It consists of shales, shaly limestones, and more or less earthy dolomites. Locally the contact with the overlying Potosi group appears to be disconformable, but in other cases there seems to be a gradation upward into the Potosi.

The Potosi is on the whole a shallow-water and perhaps in part continental deposit with conglomeratic layers, sun-cracked beds, and local erosions. The lower beds are dolomitic limestones, while sandstones of a more or less lenslike character occur in the middle portion, sometimes amounting to beds of considerable extent and uniformity (Roubidoux formation). Upward the series is again terminated by a dolomitic limestone (Jefferson City limestone), which in turn is succeeded by the Crystal City sandstone, with occasionally an erosion disconformity between the two. The Joachim limestone, however, which overlies the Crystal City sandstone, forms a continuous depositional series with it.

While the significance of the basal section appears to be marred by the occurrence of planes of erosion disconformity, it seems nevertheless true that the basal sandstone in this section has risen until it probably lies nearer the top than the bottom of the Middle Cambric series. There seem to have been elevations in the Ozark dome at stated intervals, which caused partial retreat of the sea, followed by a readvance. This is the meaning of the numerous intercalated sandstone beds.

The Upper Mississippi area—Subdivisions.—In eastern Wisconsin the subdivisions of the basal Paleozoic are, according to Chamberlin, as follows:*

* Geology of Wisconsin, vol. 2, p. 295.

	Feet
Lower Magnesian.	
Saint Croix series.	
6. Madison sandstone	35
5. Mendota limestone (including shale and sandstone)	60
4. Sandstone (calcareous)	155
3. Bluish shale (calcareous)	80
2. Sandstone (slightly calcareous)	160
1. Sandstone (very coarse, non-calcareous)	280
Total	770

Northward the lower members disappear by overlap of the higher. The Mendota bed (number 5) is the fifth Trilobite bed of Owen, with *Dicellocephalus minnesotensis, D. pepinensis, Lingula aurora,* and *L. mosia.*

The section at the Saint Croix Dalles has been studied in great detail by Berkey.* He recognized the following subdivisions:

<table>
<tr><td rowspan="5">Magnesian series (Hall and Sardeson).</td><td colspan="3">Shakopee dolomite.</td><td></td></tr>
<tr><td colspan="3">New Richmond sandstone.</td><td></td></tr>
<tr><td colspan="3">Oneota dolomite.</td><td></td></tr>
<tr><td colspan="3">Jordan sandstone.</td><td rowspan="5">The Saint Croix formation (Winchell).</td></tr>
<tr><td colspan="3">Saint Lawrence dolomites and shales.</td></tr>
<tr><td rowspan="4">Basal sandstone series (modified from Norton).</td><td colspan="3">3. Franconia sandstone (100 feet).</td></tr>
<tr><td rowspan="2">2. Dresbach shales (150 feet).</td><td>Obolella polita zone.</td><td>Greensands and shales.</td></tr>
<tr><td>Lingulepis pinnæformis zone.</td><td>Calcareous and pyritiferous shales.</td></tr>
<tr><td colspan="4">1. The lowest formation of this series is not exposed in the Dalles area, but it includes the lowest sandstone beds and possibly also the "Hinckley sandstone" (0 to 1,000 feet).</td></tr>
</table>

The Jordan sandstone of this section is correlated by Winchell with the Madison sandstone of Wisconsin. At the Dalles of the Saint Croix it contains a considerable fauna, listed by Berkey,† including *Dicellocephalus osceola.* The Saint Lawrence shales are correlated with the Mendota beds of Wisconsin (fifth trilobite bed of Owen), and include, besides a considerable fauna,‡ *Dicellocephalus minnesotensis* and *D. pepinensis* Owen. The Franconia, or third trilobite bed of Owen, contains a rich trilobite fauna,§ and so does the Dresbach, though this fauna is quite distinct from that of the overlying bed. The species here agree more closely with those of the Potsdam of New York, with which Hall and Sardeson correlate this and the Franconia sandstones. The thickness of this basal series at Minneapolis is nearly 1,550 feet.‖

* American Geologist, vol. xx, p. 377.
† Ibid., vol. 21, p. 270.
‡ Berkey: Loc. cit., p. 271.
§ Berkey: Loc. cit., p. 272.
‖ Hall and Sardeson: Bull. Geol. Soc. Am., vol. 3, p. 338.

Lake Superior sandstone.—This formation is generally referred to the Upper Cambric and correlated with the Potsdam of New York and the Saint Croix of the upper Mississippi valley. From a consideration of the facts furnished by the preceding sections, the progressive advance of the Cambric sea over the North American continent has become apparent. The advance was comparatively gradual, progressing through most of Cambric time and not reaching the upper Mississippi valley until the end of that period. It is therefore most likely that the basal beds of the Lake Superior region mark a higher level than those of the Saint Croix area, and their correspondence to the lower Magnesian series is not improbable. In fact, from their position it seems that they are more readily referable to the Lower Ordovicic than to the Upper Cambric. The section of this region is, however, complicated by the retreat and readvance of the Ordovicic sea, of which the Saint Peter sandstone is the record. This will be more fully discussed under another section of this paper, and therefore the consideration of the equivalency of the basal sandstone of the Lake Superior region is deferred. A few local sections, however, may be added here, to show that in places at least this sandstone is much higher even than basal Ordovicic.

Encampment d'Ours.*—On this island in the south channel (Lake Huron) the base of the section is formed by the quartzites and slates of the Huronian series, upon which rest unconformably 100 feet or more of light colored soft, sometimes conglomeratic, sandstone. This is succeeded conformably by 60 feet of shales and limestones. The lower beds of this series are "prevalently arenaceo-calcareous shales of a dusky green or bluish color." They contain the following species:

Species of the lower Bed	*Range Elsewhere*
Camarotoechia plena Hall	Chazy.
Rafinesquina alternata (Conrad) small var.	Chazy to Richmond.
Cyrtodonta huronensis Bill	Stones River to Trenton.
C. subtruncata	
Vanuxemia inconstans Bill	Black River to Trenton.
Matheria tener Bill	Trenton.
Liospira eugenia (Bill.)	Black River.
Orthoceras multicameratum Emmons	Stones River to middle Trenton.
O. granulosum Rominger	
Stictopora ramosa Hall	Stones River.
Callopora ramosa (D'Orbigny)	Lorraine.
Columnaria cystoceras, etcetera.	

* Rominger: Report on Paleozoic rocks of Upper peninsula of Michigan. Michigan Geological Survey, vol. i, pt. III, 1873, p. 64.

This fauna is clearly of early Trenton (Black River) or Chazy age—a fact which makes the underlying sandstone more nearly equivalent to the Saint Peter of Minnesota (transgressional portion; see beyond) than to any part of the basal sandstone series of the Upper Mississippi region.

On Sulphur island higher strata rest upon the Huronian quartzites without the intervention of the sandstones.* This, as suggested by Rominger, very likely represents a submerged reef or mound of the Baraboo type of Wisconsin; but this does not seem to be the case in the Encampement d'Ours section, where a great thickness of strata, comparable to the basal Superior sandstone, succeeds the Huronian. There can be little question that at this portion of the shore the Middle Ordovicic strata overlapped the Cambric and rested with a basal sandstone on the pre-Cambric. The reference of this bed to the Cambric is clearly erroneous.

On the island of Lacloche (Cloche island) a similar reddish, greenish, and whitish sandstone, from 20 to 30 feet thick, rests on the pre-Cambric crystallines. It passes upward into arenaceous dolomites and limestones with an abundance of fossils, which first appear in the upper layers of the sandstone and which clearly establish the age of the formation as Black River. The probable identity of this sandstone and that on Saint Joseph and Encampement islands with the Saint Marys sandstone of Sault Sainte Marie was early pointed out by Logan, who considered it improbable that these sandstones are the equivalent of the Potsdam of New York.

From a number of localities a siliceous dolomite varying up to 100 feet in thickness has been recorded as lying above the Superior sandstone; this formation, named the Hermansville limestone by van Hise and Bayley,† is generally regarded as of Beekmantown age, though the evidence for this is by no means conclusive. In the Iron Mountain region Upper Cambric fossils are recorded from the basal sandstone, but this does not prove that the basal sandstone of Marquette and the pictured rocks is of the same age. In fact, from their position with reference to the transgression of the Cambric sea, these more northern sandstones must be regarded as of later age than that of the Menominee district. If the Hermansville limestone (Auxtrains formation would be a better name, from the more typical exposure on that stream) proves eventually to be Beekmantown rather than Chazy (that is, Upper Stones River or Lowville), the late Cambric or early Ordovicic age of part of the Superior sandstone must be conceded. In that case, however, the basal sandstone of Sault Sainte Marie and eastward is of much later age, belonging to

* Rominger: Loc. cit.

† Menominee folio.

post-Saint Peter time, the great Saint Peter hiatus separating it from the basal sandstone of Cambric age.

Western Adirondacks and Canada.—Along the western flanks of the Adirondacks the Lowville (upper Chazy) overlaps the preceding formations and rests with a basal sandstone upon the crystallines. This sandstone grades upward through a calciferous sandrock into the purer limestone. The calciferous member has been compared with *the* Calciferous or Beekmantown of the Mohawk and Champlain valleys, with which it agrees in lithic character; but it is evidently a much higher member of the Ordovicic series. This basal bed is traceable northward to the Frontenac axis, on the west side of which, as at Kingston, Ontario, it is a well marked basal sandstone—the Rideau. This sandstone was formerly regarded by Canadian geologists as Potsdam, and the overlying formation has been referred to the "Calciferous" (Beekmantown), with which it agrees in lithic character. The occurrence in these overlying beds of Black River fossils, however, proved this correlation to be erroneous, and Ami suggests that the basal sandstone bed may be the shore equivalent of the Chazy. Wilson,* on the other hand, thinks it is the basal arenaceous member of the lower Black River; and this is probably more nearly in accord with the facts.

In this section and elsewhere in Canada the Trenton limestones (Black River) have been found to rest in places directly upon the crystallines without intervention of basal beds. This fact, as in the case of Sulphur island, is probably to be explained by assuming a slowly submerged island or reef of small extent, from which, in the deepening sea, the siliceous clastics would be removed by the agitated waters.

On the whole, it may be confidently asserted that it is extremely improbable that Potsdam or other Upper Cambric formations occur in Ontario west of the Frontenac axis or east of the Sault Sainte Marie, and that the basal sandstone in all this region is therefore of later age, probably in most cases of late Chazy or early Trenton.

East of the Thousand islands the Potsdam sandstone of New York has been traced northward to the Ottawa, and then eastward past Montreal, along the Saint Lawrence. In some localities along this line the fossiliferous limestones of the Beekmantown overlap the basal sandstone and rest directly upon the crystallines. In typical exposures the Potsdam grades up into the Beekmantown or Calciferous, the fossils of which are types found near the middle of the Beekmantown of the Champlain valley. At Prescott and Maitland nearly 80 feet of limestones, shales, and sandstones overlie the Potsdam, and the lower portion of this series carries

* A. W. G. Wilson: Canadian Record of Sciences, vol. ix, 1903, p. 132.

Scolithes canadensis. The section terminates with a concretionary bed, which at Grenville, where these fossiliferous beds rest directly upon the crystallines, is followed conformably by Chazy. Unless there is an unrecognized hiatus here, the Calciferous of this section represents only the uppermost Beekmantown of the Champlain valley, where this formation has a thickness of 1,800 feet, according to Brainard and Seeley.* If this is the case, then the Potsdam of this series, since it forms a continuous series with the Beekmantown beds overlying, is also of Beekmantown age; for it is hardly conceivable that under apparently uniform conditions 1,800 feet of limestones should accumulate in the Champlain valley, while less than 100 feet accumulated in the Ottawa region. Even if a hiatus exists between the Beekmantown and Chazy of the Ottawa River sections, we can still regard the Calciferous and Potsdam of these sections as above the base of the Beekmantown of the Champlain valley, since the fauna is more comparable to that of the later Beekmantown of the Champlain valley. If this deduction is sound, it leads us to question the Cambric age of all the Potsdam of the Ottawa river and the Rivière du Nord. The fossils found in this basal sandstone are the worm tube *Scolithes canadensis,* and the peculiar tracks called Protichnites, besides *Lingulepis acuminatus, Ophileta compacta, Pleurotomaria* cf. *lawrentina,* and fragments of Orthoceras. The species of gastropods are also characteristic of the Calciferous of these regions, in which formation also occurs a species of Scolithes. *Lingulepis acuminata* is not strictly a Cambric fossil, for the species is found to range up into the Beekmantown at Whitehall, New York, and in Saint Lawrence county. *Ophileta compacta* also occurs in the upper beds of the Chateaugay section in what is considered typical Potsdam sandstone, associated with *Lingulepis acuminata, Dicellocephalus* sp.?, and *Ptychaspis* sp.?†

One hundred and fifty miles up the Ottawa from Grenville, at the Allumette rapids, near Pembroke, the Chazy rests with a basal conglomerate upon the gneiss, and at Saint Ambroise the Trenton rests upon the crystallines with only 20 feet of sandstones intervening. This sandstone has been referred to the Potsdam, but it is more probably referable to the lower Trenton.

Basal Paleozoic beds of the Rocky Mountain region.—Wherever the Paleozoics are exposed in contact with the crystallines, a basal sandstône or conglomerate forms the base of the series. In a number of localities this basal sandstone (Sawatch quartzite) carries a Dicellocephalus fauna, as in Gunnison county (Crested Butte), at Aspen, the Eagle river and

* Bull. Amer. Mus. Nat. Hist., vol. iii, 1890, no. 1, pp. 2, 3.

† Walcott: Correlation papers, Cambrian, p. 343, 347.

Tenmile districts, at Leadville, and elsewhere. At Manitou park 100 feet of sands lie between the fossiliferous Ordovicic limestones and the granite. In the upper bed of this sandstone series Lingulepis and Obolus have been found, on the strength of which discovery these sandstones are referred to the Cambric. At another point in the Park the thickness of this series is 86 feet, while in still another section 40 feet of sandstone intervene between the granite and the Ordovic limestone.

The section at Perry park was examined by the writer. On the granite lie about 100 feet of sandstones, with some cherty limestones, followed by a thin bed of brecciated rock in which the fragments are limestone and chert. This is immediately succeeded by a cherty limestone carrying Carbonic fossils and referable to the Milsap limestone of Cross. The brecciated bed may indicate a line of disconformity, which would justify the reference of the basal sands to the Upper Cambric. On the other hand, the bed referred to shows no evidence of so extensive an erosion interval as would be necessary to make the basal bed Cambric. There seems to be no valid reason why we should not return to the earlier view, namely, that these basal beds are also Carbonic, resting by overlap directly upon the granite. If this is the case, this sandstone is probably not continuous with the basal sandstone of Manitou, the overlap being of the irregular instead of the progressive type.

Another section was examined by the writer in Williams canyon, near Manitou Springs, and a detailed analysis of the beds was made. The basal portion was also examined in Queens canyon. In both cases limestones with Ordovicic fossils were found a short distance above the basal sandstone, of which there are 48 feet in Williams canyon and less than half that amount in Queens canyon. At Canyon City, Walcott found the Harding sandstone resting unconformably on the Algonkian gneiss and miscaceous schist. The base is a 5-foot bed of coarse light gray sandstone, followed by sandstones becoming gradually more reddish and purplish and containing a Lower Trenton molluscan fauna. With these occurs the remarkable fish fauna characteristic of this formation.* Elsewhere in this region, however, Lower Ordovicic limestones and basal sandstones referred to the Cambric occur below the Harding.

The basal sandstones of the Front range, except in such cases as the Harding sandstone, are generally regarded as of Upper Cambric age. That some of these sandstones are of later age than Cambric, representing the continuous encroachment of the sea into Ordovicic time, can hardly be questioned. In fact, from the character of the few fossils found in the limestones immediately overlying, there is some reason to believe that in

* Walcott: Bull. Geol. Soc. Am., vol. 3, 1892, pp. 153-172.

the Manitou Springs region the basal sandstone is Lower Ordovicic rather than Cambric. That continued encroachment of the sea caused the overlap of the Ordovicic is shown in a number of cases along the Front range.

In the Sangre de Cristo range the Arkansas sandstone of Carbonic age overlaps the Lower Paleozoics, resting for the most part directly on the granite foundation of the range. This case, however, is probably not an example of progressive overlap, but of the irregular type.

Foreign examples.—The basal Paleozoic section of the north of Scotland furnishes a record of nearly continuous subsidence, and therefore of progressive advance of the sea on the land of that period. Resting uncomformably on the pre-Cambric Torridon sandstone is a basal conglomerate with pebbles up to an inch in diameter, made of the underlying material. This passes upward into cross-bedded sandstones and arkoses, which in turn grade upward into the "pipe rock," a fine quartzite penetrated by numerous worm tubes (Scolithes sandstone, Eriboll quartzite). These basal clastics, probably in part non-marine, are from 450 to 600 feet thick, and are succeeded by mudstone, the so-called Fucoid beds, in which calcareous sediment first appears. This is the beginning of the granular dolomite which becomes most characteristic of the upper beds. The dolomites, with a thickness of perhaps 1,500 feet (calciferous sandrock or Durness limestone series of Scottish geologists), ranges in age from Cambric to Lower Ordovicic. The calcareous beds bear evidence of accumulating in quiet water, yet there is near the middle of the series a cross-bedded sandstone, which indicates an interruption and temporary return of shore or dry land conditions, after which offshore sedimentation again took place in this region.

This section, then, indicates that a progressive subsidence took place (interrupted by the interval referred to), and that hence we must look somewhere for successive overlapping of the beds and the rise of the basal clastics in the series. The record of overlapping has been destroyed by erosion in the northern area, but in Wales we still find traces of it. In southern Wales the basal beds of the Cambric are conglomerates, sandstones, and shales, with lower Cambric fossils, and 1,570 feet thick (Caerfai group). They are succeeded by 1,800 feet of sandstones and slates, with mid-Cambric fossils (Solva group), and higher still by 750 feet of shales and grits, with *Paradoxide daudis* and *P. hicksii* (Menevian). These are followed by the Lingula flags (2,000 feet), and are later succeeded by the Tremadoc slates (1,000 feet), which are regarded by British geologists as forming the top of the Cambric, but are classed by continental geologists with the basal Ordovicic. There is a record of subsidence here, but the subsidence is not so marked, nor is the shore zone removed to the extent shown in northern Scotland. The deposits here, aggregating 7,000 feet in thickness, are terriginous throughout. In western England the Cambric beds have a more offshore character, consisting of basal sandstones, followed by calcareous beds and by the Dictyonema and Shineton shales. There are some intercalated conglomerates, and the thickness of the series is much less than in Wales, thereby indicating some oscillating conditions. On the whole, however, there seems to have been a steady advance of the sea westward.

In northern Wales the lowest Cambric beds are the Llanberis slates, 3,000 feet thick, and the Harlech grits, a continental formation 6,000 feet thick. This is followed by 225 feet of Menevian, and then by 3,100 feet of the Lingula flags (Upper Cambric), which in turn are succeeded by the Tremadoc (1,000 feet). The Llanberis slates rest upon quartz felsite, and have furnished *Conocoryphe* and *Hyolithes*. They are most probably to be classed as Middle Cambric, which fixes the transgression as of that data in north Wales. The transgression reached Anglesea, in northwestern Wales, toward the close of Cambric time; for here the pre-Cambric crystallines are succeeded by basal quartz-jasper conglomerates of Tremadoc age,* all the earlier beds having come to an end and being overlapped by the highest of the series. The fossiliferous Tremadoc beds pass upward into beds with Arenig fossils.† The basal conglomerate thus rises in the scale, until from Lower Cambric in southern Wales it has become uppermost Cambric in northwestern Wales.

In Scandinavia the basal Cambric is the Fucoidal sandstone, which appears to represent a reworked continental deposit, as indicated by the presence of the "drei-kanter." This sandstone is probably not of the same age throughout, but represents higher and higher horizons toward the old land, though still holding its place as a basal bed resting directly upon the crystallines.‡ It represents, in other words, a basal clastic of a transgressing sea.

The well known fact that the lowest Cambric deposits of Bohemia are of Middle Cambric age may be cited as another example of the overlap of higher on lower formations in a continually transgressing sea. The basal beds resting directly upon the pre-Cambrics are coarse conglomerates and

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* Hughes: Quart. Jour. Geol. Soc., vol. xxxvi, p. 237; xxxviii, p. 16.

† Professor Hughes, in his second communication, refers the species of Orthis found in the sandstones above the basal conglomerate, which he formerly identified as *O. carausii*, an Arenig or Tremadoc species, to *O. hicksii*, a Menevian species, making the two types con-specific. On the strength of this, he suggests the possible Menevian age of the basal Cambric beds of Anglesea. Since they are, however, followed without break by typical Arenig strata, and since the species of Orthis found is a typical Tremadoc and Arenig species, even though considered only a variety of the Menevian *O. hicksii*, the reference of these basal beds of Anglesea to the Tremadoc is probably correct.

‡ See Nathorst: Sveriges Geologi, p. 145.

sandstones, the age of which is regarded as that of the *Paradoxides œlandicus* zone—that is, some distance up in the Middle Cambric.

THE BASAL MESOZOIC SERIES

The Central area.—At the beginning of Mesozoic time the North American continent was mostly dry land. Transgression of the sea began in Jurassic time in the Mexico area, and progressed northward and westward, with some oscillations, to southern Colorado and Nebraska, and possibly to southern Dakota, when a period of extended retreat was inaugurated, as recorded in the Dakota sandstone. The record of the advance is embodied in the basal sands of the Comanche series of Texas and the states immediately to the north. The progressive advance of the sea and the resultant rising of the basal sandstone in the scale have been discussed in detail by Hill, who divides the series as follows:*

Washita	Buda limestone. Denison formation. Fort Worth formation. Preston.
Fredericksburg	Edwards formation. Comanche Peak. Walnut.
Trinity	Paluxey. Glen Rose. Travis Peak.

In central Mexico the Comanchean series is composed mainly of limestones which succeed the Upper Jurassic Aucella beds with perfect conformity and continuity of deposition. The Jurassic beds, however, rest unconformably upon the earlier formations, with a basal sand and conglomerate.†

On the tropic of Cancer the basal bed has risen into the base of the Comanchean series, the overlying beds changing progressively through arenaceous and calcareous clays to limestones (Tehuacan limestones). From this point northward to Texas and into Indian Territory the basal bed rises progressively in the series, but with several retreatal movements, which will be referred to more fully below. The general advance, however, is indicated by the change in character and thickness of the formations. Thus, at Austin, Travis Peak beds are over 800 feet thick, and

* R. T. Hill: Twenty-first Ann. Rept. U. S. Geological Survey, pt. 7, p. 115.
† R. T. Hill: Am. Journal of Science, vol. xlv, 1893, p. 311.

begin with basal sands and conglomerates. More than two-thirds of the formation is limestone, and it is succeeded by 600 feet of Glen Rose limestone, the Paluxy being undeveloped as a sandstone. At Twin mountain, in Erath county, Texas, the Glen Rose is a slightly siliceous limestone 5 feet thick, and is inclosed between 115 feet of basal sands and conglomerates and 190 feet of Paluxy sands. At Decatur, Wise county, nearly 100 miles northeast along the strike from the preceding locality, the merest trace of the Glen Rose limestone appears between 200 feet of basal sand and 125 feet of Paluxy. This indicates the uniform thinning northwestward of the formation, largely by disappearance through overlap of the basal members. The age of the basal bed at the localities of the last two sections is clearly Glen Rose, though, as will be shown later, it is nearer the middle than the upper part of the formation.

Along the Texas-Indian Territory line the Trinity beds have disappeared by overlap of the Fredericksburg. Here the basal bed is known as the Antlers sands, and, though spoken of as Trinity by Hill, clearly belongs in the Fredericksburg, since the overlying limestone (the Goodland) is only 25 feet thick, whereas the Comanche Peak and Edwards limestones, which it represents, are 350 feet thick in the Austin region and approximate 700 feet on the Rio Grande. In western Texas, in New Mexico, and in southern Kansas,* the upper Fredericksburg beds are represented only by shore-derived clastics. In southern Kansas they are the plant-bearing Cheyenne sandstone, which rest directly upon the Red beds (Permian) and have a thickness of 65 feet. They are followed by the Kiowa shales, with *Gryphæa corrugata,* which have been found to extend northward into southern Colorado, where they overlie the Morrison formation.† It is not impossible that this horizon or a somewhat higher one will be traced north as far as the Black hills, where a thin limestone band holds the proper position. As will presently appear, only the lowest Washita beds are deposited over this more northern area, the Dakota regression beginning in early Washita, if not actually at the beginning of Washita time, and continuing throughout that epoch.

The West Coast transgression.—Marine Mesozoics are found in various parts of the Pacific coast province of North America. The series begins, as far as we know, with Lower Triassic, though the lowest Triassic (lower Brahminic) has not yet been found. In the Meekoceras beds of the Aspen Mountain, upper Brahmanic and lower Jakutic horizons are known, the former (with Meekoceras, Aspidites, Pseudosageceras, Ophiceras, Proptychites, etcetera) occupying the lower 700 feet and resting upon Carbonic

* Prosser: Geological Survey of Kansas, vol. ii, p. 96.
† Stanton: Science, n. s., vol. xxii, p. 756.

strata. Higher up in the series occurs *Pseudomonotis pealei*, representing the lower Jakutic stage. Less than 30 miles east, in the Salt River range of Idaho, the *Pseudomonotis pealei* beds rest on limestone with *Productus multistriatus*,* thus indicating an eastward overlap.

In the Humboldt mountains of Nevada the Star Peak group of more or less arenaceous limestones, which represents the middle and upper Muschelkalk horizon (Anisic and later), rests on the metamorphic Koipato formation. If no lower horizon is observed in the Star Peak series, an eastward overlap is indicated, since the Meekoceras beds are present in the Inyo mountains of eastern California.

A typical case of overlapping of formations due to the encroachment of the sea exists in the Shasta-Chico series of Oregon, Washington, and British Columbia. The series rests unconformably upon an old land surface composed of more or less metamorphosed strata, ranging in age from Paleozoic to Jurassic and complicated by igneous intrusions. A basal sand or conglomerate is generally present and sometimes seems to grade downward into the rocks of the old land, owing to the apparent slight rearrangement of the disintegration soil formed by the decay of the crystallines. The Lower Shasta or Knoxville beds extend north to the Shasta county line in California, where they are overlapped by the Upper Shasta or Horsetown beds, which extend 125 miles beyond the Knoxville. In this distance the higher beds of the Horsetown progressively overlap the lower ones. Where the Horsetown beds come to an end, the Chico overlap them, resting unconformably on the metamorphics. "The subsidence continued until the sea reached the western base of the Sierra Nevada, near the fortieth parallel, and all or nearly all that part of California north, northwest, and west of Lassen peak, as well as almost the whole of Oregon, was beneath its waters."†

Foreign examples.—The Hils of Germany has long been recognized as a typical basal formation of the transgressing sea of early Neocomian time. This formation consists of a series of clays, with sandstones and conglomerates at the base. They rest, with an hiatus, on various members of the upper Jura from Kimmeridgian to Purbeckian, containing pebbles and worn fossils of these in the basal bed. The age of the basal bed of the Hils varies, ranging from lowest Neocomian to post-Wealden, as shown by the succeeding fossiliferous clays in the various localities. This rise of the basal bed in the column marks the progressive advance of the Neocomian sea over central Europe.

A comparison of the English and Irish Cretacic brings out an interest-

* A. C. Peale: Bull. U. S. Geological and Geographical Survey, vol. v, no. 1, p. 121.
† J. S. Diller: Bull. Geol. Soc. Am., vol. 4, p. 27.

ing correspondence in the lithic character of the sections when read from the base upward; but this correspondence is not parallel in synchronous formations, for the base of the Irish Cretacic is much higher than that of the English. The following sections will illustrate this point:

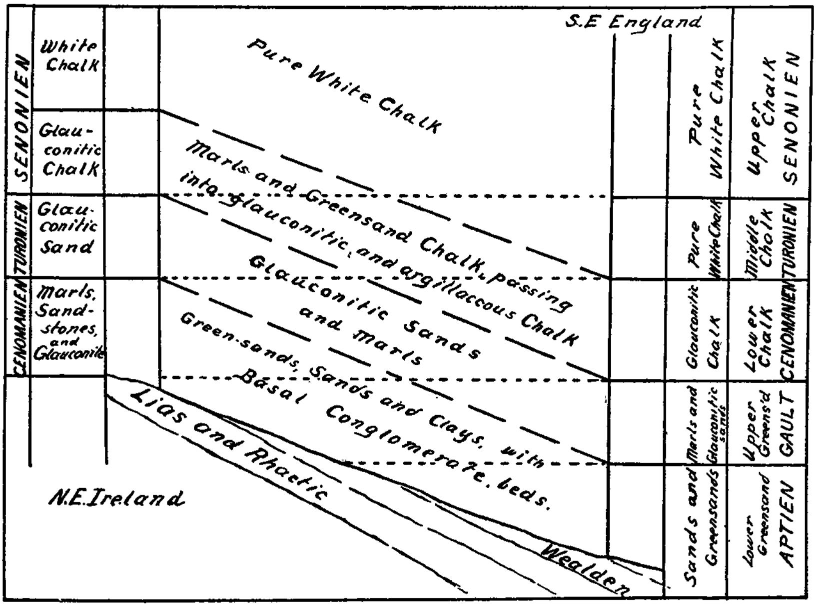


FIGURE 3.—*Diagrammatic Comparison of Irish and English Cretacic.*

In England the basal formation is the lower Greensand (Aptian), which rests on the non-marine Wealden, and is a glauconite and clay formation with basal conglomerates. The corresponding lithic bed in Antrim county, Ireland, is the Cenomanian, which rests on Lias and Rhaetic. The distance is from 300 to 400 miles, in which interval the lower Greensand and Gault have disappeared by overlap, bringing the Cenomanian directly on the old land surface. During the advance, however, the deepening of the English area, and above all the removal of the coast, permitted the deposition of chalk in that region, so that the Cenomanian of England is a chalk, though it still contains Greensand and marl. It is the Lower Chalk of the British geologists. The corresponding lithic bed of Ireland—that is, the Lower Chalk of Ireland, lithically considered—is lower Senonian. Between this and the basal Lower Greensand (Cenomanian of Ireland, Aptian of England) is a glauconitic sand, clay, and marl formation, which in England is the Gault or Upper Greensand (Albian), while in Ireland it is the Turonian, and in part perhaps Upper Cenomanian. The Turonian, or Middle Chalk of England, is already a pure white chalk, a lithic characteristic attained in Ireland only in the upper Senonian. Thus a regular and progressive advance of the sea from southeast to northwest is indicated, with a corresponding change in lithic character as the sea advanced.

The Nubian sandstone of North Africa and Asia Minor appears to present another case of a lithic formation rising progressively in the time scale. It is the basal sandstone of the Cenomanian and later transgression, and is probably, in part at least, a non-marine deposit reworked by the advancing sea. In mount Lebanon, where this sandstone is 1,600 feet thick, it is succeeded by Turonian strata, while in the Lybian desert Senonian chalk follows it, making the age of the sandstone itself probably Turonian.

Progressive Overlap and the Black Shale Problem

Wherever the relief of the land has been reduced to the condition of a peneplain, the rock surface of the old land becomes mantled with the products of subaerial decay. Prolonged exposure to this process results in the complete disintegration of the mineral constitutents of the rocks, and in the removal, by solution, of all soluble portions. When the rock of the old land surface is a limestone, only the finest residual clay soil will remain behind. The surface of a peneplain is preeminently characterized by obstructed drainage conditions, and this character is the more pronounced the more closely the surface of the peneplain approaches that of an actual plain; hence swampy conditions may be regarded as normal to the peneplain surface; and this brings us to the conclusion that the residual soils of such an area must be highly tinged with the carbon of the decaying vegetation. On old limestone surfaces, the clay becoming thus highly stained with carbon and the residual soil of limestone regions being exceedingly fine in texture, it follows that the resultant deposits from such areas of decomposition will be a fine and uniform grained black clay rock. When the sea encroaches upon such an area of residual soil, the basal formation of the resulting series of deposits will be a black shale, succeeded upward generally by calcareous members, since the shale itself constitutes the finest clastic of shore-derived origin, and any further deposits must be sea-derived—that is, organic or chemical precipitates. It is by no means implied that all black mud deposits originate in this manner. The black muds of the protected lagoons and mudflat areas of our coasts owe their color and carbonaceous character to the growth and decay of the sea grasses (Zostera, etcetera) and the animals living buried in this mud. The black shales of the Ohio Upper Devonic probably owe their color to the presence and innumerable minute spores of Rhizocarps, *Protosalvinia huronensis;* and the black muds of partly inclosed basins like that of the Black sea are deep-water deposits, where in the denser lower portions of the water H_2S is generated in great quantity by the activities of sulpho-bacteria.*

If we now set out to interpret the black shale so characteristic of the mid-Paleozoic of the interior region of North America by the light of the facts gained from a study of modern black mud deposits, we are confronted by evidence which points to one or more of the causes cited as probably operative in the production of this deposit. That portions of this shale are due to deposition in a relatively inclosed area, under conditions similar to those existing in the Black sea at the present time, seems probable, since some of these shales in the Portage formation of New York are especially rich in iron sulphide, and are further characterized by the presence of a dwarf fauna, such as is found to be buried in the black muds accumulating in the Black sea today.† But it by no means follows that all the Black shale of eastern United States was deposited in this manner; indeed, the evidence does not admit it even as a tentative assumption. The facts are best set forth by a review of the sections in which the Black shale holds a significant position.

Beginning in the westernmost area of its development on the Mississippi, we find a significant series of sections which may form the basis for the interpretation of the southern shale deposits. The following section was studied by the writer at Louisiana, Missouri, the northwesternmost point of appearance of the so-called Devonian Black shale:

Section at Louisiana, Missouri

	Feet
Louisiana limestone.—Compact limestone or calcilutyte resembling lithographic limestone	50
Immediately below this limestone is a bluish gray arenaceous mud rock, resembling the unweathered Chonopectus sandstone of the Burlington section; when weathered it has all the aspect of that sandstone	1
In one locality the lower part of this lower bed is more argillaceous, containing a fairly rich Kinderhook fauna, with *Spirifer marionensis* and *Productella concentrica* predominating. This shale passes downward without any perceptible break into black fissile rusty shale, resembling in all respects the Genesee shale of New York or the Black shale of Ohio, with which, on this account and on account of its position, it has been identified............................	4

* Andumow: La Mer Noir.

† See Clarke: Naples Fauna, pt. ii, Mem. 6, N. Y. State Museum. Also F. B. Loomis: Rept. State Pal., 1902.

	Page
Where the one-foot bed below the Louisiana limestone retains its sandy character throughout, the change from it to the underlying black shale is abrupt in color and texture, but there is no indication of discontinuity of deposition; the Black shale and the overlying beds represent one depositional series.	
Below the Black shale, and apparently conformable with it, is a brown, much decomposed limestone of arenaceous texture................	¾
This passes downward conformably into a fine grained buff siliceous limestone. The thickness of this bed varies in different sections from	4 to 10
Underlying this with a somewhat irregular contact is a fossiliferous lime rock with corals and Stromatoporoids indicating its Siluric age.	

Although the contact between the brown fine grained limestone and the coarse coral limestone is somewhat irregular, there is no direct evidence of a stratigraphic break here. The irregularity is not more striking than that often found between successive tiers of limestones, where solution along the contact lines will necessarily produce minor irregularities. Moreover, the lower limestone retains its thickness and character in all the sections examined, while the upper brown limestone varies in thickness from place to place. No bedding planes are visible in this brown limestone, and the bedding planes of the overlying shale are apparently conformable with its surface. Nevertheless, it seems as if the line of stratigraphic unconformity (disconformity) is to be sought at the base of or within the Black shale. This deposit is entirely unfossiliferous, but passed upward into a bed with Kinderhook fossils.

At Burlington the Louisiana limestone is underlain by 25 feet of the Chonopectus sandstone, and about 120 feet of a similar but more argillaceous rock, which probably rests upon the Devonic limestones. There is nothing at Louisiana to represent this series, except the 1 foot of rock of the Chonopectus sandstone type and the Black shale. It is true that the Louisiana limestone and the overlying Hannibal and Choteau beds form a greater thickness of rock below the Burlington formation at Louisiana than at Burlington, but it is also true that the fauna of the Louisiana limestone, as far as it is known, is a higher fauna than that of the Chonopectus and lower beds. While the base of the Louisiana limestone may not be and probably is not synchronous in the two localities, yet it seems nevertheless to be the fact that deposition of the Kinderhook began in the Burlington region before it reached the Louisiana region. Thus there appears to have begun a southward transgression of the sea in lower Kinderhook time, and the Black shale of the Louisiana section seems to be the basal bed of the series in that locality.

That this shale is not a deep-water deposit seems evident from its position at the base of a transgressive series of deposits. It seems more in accord with the facts to consider it a slightly reworked residual soil, which had accumulated on the old limestone land surface, probably at the summit of a decomposed mass of limestone, of which the brown bed of variable thickness is the consolidated record.

A section studied by Weller near Springfield, Green county, southwestern Missouri, and one in northern Arkansas has a significance in this connection. The first of these is as follows:

	Feet
Saint Joe limestone—Burlington.	
Kinderhook, consisting of	
Pierson limestone, a fine grained, buff colored limestone with upper Choteau fauna	3 to 10
North View sandstone, lithically identical with the Vermicular or Hannibal sandstone of the Mississippi section, but having a fauna similar to that of the upper yellow sandstone of Burlington	10 to 90
Phelps sandstone, carrying numerous black phosphatic nodules and fragments of worn fish teeth, identified as Devonic	0 to 4
Sac limestone, a hard bluish gray compact limestone, with a Choteau fauna	1 to 18
Eureka (Noel) black shale, with Kinderhook fossils	0 to 4
Disconformity.	
Magnesian limestone (Ordovicic).	

Weller correlates on faunal basis the Sac limestone with the upper yellow sandstone overlying the Louisiana limestone in the Burlington section, or the Hannibal sandstone and Choteau limestone of the northeastern Missouri sections. Accepting this correlation as the true one, we find that the overlap southward has brought the black basal shale (Eureka or Noel) into the upper part of the Kinderhook formation. This is borne out by the fossils of the Black shale, which are later than the Chonopectus horizon. It must be remembered, however, that the northeast Missouri sections are on the flanks of the Ozark uplift, and that the transgression there may have been a local one. If that is the case the total southward overlap is actually greater, since in the absence of the Ozark uplift the actual base of the section would be lower than it is in northeastern Missouri, and hence the rise of the basal black shale would be from a lower position than now in the northeast to the indicated position in the southwest of the state.

In northern Arkansas the Eureka, or Noel black shale, represents the same facies of sedimentation as in southwestern Missouri, and, as in that section, contains fossils showing its age to be younger than that of the

Chonopectus sandstone of Burlington. It rests on the eroded lower Magnesian limestone (Ordovicic) and varies in thickness from a few inches to 70 feet. It is not always black, but sometimes greenish or yellowish, and has thin limy members toward the top. It is immediately succeeded by the Saint Joe limestone (Burlington), into which it is often seen to grade. The connection between the two is an intimate one and represents continuous deposition. This fixes the date of the Eureka (Noel) shales of Arkansas as latest Kinderhook and shows an overlap from the base of the Choteau to the base of the Burlington, during the transgression of the Kinderhook sea from southern Missouri to northern Arkansas. Here the basal black shale takes the place of the basal sandstone of the basal Paleozoic sections; but, like that sandstone, this basal shale rises in the scale with the progress of the transgression. It is hardly questionable that the Black shale represents the reworked residual soil of the old land of Ordovicic limestones in the Missouri-Arkansas section. The shale rests unconformably on various members of the Lower Paleozoic limestones, and in each case derives its mineral character from the bed underlying. According to Ulrich, the shale is found resting only on the Key sandstone (Saint Peter), or the magnesian limestone of earlier age (Yellville formation). Where the Black shale is not developed, another formation, the Sylamore, often lies between the Saint Joe and the underlying Ordovicics (Polk Bayou limestone). The Sylamore formation consists of a shale with a maximum thickness of 15 feet, succeeded by a sandstone of coarse rounded quartz grains containing phosphate nodules. The shale is sometimes black and then resembles the Noel shale, with which it is generally correlated. Ulrich, however, insists on the Devonic age of this rock, on the strength of some fragmentary fish remains (a mandible doubtfully referred to Dynichthys) which indicate that age, and of some invertebrate fossils "which tend to corroborate this view." The fossils recorded are "a small Lingula that may be the same as *L. spatulata* of the Genesee shale of New York, and some conodonts." If this view is correct, there is a pronounced hiatus at the top of the sandstone, for the whole Kinderhook formation is wanting. The phosphatic pebbles of the Sylamore are sparingly represented in the basal portion of the Saint Joe, which is interpreted by Adams and Ulrich as the result of reworking. Ulrich states that "the Sylamore formation impresses one as the waste of a near-by shore, and thus agrees, not only in its faunal and physical character, but also in its origin, with the Chattanooga formation as developed in middle Tennessee."* The Noel shale, on the other hand, is correlated

* George Adams and E. O. Ulrich: Professional paper no. 24, U. S. Geological Survey.

by Ulrich with the base of the Tullahoma formation of middle Tennessee. That the hiatus recorded or believed to exist between the Sylamore and Saint Joe is equivalent to the whole Kinderhook may be doubted. The evidence on which to base the reference of the Sylamore to the Devonic is altogether too meager; it is far more likely that this formation represents a basal bed of Kinderhook age, possibly in part continental, and that it is in general equivalent to the Noel shale, as held by earlier writers.

Whatever the age of the Sylamore, the relationship of the Black shale (Eureka or Noel) to the overlying and underlying formations is clear. It represents a basal bed of an advancing sea, and progressively rises in the scale southward from middle Kinderhook to uppermost Kinderhook or lowest Burlington. That this basal bed is such a fine grained rock can only be explained by the assumption that the land was very low, and that the residual soil covering it was clay mixed with much carbonaceous material. In other words, the Noel shale can only represent the re-

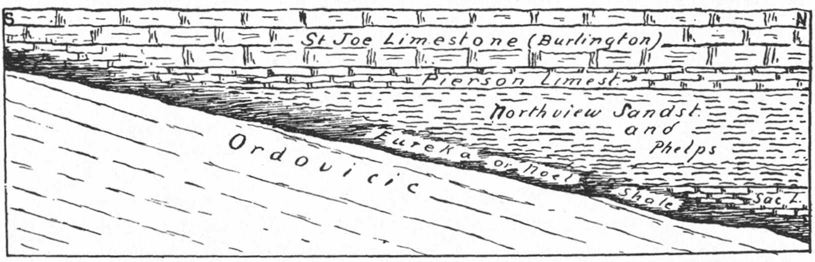


FIGURE 4.—*Diagrammatic View of the Relationship of the Black Shale of southern Missouri and northern Arkansas to the overlying Formations.*

worked residual soil of an old peneplain surface which was slowly submerged beneath the advancing Mississippian sea. Taken in connection with the position of the Black shale at the base of the Louisiana limestone in northeastern Missouri, we see that the transgression went on through the entire Kinderhook.

There seems to be no valid reason for considering that the Black shale of northeastern Missouri had a different origin from that of southwestern Missouri; and if the Noel shale represents the basal bed of a transgressing sea in southern Missouri and northern Arkansas, there is no reason for regarding the Louisiana Black shale as having a different meaning. A significant fact in this connection is the similarity in the general lithic character of the section in northeastern and southwestern Missouri. In the northwestern section the shale is succeeded by the compact Louisiana limestone; this by the Hannibal sandstone or vermicular sandrock, and this by the Choteau limestone. In the southwestern section the Black shale is also succeeded by a compact limestone (the Sac), followed by a vermicular sandstone (the North View, identical in character with the Hannibal, and formerly identified with it by the Missouri geologists); and finally by a fine grained buff limestone (Pierson limestone) representing the Choteau of the northeastern section. In actual age the Sac, North View, and Pierson of the southern section are equivalent to the Hannibal and Choteau of the northern one. This similarity of lithic succession strengthens the case and makes it practically certain that we have in the Black shale of the Mississippi valley a basal bed of a transgressing sea, and that the age of this basal bed, as in the case of basal sandstones, varies from place to place, rising southward in the series. Compare figure 4.*

With this demonstrated example before us, we may next consider the Black shale of the southern Appalachians, which is universally regarded as of Devonic age in all of its exposures. Ulrich has recently restated his convictions in this matter by proposing to apply the name Ohio shale to this formation wherever found. Even if this shale represented only Devonic beds in its different outcrops, the fact remains, and is recognized by Ulrich, that it does not represent the same portion of the Ohio series in all its exposures. That part generally known as the Chattanooga shale is regarded by Ulrich as representing the upper part of the shale in Ohio, and to call this small portion by the name of the whole is at least a questionable proceeding.

The Devonic age of the Chattanooga shale may, however, be seriously doubted. The establishment of this age is not based upon fossils; for those found—a few Lingulas, doubtfully referred to *L. spatulata* of the Genesee, and some Conodonts—are wholly inconclusive. Ulrich himself says:

"Although there is little besides stratigraphic position and lithologic characters on which to base the reference of this black shale to the Ohio formation, it is so referred with the utmost confidence. In every feature this [Hardin County] shale is practically identical with many of nearly a hundred exposures of this formation examined by the writer in Kentucky, Tennessee, and Ohio. From lake Erie southward to northern Georgia and westward to this district the Ohio shale is remarkably constant in its lithologic characters. Despite this constancy this formation has received a number of names. The name Ohio shale, proposed by Andrews, the oldest of the geographic names applied to this formation, is here adopted."†

* Compare this similarity of succession with that found in the chalk of England and Ireland, cited above.

† Professional paper no. 36, p. 25.

According to this reasoning, based wholly on lithic characters, the Marcellus and Genesee shales of western New York should be regarded as synchronous, and both should be identified with the Rhinestreet or any other of the black shales of that region; for "in every [lithic] feature this . . . [Marcellus] shale is practically identical with many of nearly a hundred exposures . . . [of black shales of varying horizons] examined by the writer."

The Chattanooga shale in the region of the Columbia quadrangle in central Tennessee is described as having generally at the base a thin bed consisting largely of calcium phosphate and forming the source of the Tennessee black phosphate. In many cases these phosphate nodules surround minute coiled shells derived from the underlying Ordovicic limestones. This phosphate bed passes by gradation laterally into a bed of coarse sandstone or conglomerate containing varying amounts of phosphate and much water-worn material, together with some unidentified fish bones. Sometimes, toward the southwest, the phosphate is replaced by a fine grained gray or black sandstone, with a maximum thickness of 12 feet in Hardin county (Hardin sandstone). Where the Chattanooga formation rests on the Clifton or on the Fernvale formation (limestones), it is always a black shale at the base. The Maury green shale is generally found at the top of the Chattanooga formation. It varies from a few inches to 4 or 5 feet in thickness in central Tennessee, though it does not exceed 2 feet in the Columbia quadrangle. It contains lime phosphate and Greensand grains, which are the cause of the color.

"Rarely, as in the upper part of East fork of South Harpeth creek, the green shale is absent or not distinguishable, and in these cases the black shale *seems to pass very gradually into the overlaying green shale* * which constitutes the base of the full Tullahoma section."†

The Tullahoma formation of shales passing up into cherty limestones is from 200 to 500 feet thick and is believed by Ulrich to represent the whole of the Waverly of Ohio; but it is probably more correctly regarded as representing only the upper part of that formation, which in southern Ohio is considerably over 600 feet thick.‡ There is no recorded evidence from fossils which would establish the equivalency of the Tullahoma to the whole of the Waverly, since fossils are extremely scarce in the Tullahoma of Tennessee. Apparently the correlation is based on position alone, as the formation succeeds the black shale, which is on *a*

* The italics are the present writer's.
† Columbia folio, p. 3.
‡ Harrick: Bull. Geol. Soc. Am., vol. 2, p. 40.

priori grounds considered by Ulrich to be Devonic, and is followed by the Saint Louis limestone series. Of course if we regard the black shale as Devonic, then the fact that it grades up into the Tullahoma indicates that the base of the Tullahoma is basal Mississippian; but until more convincing evidence is brought forth of the Devonic age of the black shale and the basal Mississippian age of the Tullahoma, the more normal interpretation is that both are above the base of the Mississippian—approximately of upper Kinderhook or lower Osage age.

Foerste has recorded the frequent presence of sandy and earthy layers at the base of the Black shale in the most eastern exposures on the Cumberland river, these layers being phosphatic.* This basal portion usually varies between 2 and 3 feet, but thicknesses of even 6 feet are found locally. Sometimes it is replaced wholly or in part by greenish more clayey layers. In this sandy layer occur weathered out fossils of the underlying Ordovicic rocks. Foerste has also recorded traces of Chonetes and other fossils in the fine grained rock immediately above the Black shale, south of Rockdale.† He considers that the beds containing these fossils may be of Waverly age. In regard to the contact between the black shale and the Waverly, he says:

"In the gulley southeast of the Oliver Williams house the base of the section consists of a dark, sandy, partly conglomeratic rock 18 inches thick. Both the Black shale and the phosphate rock are absent. Immediately above the conglomeratic rock occur 11 inches of light green clayey rock containing purple brown phosphatic material, both in the form of small irregular particles and of nodules. Above this are found 8 inches of crinoidal greenish rock, with fish teeth. At the 'Big hill,' immediately westward, on the road to Waynesboro, the entire Black shale section is absent.

"The purple brown phosphatic material found immediately above the conglomeratic, sandy rock at the Oliver Williams locality resembles the material forming the phosphatic nodules at the top of the Black Shale section in most parts of Tennessee and Kentucky. The fish teeth appear to belong to the same formation as the bed from which the phosphatic material was obtained. The greenish clay material, however, belongs to the Waverly horizon, so that the base of the Waverly appears to contain material derived from the eroded top of the Black Shale bed. The crinoidal material is unquestionably of Waverly age. The fine grained but not fissile rock in the old Sawmill hollow may also be of Waverly age, since species of Chonetes of the same general form are rather common at the base of the Waverly section in the northern part of Giles county. The dark color of the rock may be due to the carbonaceous material received from the denuded Black shale of this area, while the more sandy character may be due to material washed in from some other source by the Waverly sea. The gradual passage of the black rock upward into the

* A. F. Foerste: Silurian and Devonian limestones of Tennessee and Kentucky. Bull. Geol. Soc. Am., vol. 12, 1901, p. 427.

† Loc. cit., p. 428.

greenish rock, as already described, is also favorable to the view that the black rock, without good fissile cleavage, may be of Waverly origin. In case these observations are correct, the absence of the Black shale at the 'Big hill' may be due, not to original lack of deposition, but to subsequent erosion."

Foerste raises the question whether the observed thinning of the Black shale toward the Cincinnati dome may not be due to a "marked development of the southern end of the Cincinnati anticline at the time of the deposition of the Black shale and the base of the Waverly."* In other words, he believes that less shale was deposited on the rising portions of the dome. It may also be interpreted as resulting from the washing of the residual soil from the higher into the lower places; and this readily accounts for the absence of the shale in many places not as due to erosion prior to the deposition of the Waverly and the occurrence of a disconformity, which such a fact would imply, but as the result of the washing of the original soil from the higher parts, on the encroachment of the lower Mississippian sea. This explanation is further suggested by the fact that within short distances in all directions the shale reappears. In general the coarseness of the material increases from the northeast to the southwest. Regarding the physical conditions under which the shale was deposited, Foerste says:†

"In the case of the Black shale, the evidence of land conditions or of fresh-water conditions is more favorable. At many points through its entire extent it has retained remains of land plants. Its strongly carbonaceous character, which gives rise to the black color of the shales, does not necessarily indicate the presence of land plants, although the presumptive evidence is in favor of this view. At various localities the remains of animals have been preserved in this shale. . . .

"The base of the Black shale is often decidedly earthy and is often also phosphatic. It is well known that the base of the Black shale is in many parts of southern Tennessee sufficiently phosphatic to be worked as a phosphate rock. One of the theories of the accumulation of the phosphatic material at this horizon is that it was derived from the phosphatic material included in the shells of the underlying Silurian and Ordovician rocks; that it is an accumulation in one sense of residual material.

"This sandy base of the Black shale occasionally incloses fossils derived from the underlying formations. The sandy material itself is probably of residual origin. It may represent a residual soil, but the evidence is again inconclusive.

"The fissile black shale is composed of particles so light that they could have easily been blown by the wind. The remarkably fine grained character of the fissile shales, the entire absence of coarser material except at their base, and their remarkably wide geographical distribution suggest that they may possibly consist of wind-blown particles, derived perhaps from many strata, from

* Loc. cit., p. 429.
† Loc. cit., pp. 430, 431.

points far distant from one another. The absence of coarse detrital material suggests that the region of deposition was practically flat. The preservation of fragments of land plants indicates that it was probably a region of marshes. It may be imagined that the same particles traveled in many directions before finding a final lodgment. Marshes at one point may have dried up, and the material accumulated in it may have again turned into dust, thus permitting the frequent shifting by the wind of the materials which now form the shale."

Safford records the occurrence of thin seams of bituminous matter from an eighth of an inch to an inch in thickness. "The bitumen of these shales is hardly an asphaltum, being *generally*, perhaps, more like the bitumen of cannel coal."* Petroleum also oozes from the shale in a few places and can be readily distilled from it.

In Wayne county, south central Tennessee, the following section was made by Safford at T. A. White's mill, on Buffalo river, a few miles below the mouth of Green river:

	Feet
(4) A thin bed of *gravel* (water-worn pebbles) on top, with some loose, angular chert. The gravel is found at the top of all the high ridges in this region. Specimens of *Lithostrotion canadense* (not water-worn) are also found loose on the surface.	
(3) *Siliceous group:*	
Rocks concealed, surface covered with small, angular, cherty masses, to top of ridge	190
Bluish shale, with layers of chert	15
Bluish shale	24
In all	238
(2) *Black Shale group:*	
(*c*) Layer of kidneys	½
(*b*) Black shale	2
(*a*) Sandstons, at top thin bedded, surfaces abounding in Lingulæ	9
In all	11½
(1) *Meniscus limestone* (Niagara):	
Gray, mostly crinoidal limestone; contains the characteristic *Haplocrinus hemisphericus* immediately below the sandstone; thickness down to the water	67

In eastern Tennessee (McMinnville folio) the Chattanooga Black shale rests on the Chickamauga limestone (Ordovicic) and has a thickness of from 10 to 30 feet. It consists mainly of highly carbonaceous non-fissile shale. The upper stratum, about 2 feet in thickness, is generally bluish green, somewhat sandy, and contains a layer of small phosphatic concretions an inch or less in diameter. "It seems probable that this upper greenish layer of shale represents an ancient ash bed, the material of which was ejected from a volcano and transported a long

* J. M. Safford: Geology of Tennessee, 1867, p. 334.

distance from its source, partly by winds and afterward by currents, when it had fallen on the surface of the sea which then covered this region."* Small concretions of iron pyrites occur in the shale.

The shale is here overlain by from 150 to 225 feet of the Fort Payne chert. This begins usually with heavy beds of chert at the base, with only a little limestone or shale, passing upward gradually into purer limestone and "without abrupt transition into the Bangor limestone above." This series is from 700 to 800 feet thick. The Fort Payne chert is very fossiliferous, and is the "siliceous group" of Safford, which he divided into a lower, or Protean (Lauderdale, McCalley), and upper, or Lithostrotion (Tuscumbia, McCalley). Ulrich makes the Tullahoma of central Tennessee and the Fort Payne of eastern Tennessee equivalent, and correlates both with the Kinderhook and Osage of the Mississippi valley. There is here an inconsistency, for the upper part of the Fort Payne (Tuscumbia) is clearly of lower Saint Louis age, as shown by the abundance of *Lithostrotion canadense* (= *L. mamillare*).

Stevenson considers that the upper part of the Fort Payne is unquestionably Tuscumbia, but he also says:†

"It is difficult to determine, by means of available observations, whether or not the Fort Payne of the extreme southeasterly areas embraces any Tuscumbia. For the most part the features are those of the Lauderdale (Logan), there being an almost total absence of limestone in the upper part; but in Calhoun county of Alabama, very near the extreme southeast exposure, one finds the Tuscumbia clearly present. One may conjecture that as the Lauderdale is practically without limestone nearer the shore line the Tuscumbia would undergo the same change, so that the thin Fort Payne on the border would represent both. This is in accordance with the conditions in this region, as each of the Mississippian formations apparently overlaps its predecessor."

Nor is the Protean, or Lauderdale, the equivalent of the whole Tullahoma (as defined by Ulrich—that is, = Kinderhook-Osage); for, according to Safford:‡

"This lower, or Protean, member of the Siliceous group, is, in general, equivalent to the divisions of the Lower Carboniferous limestone lying below the Saint Louis limestone. It is, perhaps, more especially the equivalent of the Keokuk limestone; it contains, however, some Burlington forms."

He lists the following species from this member: §

Spirifer imbrex Hall. "Occurs *immediately* above the Black shale below Huggins's mill, near Manchester, in Coffee county, associated with *Productus*

* Hayes: McMinnville folio.

† J. J. Stevenson: Lower Carboniferous of the Appalachian basin. Bull. Geol. Soc. Am., vol. 14, 1903, pp. 14-96.

‡ Safford: Loc. cit., p. 342.

§ Ibid.: Loc. cit., pp. 342, 343.

semireticulatus; also in the same horizon at White's Creek Springs, and near Colonel Robinson's, on the Middle fork of Cold water, in Lincoln county."

Spirifer subequalis? Hall.
Spirifer tenuicostatus Hall?
Spirifer suborbicularis Hall.
Spirifer subcuspidatus Hall [*Syringothysis texta*].
Spirifer lineatus Martin.
Orthis [*Rhipidomella*] *michelini* L'Eveille.
Platyceras equilatera? Hall.
Granatocrinus granulatus Roemer.
Agaricocrinus americanus Roemer.
Actinocrinus conicos Cassedy and Lyon.
Actinocrinus nashvillæ Troost.
Actinocrinus (*Batocrinus*) *magnificus* Cassedy and Lyon.
Actinocrinus (*Dorycrinus*) *gouldi* Hall.
Cyathocrinus stellatus Hall.
Forbesiocrinus meeki Hall.
Forbesiocrinus saffordi Hall.
Ichthiocrinis tiaræformis Troost.

Commenting on these, he says:

"Most of the above species occurring out of Tennessee are Keokuk forms. *Spirifer imbrex* and *Orthis michelini* are found in the Burlington limestone; *Spirifer subæqualis* and *S. tenuicostatus* are Warsaw forms, and the latter also Keokuk."*

The thickness of the Lauderdale in its typical development in Tennessee is 250 to 300 feet, but it decreases southward, undoubtedly through the failure of the lower beds. The Tuscumbia, the equivalent of the Saint Louis limestone of Missouri geologists, has a maximum thickness of 250 feet. Safford holds that the lower member (Lauderdale) thins away southward. He says:

"In the southern part of the state, at certain points, the member is cherty, crinoidal limestone, resembling the Lithostrotion bed above. In fact, going southward, the lower member becomes thin, and below Huntsville on the anticlinals of Alabama, the two members, in my opinion, become one bed, characterized throughout by *Lithostrotion canadense.*"†

In a foot-note he adds:

"A little below Gadsden, in Alabama, I have seen a number of specimens of this coral [*L. canadense*] in an outcrop of the Siliceous chert, very near the Black shale."

* Ibid.: Loc. cit., p. 343.
† Ibid.: Loc. cit., p. 340.

Except where an erosion interval is responsible for the thinning away of the Fort Payne or Siliceous group, we must assume that the thinning is due to the failure of the basal members which are overlapped by the higher members. All the descriptions indicate a passage of the Fort Payne into the overlying lower Bangor, or its equivalent, the Floyd shale. Where the Fort Payne is represented by less than 100 feet, this thickness must represent the upper, or Tuscumbia, portion, unless an erosion interval has removed a part of the upper portion before the deposition of the Bangor. As already noted, however, such a disconformity has not been recognized. It may, of course, be true that the Fort Payne, recognized by its lithic character, has not the same position everywhere, and that the lower Bangor of the southeast may represent a part of the Tuscumbia farther west. However that may be—and the point can only be settled by a careful examination of the sections—the fact remains that the Lithostrotion bed in many places is close to the Black shale, and in fact lies directly upon it.

In the McMinnville quadrangle the base of the Fort Payne, which varies from 150 to 225 feet, is probably of Keokuk age.

Southeastward, in the Sequatchee valley, the Chattanooga (12 to 25 feet thick) is succeeded by only from 60 to 80 feet of the cherty Fort Payne, which here represents the highest part of the group, or the Saint Louis horizon, unless there is an erosion break at the top or the top is here lower than elsewhere. It is described as passing upward into the Bangor limestone.*

In the type region, in the Tennessee valley, near Chattanooga, Tennessee, the shale is from 10 to 25 feet thick, while the overlying Fort Payne is reduced to from 60 to 150 feet in the western region and from 50 to 75 feet in the southeastern region. As before, if the section here is complete, the Fort Payne can only represent the Saint Louis horizon. Above it comes the Floyd shale in the eastern, nearer shore section, and limestones in the more western, offshore district. The Floyd shale of the eastern section is later replaced by limestone of the type of the Bangor, but the equivalent of only the upper Bangor of the sections farther west, the Floyd shale itself being the equivalent of the lower Bangor.

A remarkable condition is found in the Chilowee mountain area. Here the Chattanooga shale ranges from 6 to 30 feet in thickness, and is succeeded by the Grainger shale. It "comprises flaggy sandstones, sandy shales and sandstones, with white sandstone and red and brown sandy shales at the top; and this series is present throughout."† The lower

* Sewanee folio.

† Loudon and Knoxville folios.

sandy beds are fossiliferous, containing fenestellæ, linguæ, and brachiopods. The age of these shales in this section has not been determined. They are, however, classed as Devonic, together with the Black shale, though from what is known of these deposits farther northeast their age is, at least in part, lower Mississippian. The thickness of the formation is 1,100 feet. It is succeeded by the Newman limestone, which includes 100 feet of massive blue limestone at the base, followed by 500 feet or more of gray calcareous shale and shaly limestone. The basal portion is highly fossiliferous, containing crinoids, corals, and brachiopods. It is succeeded by the Lee conglomerate (Pottsville). Northwest of Chilhowee, some 30 to 35 miles, in the Walden ridge, the Newman limestone, 700 feet thick, rests directly on the Chattanooga shale, which is here 80 feet thick and rests disconformably on the Rockwood. The Newman is here mainly a marine limestone, with chert nodules in the base. Its age is Saint Louis and it is succeeded by the Lee conglomerate. Northeastward, in the Clinch mountains of northeast Tennessee and southwest Virginia, the Grainger shale and Black shale are both well developed.* At Big Stone Gap, Virginia, the Black shale, which is at least 500 feet thick, rests on sandstones of late Helderbergian age.† The Black shale contains an abundance of *Lingula ligea* and *Schizobolus concentricus,* both late Devonic species. The age of the base of the shale in this place is therefore Upper Devonic. Professor Williams studied the section at Big Stone Gap in great detail, and he found "that the following arenaceous shales and sandstones began as very thin intercalated sheets, thin as paper at first, far down in what, to the casual observer, appeared to be pure black shale."‡

Farther eastward, at Big Moccasin Gap, Virginia, the following section was made by Williams and Kindle:§

	Feet
7. Limestone and shale (Mississippian)	
6. Soft yellowish clay and crumbling sandstone	100
5. Hard, drab colored sandy shale and sandstone	40
4. Conglomerate bed near top of 3 feet.. 3. Hard, bluish gray to drab sandy shale	60
2. Black shale, varying to gray, and much crushed and folded	150
1. Tough quartzitic fine grained sandstone	75

"In the Estillville folio, 2 is called the Chattanooga Black shale, and 3 to 6 are assigned to the Grainger shale. The lowest fauna obtained from the section is from the lower part of 3, about 20 feet above the Black shale."

* Estelville folio.
† Williams and Kindle: Bull. U. S. Geological Survey, no. 244, p. 28.
‡ Williams: Southern Devonian formations. Am. Jour. Sci., vol. iii, 1897, p. 389.
§ Williams and Kindle: Loc. cit., p. 30.

The following species are listed:*

[*c*, common; *r*, rare.]

Zaphrentis sp. (*r*).	*P.* cf. *wortheni* (*c*).
Crinoid stems (*c*).	*P.* sp. (*r*).
Fenestella sp. (*r*).	*Camarotœchia* sp. (*r*).
Lingula gannensis (*r*).	*Spirifer* cf. *marionensis* (*c*).
Orbiculoidea sp. (*c*).	*Reticularia pseudolineata* (*c*).
Chonetes sp. (*r*).	*Syringothyris carteri* (*r*).
Productus cora var. (*r*).	*Athyris lamellosa* (*c*).
P. cf. *semireticulatus* (*r*).	*Conularia* sp. (*r*).

Forty feet higher another rich Kinderhook, or early Burlington fauna was found, including *Spiriferina* cf. *solidirostris, Palæoneilo perplana, P. sulcatina, Nuculana spatulata, Pleurotomaria stulta, Prolecanites greeni,* Phæthonides, and others. Thirty to forty feet higher still the fauna is still more characteristically lower Mississippian, for such species as *Lingulodiscina newberryi, Spirifer keokuk, Sphenotes flavius, Palœoneilo bedfordensis,* and *Conularia newberryi* occur, most of them common, besides many others not determined specifically.†

The sandstone number 6 of the section afforded *Productus cora* and *Camarotechia contracta,* both common.

At Hicksville, Bland county, Virginia (Pocahontas folio), the Black shale, here called Romney, has an estimated thickness of from 400 to 600 feet and rests upon sandstone with an Oriskany fauna. It contains *Schizobolus truncatus, Palæoneilo brevis,* and Goniatites, which occur 100 feet above the top of the Black shale; and, higher still, the Kimberling shales and sandstones have yielded a rich Chemung fauna. The Black shale has here descended in the scale and apparently represents Portage time. Still farther northeast, at White Sulphur Springs, West Virginia, the Black shale, resting on Oriskany sandstone, is succeeded by sandy and green shales with a *Buchiola speciosa* or Naples (Portage) fauna, followed, 300 feet above the Black shale, by a Chemung fauna.

At Covington, Alleghany county, Virginia, 20 miles from the last section, and at Hot Springs, Bath county, Virginia, the Black shales carry in the lower part Marcellus species, though associated with species of late Devonic time. Williams holds that the Black shales began to be deposited here while the Onondaga fauna still continued in the more central area. The evidence for this seems hardly conclusive. At Covington, Virginia, the Black shale is underlain by a greenish shale with *Schizophoria striatula, Atrypa spinosa, Ambocœlia umbonata,* and

* Ibid.: Loc. cit., p. 30.
† Ibid.: Loc. cit., p. 31.

Phacops rana. This is a Hamilton or later fauna, and although the fauna of the Black shale includes *Leiorhynchus limitare* and *Agoniatites vanuxemi,* both of them typical Marcellus species, the fauna as a whole is certainly Upper Devonic (Naples-Portage), as stated by Williams. The same thing may be said of the Hot Springs section; for here the *Buchiola speciosa* fauna is abundant only 70 feet above the Black shale, 60 feet of the interval immediately below the shales with this fauna being concealed. In the 9 feet of white or cream colored shale immediately over the Black shale occur *Orbiculoidea doria, Bellerophon leda,* and *Styliolina fissurella,* besides others unidentified specifically. The Black shale itself contains *Orbiculoidea doria, Styliolina fissurella,* and questionably identified *Chonetes* cf. *coronatus,* and *Anoplotheca* cf. *acutiplicata.* The evidence adduced, then, points to an early Upper Devonic age of the Black shales at Hot Springs, rather than a lower Middle Devonic, as advocated by Williams. The Black shale is 10 feet thick and rests upon Oriskany (?) sandstone.

In Allegany county, Maryland, the Black shale forms the base of the Romney formation, which has a thickness of about 1,600 feet. Here the shale is clearly of the age of the Marcellus of New York, and in part it also represents the Onondaga. This portion of the formation rests upon the Oriskany and has a thickness of about 500 feet. The upper 1,100 feet of the Romney contains a typical Hamilton fauna.* Eastward from this, in Washington county, the Hamilton division of the Romney overlaps the Marcellus, which is only sparingly represented.†

We have here clear evidence of a continued southwestward progression of the encroaching sea, and a corresponding progressive overlap of the higher formations southward. In all cases a basal black shale occurs, rising in the scale from Marcellus or lower in the north to uppermost Devonic and, as indicated in Big Moccasin Gap, to Lower Carbonic.

At Irvine, Kentucky, the Black shale again lies high up in the series, for here it has intercalated in its upper part calcareous and ferruginous concretionary sheets which carry undoubted Lower Carbonic fossils. These occur in the sections before the Black shale loses its characteristic expression.‡

In the London quadrangle of central Kentucky the Chattanooga shale rests on Devonic limestones with an erosion interval. It has a thickness of 150 feet, is very black and bituminous. It is succeeded upward by a light blue clay shale and argillaceous sandstone, the shale abounding in light blue or drab ironstone concretions. Many siliceous concretions

* Prosser: Journal of Geology, vol. xii, p. 361.
† Ibid.: Loc. cit., p. 362.
‡ Williams: Amer. Jour. Sci., vol. iii, 1897, p. 398.

occur. Upward it passes into sandy shale and argillaceous sandstone. The thickness averages 350 feet, and it is succeeded by the Newman limestone, 100 to 250 feet thick, and the Pennington shale, which is occasionally absent. Above this is a great erosion break, followed by Pennsylvanian sandstone. The shale above the Black shale is referred to the Waverly, of which it probably constitutes the upper portion only. As at Irvine, the transition from the Black shale to the overlying beds is probably a gradual one.

Taken together with the section at Chilhowee mountain, Tennessee, where the Grainger shale, 1,100 feet thick, separates the Black shale from the Newman limestone—and with the section in Walden ridge, 30 miles northwest, where the Newman limestone rests directly on the Black shale—it becomes apparent that a ridge of land extended southeastward, approximately along what is now the Walden ridge of Ten-

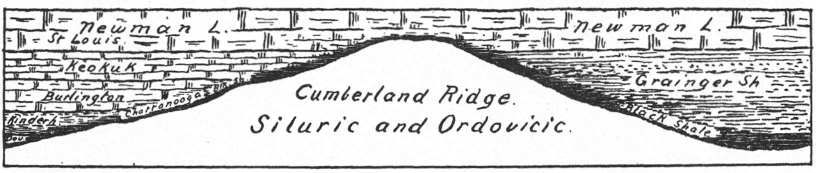


Figure 5.—*Diagram of Cumberland Ridge showing Relationship of interior Sea to oceanic Channel.*

nessee and the Cumberland mountains and westward in Kentucky, separating the interior basin from a channel to the east of this ridge. Whether this channel was in direct communication with the Atlantic to the south or whether it represented an encroaching arm of the sea from the north is a matter for further investigation. The sections given so far indicate that the latter condition obtained, since the formations overlap progressively southward along this channel. West of this barrier the Mississippian sea was slowly encroaching southward and eastward, as shown by the overlapping beds, until in Saint Louis time the barrier became submerged and the Newman limestone was spread uniformly over the whole area. The relationship of the interior sea to this channel and to the formations accumulating in each is shown in the accompanying diagram.

In the region about Rome, Georgia,* the Frog Mountain sandstone rests unconformably on the Rockmart and other formations in the southwest area and in the adjoining Fort Payne quadrangle. "It consists chiefly of white quartzitic sandstone and yellow porous sandstone, the latter prob-

* Rome folio.

ably containing feldspar. It also contains some sandy shales." The age is Oriskany, as shown by the occurrence of some poorly preserved fossils. It has a thickness of 1,200 feet and over. On the north side of the Coosa valley the Armuchee chert replaces the sandstone with a thickness of 50 feet. The chert is bedded and contains fossils similar to those of the Frog Mountain sandstone, of which it probably represents an off-shore deposit.

There is a marked time break and erosion interval above these formations, followed by the Chattanooga Black shale. This consists of two divisions. The lower, with a maximum thickness of 40 feet, but decreasing to 1 or 2 inches in places, is jet black and rests on the Armuchee chert or directly on the Rockmart sandstone. The upper member consists of blue or greenish clay shales, usually with phosphatic concretions, which are generally perfectly round, when small; but when sometimes they reach a diameter of a foot or more, they are oval. The green color of the formation is due to the presence of glauconite. This upper member varies from 1 to 3 feet in thickness and apparently represents the Maury shale of central Tennessee. The Chattanooga is succeeded by the Fort Payne, from 20 to 200 feet thick, and this by the Floyd shale, 2,000 feet or more in thickness, or by the Bangor limestone.

At the base of the Black shale opposite Rome, Georgia, a few fossils have been found suggestive of Hamilton age, but the evidence is scarcely conclusive.*

Summing up the facts so far determined, it becomes apparent that there is in the interior area a progressive overlapping of the Mississippian formations southward and eastward, beginning in Kinderhook time and continuing, practically without interruption, throughout that epoch; for Mississippian strata are wanting in central Texas, where the mid-Carbonic strata rest directly and unconformably on earlier Paleozoics. A southward transgression also took place in the area east of the old Cumberland land ridge, which was eventually submerged in later Saint Louis time. Whether or not land conditions existed throughout the southern parts of the Gulf states is not determinable from the data at hand.

Nearly everywhere resting directly on the surface of the slowly subsiding old land lies a bed of highly carbonaceous shale. In its basal portion, in many localities, it contains fossils weathered out of the underlying Ordovicic strata. Sometimes it is replaced by a sandstone or conglomerate; sometimes it carries worn fish bones; in many places, too, it carries remains of land plants. Several observers have been struck

* Schuchert: American Geologist, vol. xxxii, p. 152.

by the resemblance of this basal shale to an old residual soil, though Hayes believes that in some areas the old-land surface was scoured by ocean currents before the deposition of the shale.† Where detailed observation has been made the shale is said to pass upward into the overlying beds. Though Ulrich has marked an unconformity at the top of the shale in central Tennessee, he has so far failed to substantiate it by evidence. Fossils are found in this shale in the northern areas indicating that its age is late Devonic. Conodonts and the spores of freshwater Rhizocarps are among the most characteristic fossils found, and the former occur in many southern exposures of the shale. Zittel and Rohen have clearly shown that these organisms are referable to œsophageal teeth of annelids. Such organisms are today very characteristic of the muds and sands of shallow shores and lagoons. The few marine fossils found in the southern exposures west of the Cumberland ridge are either inconclusive as to the age of the shale in that region, or, as in the Noel shale of Missouri and Arkansas, they mark the age as Mississippian. From all this it appears that the Black shale of southern United States is a basal deposit—a residual soil of an ancient peneplain, very fine and very carbonaceous, and the result in many places of the solution of calcareous strata. This soil was worked over by the transgressing Mississippian sea, which rearranged it, washed it from the higher points, and collected it in greater thickness in the depressions of the old peneplain. As the water deepened, deposition of calcareous shales or of limestones followed, the transition being a perfect one—sometimes gradual, sometimes abrupt.

If the view that the Black shale is the shore deposit of the sea, which farther out deposited calcareous strata, is not accepted, a serious difficulty confronts us; for if we assume, with Ulrich and others, that after the deposition of the Black shale the sea retreated, and then readvanced, we must account for the absence at the base of the calcareous strata of a shore facies; for, surely, if the strata were successively deposited one by one, each later overlapping the preceding one, the point of contact between these strata and the Black shale, which point, at the time of deposition of that stratum must have been the shore, should show some evidence of that fact in the coarser clastic character of the strata and in their inclusion of some fragments of the Black shale surface of the old-land. That no such evidence is found clearly proves that the Black shale represents the shore facies of each succeeding limestone or calcareous shale stratum, and that it is hence not of uniform age throughout, but varies from place to place. If we accept this view—and there seems to

† C. W. Hayes: The Tennessee phosphates, Seventeenth Ann. Rept. U. S. Geological Survey, pt. vi, p. 610.

be no escape from it—the name Ohio shale, adopted for a black shale of Upper Devonic age, which was probably deposited at the mouth of a great river, is not applicable to the Black shale of the southern Appalachians; but the name Chattanooga shale may be applied, if it is dissociated from the idea of any definite age relations.

It may be recalled in conclusion that stratigraphers have not hesitated to consider the base of the Black shale as rising in the scale through the Devonic, but they have been reluctant to carry it higher than that horizon. Williams alone of recent writers has suggested that the Black shale did continue on into the Mississippian; but he, also, has considered the basal portion in all exposures as Devonic. The evidence to the contrary is, however, so overwhelming, and the explanation here set forth accounts so perfectly for all the observed phenomenon, that the old assumption of the synchroneity of the different parts of this formation can no longer stand, since it has no basis in fact.

Statement of the Principle of the Regressive Overlap

This term is applied to the arrangement of strata produced by a retreating sea, the result either of a progressive elevation of the sea bottom or of stationary conditions with a continued supply of detritus. A slow rate of subsidence of the sea bottom, with an excessive supply of detritus, such as might result through a change in the climate from dry to moist, would have essentially similar results.

A slowly retreating sea will carry the shore zone seaward—that is, in the direction of retreat. As a result, the shore detritus will be carried farther out with reference to the original position of the seashore. In other words, the various belts of shore-derived detritus will migrate in the direction of shore retreat and at approximately the same rate. The migrating belts of shore detritus will thus pass successively over areas of formerly deeper water, and hence over areas of offshore deposition. If the retreat is a gradual one, the upward gradation from offshore to nearshore deposits, or in general from fine to coarse deposits, will be a gradual one. In any case, however, the result will be the formation of a conglomerate or sandstone of emergence* or a retreatal conglomerate or sandstone bed. Since, however, during the retreat offshore deposits are continually forming at a distance from shore, we may consider that in

* A. Rutot: Les phénomène de la Sedimentation marine, Bull. du Musée Royal d'Hist. Nat. d. Belgique, ii, p. 41, 1883. I am indebted to Dr A. C. Lane for calling my attention to this author, who has treated some of the principles here discussed. The reference came too late to be made use of in the body of the paper. Reference should also be made to Dr A. W. G. Wilson's paper, in Can. Rec. Sci., July, 1903, vol. 9, no. 2, this author also recognizing the bearing of these principles.

the region unaffected by the shore detritus, even during the retreat, a continuous and uniform, or nearly uniform, series of deposits is accumulating. Even within the outermost zone affected by the retreat—that is, the region reached by the shore detritus at the end of the regressive movement—continuous deposition of offshore sediments is accumulating, until near the end of the movement, when shore detritus will replace the more open-water sediment. It thus becomes apparent that an additional series of strata is forming in the offshore district of which there is no representation in the nearer-shore area. When the retreat is a slow one a considerable amount of sedimentation may result in the offshore area. If the retreat of the sea is rapid, a relatively small amount of sedimentation records it. In any case the amount of sedimentation in any area over that of another area in the line of retreat becomes a measure of the interval occupied by the retreat of the sea from one to the other point. This implies, of course, that the amount of sedimentation

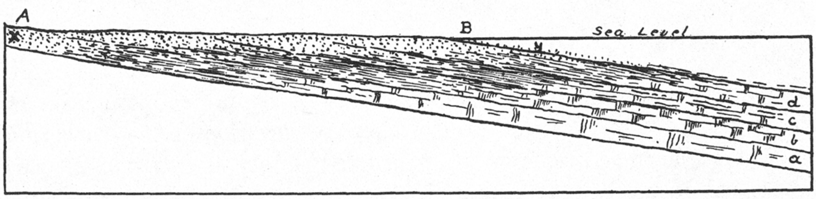


FIGURE 6.—*Diagram showing Planes of Sedimentation and Relationship of Seashore Bed.*

measured in each section begins at the same datum plane—that is, the plane of sedimentation at the beginning of retreat. It becomes, furthermore, apparent that the retreatal sand or conglomerate bed is not of the same age throughout, but rises in the scale *seaward*. Hence, if the gradation is a gradual one, the retreatal bed will grade down, near the old shoreline, into and may contain the fossils of a bed very much older than the bed into which it will grade at a distance from the old shore; for during the period of retreat a considerable space of time has been consumed and a certain amount of sediment has collected at the point eventually reached by the farthest retreat. The relationships of the beds are indicated in the diagram, figure 6.

In this diagram each bed from *a* to *d* was in turn laid down during the retreat, each later bed reaching to a less extent upon the old shore and each bed ending in a sand member. Thus bed *b* does not extend as far as bed *a*, nor *c* as far as *b*, but each ends landward in a sand facies; and these sand ends together constitute a more or less continuous bed of sand passing diagonally across the beds *a*-*d*. It is evident that the thickness of the beds *a*-*d* at the point *B* is a depositional measure of the time consumed in the retreat of the sea from *A* to *B;* and that the retreatal sandstone bed *x-y* is of much later age at *B,* where it represents bed *d,* than at *A,* where it represents bed *a.* If this retreatal bed contains fossils in its basal portion, they will be fossils of successively higher formations when traced from *A* to *B.*

Where the land is sufficiently elevated during this retreat of the sea stream erosion will set in and the material left by the retreating sea may be removed by this process. Furthermore, since elevation of the land is responsible for the retreat of the sea, the streams coming from the higher land will have their slope, and hence their velocity, accentuated. As a result, more detrital material is carried down, and where erosion is not going on deposition of land-derived detritus will take place. Thus pebbles derived from the old-land or from old conglomerates may be carried out for great distances over the emerging coastal plain. Wind deposits of assorted sands with rounded and pitted grains will likewise accumulate on this plain; and remains of land plants and of land and fresh-water animals may be buried in these sands. These sands, being wind or river deposits, will often show cross-bedding and wind ripples.

Examples of regressively overlapping or, better, off-lapping formations are frequently met. Since, however, in the most typical cases available for investigation the conditions are complicated by the structures resulting from the readvance of the sea, a brief account of these complicated phenomena may first be given.

Compound Regressive and Transgressive Overlap

Statement of the Principles

After the retreat of the sea and the washing seaward, during this retreat, of the land-derived detritus, a period of readvance, we may assume, invariably sets in, because stationary conditions in nature, if they ever occur, are so rare as to be negligible.

The readvance will, of course, have all the characteristics of a first advance, except that the material of which the basal bed of the readvancing series is formed is that of the retreatal bed deposited during the regressive movement and the river deposits and sand dunes accumulated on the recently emerged coastal plain. Thus the retreatal sands and pebbles will be reworked by the advancing sea and incorporated in the progressively overlapping beds of this readvance as a basal or shore facies. If the deposit by wind and streams on the emerged coastal plain was a heavy one, the advancing sea will work over only the upper portion, leaving the middle and lower portions undisturbed. Thus the resulting bed may be a wholly non-marine deposit in the middle, and yet grade downward into a marine series belonging to the lower and upward into a marine series belonging to the upper formation. Such a sandstone will occupy a stratigraphic gap which widens progressively toward the shore; for it was this region that the retreating sea first laid bare, and it is this region that the advancing sea covers last. Thus the time interval represented by the top and the bottom of the sandstone formation widens more and more toward the shore of the period, while seaward it decreases until it finally dies away, and with it, generally, the sandstone. These relationships are expressed in the following diagrams:

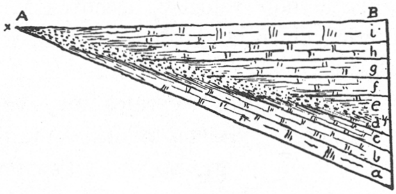


FIGURE 7.—*Diagrammatic Illustration of compound Overlap; actual relationship.*

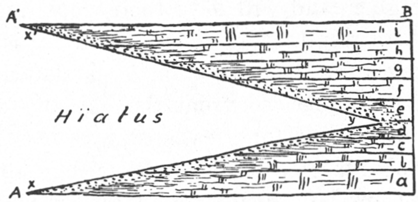


FIGURE 8.—*Diagrammatic Illustration of compound Overlap; showing the hiatus.*

Figure 7 represents the conditions as they will actually appear after a period of combined retreat and readvance. Beds *a* to *d* are deposited during the retreat of the sea; beds *e* to *i* during the readvance. *x–y* is the retreatal sandstone reworked by the advancing sea and made into a basal bed. At *A* it fills the interval between *a* and *i;* at *B* it forms the dividing line between *d* and *E* and is no more than the basal part of bed *e,* the stratigraphic break of *A* having disappeared entirely. At *B,* then, the sandstone *x–y* is wholly marine and may contain fossils intermediate between those of *d* and *f,* or the fosssils of the deeper-water bed *e,* farther out. This relationship is expressed in figure 8, where the widening gap from *y* to *x–x′* represents the increasing time interval comprised within the sandstone member. It need hardly be said, that in nature the beds of the lower and upper series will be so nearly parallel as to seem absolutely so.

It is evident that such a retreatal-transgressive sandstone can not serve as a horizon marker, since it not only varies in age in different localities, but also includes within itself a hiatus which widens progressively toward the source of the material.

APPLICATION OF THE PRINCIPLES

*The Saint Peter sandstone.**—Although there are numerous examples of retreatal-transgressive beds, only two cases, the Saint Peter sandstone

* C. P. Berkey: Paleography of Saint Peter time, Bull. Geol. Soc. Am., vol. 17, pp. 229-250.

and the Dakota sandstone, have so far been worked out in any detail. These will be sufficient, however, to illustrate the foregoing principle.

The Saint Peter formation is typically developed in the upper Mississippian region. In Minnesota it is a friable quartz sandstone of extreme purity in most cases. An analysis of material south of Saint Paul give:*

SiO_2	99.78
Fe_2O_3	trace
MgO	trace

Sometimes, however, impurities in the form of kaolin or iron stain occur. The sandstone is mostly of a white color. "This white color is due to the condition of the surfaces of the grains; they are worn simply to a dead finish—not polished, as can readily be seen by immersing them in water, when they become limpid."† In texture the sandstone is somewhat coarser in the bottom than in the middle and upper beds, but no conglomeratic texture is known. In Wisconsin, however, dolomitic pebbles from the underlying rock are included in its base, this being also more or less eroded.‡ The occurrence in the upper portion of *Hormotoma gracilis* (Hall) and *Lophospira perangulata* (Hall) shows its close relation to the overlying Stones River beds, with which it is perfectly conformable.

One of the most striking features of this formation in Minnesota is the fact that its base is perfectly conformable with the underlying Lower Magnesian limestone (Shakopee), while its top is also perfectly conformable with the overlying Stones River formation. "Nowhere," say Hall and Sardeson,§ "is there any indication, however slight, of an unconformity [between the Saint Peter and the overlying rock]. The transition zone of a green shaly calcareous sandstone shows the steady oncoming of the Lower Silurian [Ordovicic] sea. . . . The Saint Peter has a thickness varying from 75 to 164 feet in Minnesota. It rests, as noted, conformably on the Lower Magnesian or Shakopee dolomite, which, with the New Richmond and Oneota, is, as shown by Berkey and others, a normal depositional successor of the late Cambric. The thickness of the lower Magnesian (Oneota to Shakopee) varies from 105 to 260 feet,‖ and the fossils show it to be of basal Ordovicic age. The beds overlying the Saint Peter are 32 feet thick¶ and are conform-

* Hall and Sardeson: Bull. Geol. Soc. Am., vol. 3, 1892, p. 351.

† Hall and Sardeson: Loc. cit., p. 351.

‡ T. C. Chamberlin: Geology of Wisconsin, vol. ii, 1877, p. 287.

§ Loc. cit., p. 355.

‖ Hall and Sardeson: Loc. cit., p. 368.

¶ Winchell and Ulrich: Paleontology of Minnesota, vol. ii, introduction.

ably succeeded by the Black river. This and the fossils found in them show these beds to be the highest Stones River (Chazy) and equivalent to the Lowville or Birdseye of New York. In the Champlain valley the Beekmantown is at least 1,800 feet thick,* while the Chazy is nearly 900 feet thick on Valcour island,† the lowest beds not being shown.

It thus appears that the Saint Peter sandstone of Minnesota fills the interval represented in the lake Champlain region by the deposition of over 1,500 feet of Beekmantown dolomites and more than 800 feet of Chazy limestones. Its perfect conformity with the overlying and underlying beds proves that this great hiatus lies within the sandstone itself.

In eastern Tennessee the Knox dolomite has a thickness of about 4,000 feet, of which the upper half, if not more, is basal Ordovicic. It is succeeded by the Maclurea limestone (Chazy, with *Maclurea magna*), which has a maximum thickness of 600 feet, and this is followed by several hunderd feet of upper Stones River. In central Tennessee the Stones River group is 360 feet thick, at Cincinnati 500 feet, and in central Kentucky about 375 feet. In all these cases it is underlain by a representative of the Saint Peter sandstone.‡

In the Arbuckle mountains of Indian Territory the upper 1,250 feet or more of the Arbuckle limestone are of the age of the Beekmantown of New York—that is, basal Ordovicic. A slight erosion interval and some beds of pure sand separate this formation from the overlying Simpson series, which has a maximum thickness of 2,000 feet. It includes at least one heavy bed of sandstone near the center. The fauna of the lower half of the formation (below the sandstone) is that of the Chazy of New York, while that of the upper half is similar to the fauna of the upper Stones River of central Tennessee or of the Stones River beds lying between the Saint Peter and Black River, in the Minnesota area. It thus becomes clear that in the Arbuckle Mountain area as well as in eastern Tennessee the whole or nearly the whole of the basal Ordovicic (Beekmantown) was deposited while the sea retreated from the Lake Superior region. That the Arbuckle region was also laid bare toward the end of this retreat is shown by the erosion plane between the Arbuckle and Simpson formations. During the readvance of the sea the lower Chazy beds were laid down in the Arbuckle region, but, as before noted, they thin away northward. This thinning away of basal beds continued throughout the period of advance, until only the upper 32 feet of Chazy (Upper Stones River) were deposited in the Minnesota region. Thus the

* Brainard and Seeley: Bull. Am. Mus. Nat. Hist., vol. iii, 1890, pp. 2, 3.

† Brainard and Seeley: Ibid., vol. viii, pp. 305-315. Bull. Geol. Soc. Am., vol. ii, 1891, pp. 293-300.

‡ Winchell and Ulrich: Loc. cit., p. xciv.

break included within the Saint Peter sandstone of Minnesota is equivalent to the upper thousand feet of the Arbuckle plus the lower 1,900 feet or more of the Simpson formations, since this latter formation is followed by beds with a Black River fauna (lower Viola limestone). These relationships are graphically shown in the following diagram:

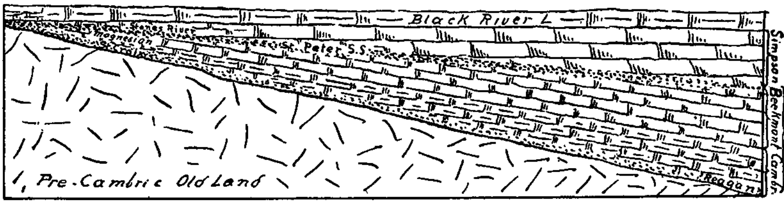


FIGURE 9.—*Relationship of the Arbuckle and Simpson and the Stones River and Magnesian Formations, and position of the Saint Peter Sandstone.*

In the Nittany valley of Pennsylvania* (Center county) the Beekmantown consists of nearly 2,500 feet of limestones, sometimes brecciated, often dolomitic and with siliceous sands at the base. *Ophileta complanata* occurs about 200 feet above the exposed base, but the lowest beds are not shown in this section. Toward the middle occurs *Asaphus marginalis* and *Ribeiria calcifera,* and toward the top of the series *Bathyurus amplimarginatus, Maclurea affinis, Liospira strigata, Protowarthia rossi,* and *Dalmanella subæquata gibbosa.* This fauna, as remarked by Collie, is an Upper Beekmantown fauna.

The fossiliferous beds are succeeded by 2,335 feet of ". . . compact yellowish gray and drab dolomitic limestone frequently thin bedded and laminated, alternating with numerous thin beds of dark limestone, weathering to a light gray color. Nodules of chert occur frequently, and in such occurrence the rock tends to be arenaceous." This is also referred to the Beekmantown by Collie, but may be of later age. It is followed by 235 feet of carbonaceous crystalline black limestone alternating with gray limestone and containing *Leperditia fabulites, Protorhynchula ridleyana,* and other fossils of Upper Stones River age. Succeeding this are 93 feet of Black River and 603 feet of Trenton limestone.

Since the fossiliferous horizon below the 2,335 feet of unfossiliferous (?) beds is upper Beekmantown and the first fossiliferous horizon is Upper Stones River (Upper Chazy), the lower Stones River, or Chazy proper, seems to be represented by this unfossiliferous (?) horizon. If, then, this series is taken from the Beekmantown and added to the Chazy, we have 2,500 feet—of the former and 2,500 feet (+) of the latter, a

* George L. Collie: Ordovician system near Bellefonte, Pennsylvania. Bull. Geol. Soc. Am., vol. 14, pp. 407-420.

division which agrees more fully with the Arbuckle Mountain section. Comparing with this the Mohawk River section, 250 miles to the north, we find a striking discrepancy. In the Mohawk section less than 500 feet of Beekmantown rest with a basal conglomerate upon the Adirondack gneisses, and is followed after an erosion interval by at the most 30 feet of Lowville (= Upper Stones River or Upper Chazy). This is conformably succeeded by the Black River and Trenton limestones.

It is evident that we have here much the same relationship that exists between the Upper Mississippi region and the Arbuckle Mountain section; only, in the case of the eastern section, no sands were deposited during the period of retreat, and hence none during the advance. While the Beekmantown of the Mohawk valley is probably not lowest Beekmantown, and although some erosion went on, during the retreat of the sea, in the exposed area, nevertheless it seems not unlikely that at least 1,000 feet of Beekmantown were deposited in central Pennsylvania during the period of retreat, while, if the reference of the "barren" beds to the Chazy is correct, nearly 2,500 feet of limestones were forming in Pennsylvania during the readvance. If the barren beds are Beekmantown, the amount of deposition in Pennsylvania during the readvance would only be about 200 feet, which amount agrees more nearly with the rate of deposition shown in the Arbuckle region during the Saint Peter advance.

The case here set forth takes account only of the greater movements and their results. That there were minor movements is shown by the several sandstones intercalated in the Simpson formation of the Arbuckle mountains and in the Ozark series of Missouri. These, however, did not alter the main course of events to any perceptible degree.

The Dakota Sandstone problem.—The Dakota sandstone presents another interesting problem of a retreatal sandstone worked over by a readvancing sea. As already noted, the marine sedimentation at the end of Fredericksburg or the beginning of Washita time extended northward as far as central Colorado. On the Purgatoire river, where the Dakota is 100 feet thick, it is underlain by 50 to 100 feet of dark shales and shaly sandstones similar to the Dakota and carrying in the shaly portion

Inoceramus comancheanus Cragin.	*Pholadomya sancti-sabæ* Roemer.
Trigonia emoryi Conrad?	*Protocardia texana* Conrad.
Cardium kansasense Meek.	*Leptosolen conradi* Meek.
Cyprimeria sp.	*Tapes* sp.

This rests on 15 to 60 feet of coarse gray cross-bedded sandstone, which in turn rests on the Morrison beds.* Similar conditions exist in Oklahoma and New Mexico.

* Stanton: Journal of Geology, vol. xiii, 1905, pp. 657-669.

At Two Buttes uplift, in southern Colorado, the shales beneath the Dakota furnish further

Gryphœa corrugata Say.
Pachydiscus brazoensis (Shumard).

and others. The beds appear to rest directly on the eroded surface of the Red beds.

On the Cimarron, in western Oklahoma, the fossiliferous Comanche beds beneath the Dakota are dark shales, with layers of brown flaggy sandstone and bands of somewhat calcareous sandstone 50 to 60 feet thick. They contain

Gryphœa corrugata Say.
Ostrœa subovata Shumard.
O. quadriplicata Shumard.
Plicatula incongrua Conrad.
Inoceramus comancheanus Cragin.
Gervilliensis invaginata White.
Trigonia emoryi Conrad.
Protocardia multilineata Shumard.
Pholadomya sancti-sabœ Roemer.
Anchura kiowana Cragin?
Turritella seriatim-granulata Roemer.
Hamites fremonti Marcou?
Pachydiscus brazoensis (Shumard).

Below these beds, and resting with apparent disconformity on the Morrison, are coarse cross-bedded sandstones with irregular bands of pebbles, varying from 4 to 15 feet in thickness.

This horizon with *Gryphæa corrugata* was traced westward to about 30 miles east of Folsom, New Mexico. At Tucumcari 60 feet of fossiliferous shales and sandstones underlie the Dakota, and at Canyon City, Colorado, 85 feet of these shales and thin bedded sandstones underlie the Dakota, and are separated from the Morrison by 35 feet of massive gray sandstone with bands of fine conglomerate near the top.

These beds are correlated with the Kiowa and Mentor beds of Kansas (Stanton). Regarding the age of these beds, Cragin* considered that they "represent a group of sediments intermediate between the Fredericksburg and Washita division, and one which, as a meeting ground of the faunas of these two divisions, can not satisfactorily be referred to either."† Hill,‡ on the other hand, holds that the beds "represent the modified, attenuated northern portion of the Washita division, and probably a portion of the Fredericksburg division of the Comanche series of Texas." Though there is a difference here as to the classification of the "Kiowa division," as Cragin proposed to call it, there is unanimity in regarding it as representing the border line of the Fredericksburg and Washita.

At Marquette, McPherson county, Kansas, the following sections occurs:§

* American Geologist, vol. xvi, pp. 357-386.
† Ibid.: Loc. cit., p. 383
‡ Am. Jour. Sci., 3d ser., vol. 49, pp. 205-235.
§ C. N. Gould: American Geologist, vol. 25, pp. 35, 36.

	Feet
11. Equus bed	±50
10. Dark brown to black sandstone, forming prominent escarpments, very fossiliferous in a layer 1 to 2 feet thick in the middle of the ledge. The fossils are listed by Gould.*	8
9. Soft yellow sandstone	2
8. Hard massive gray and yellowish sandstone	4
7. Yellowish and bluish shales	16
6. Rather hard yellowish sandstone	8
5. Bluish to yellowish paper shales, very like Kiowa, with selenite and cone-in-cone gypsum; contains layers of soft yellow sandstone with dicotyledonous leaves	40
4. Two six-inch ledges of very fossiliferous limestone separated by shales. The fossils are listed by Gould.†	8
3. Shales like the Kiowa, with iron pyrites, selenite, and cone-in-cone gypsum	20
2. Gray to yellowish sandstone, with much lignite and crushed plant material in places; very like Cheyenne	4
Total Comanche-Dakota	105
Disconformity.	
1. Permian shales, red, blue, green, etc.	

The sandstone number 10 has all the appearance of the Dakota sandstone and lies 50 feet above the stratum in which the first disotyledonous plant remains are found. Lithically this entire series belongs in the base of the Dakota. Similiar conditions exist at Mentor, 20 miles northeast, but the exposures are not so satisfactory.

The fauna of both the lower and upper beds is that of the Kiowa shales. In the typical section this comprises 125 to 150 feet of bluish gray paper shale, becoming more arenaceous upward. Interspersed throughout the formation are layers of hard gray limestone, soft sandstone, and pebbles. Gypsum occurs throughout and the shales are fossiliferous. The fauna as listed by Cragin‡ contains 51 species of intertebrates and 13 species of vertebrates.

The base of the Kiowa shales of Kansas is formed by the Champion shell-bed, a thin stratum of shell conglomerate commonly less than a foot in thickness and rarely more than a foot and a half. *Gryphæa hilli* is the only fossil found in it in some localities, but elsewhere a considerable number of species have been found. Of 36 species listed by Cragin, 22 pass upward into the Kiowa shale, the remainder apparently not occurring above the shell-bed. Among these latter is *Gryphæa hilli*, which

* Ibid., p. 37.
† Loc. cit., pp. 36, 37.
‡ American Geologist, vol. xvi, 1895, pp. 372, 373.

is an abundant and characteristic fossil of the Comanche Peak and Walnut beds (Fredericksburg) of Texas. A number of other characteristic species of this bed do not occur above the Fredericksburg horizon in Texas. On this account Cragin thinks that . . . "the Champion shell-bed should be referred to the Fredericksburg division and perhaps to a horizon not higher than the middle of that division."*

The Champion shell-bed is underlain by the Cheyenne sandstone, which rests disconformably on the Red beds. It consists of soft variegated grayish or yellowish cross-bedded sandstones in the lower part, with pebbles of quartz, clay granite, etc., smoothly water-worn and ranging in size up to a hen's egg. They are often seen in pockets on the Red beds. Lignite and other carbonaceous matter also occurs here. The upper part consists of alternating vari-colored sandstones, sandy shales, and hard argillaceous shales. The total thickness ranges from 50 to 100 feet. From the upper part of this sandstone dicotyledonous plants of the genera Rhus, Sassafras, Sequoya, etc., are obtained. No animal remains have been recorded from this formation, which is probably entirely of continental origin.

In the Arbuckle mountains of Indian Territory the Cretacic beds rest on a nearly flat floor of older rocks. The base consists of approximately 240 feet of sands, with local conglomerates at the bottom. They are succeeded by the Goodland limestone, 20 to 30 feet thick, and a nearly pure limestone formation. Above this lie the Kiamitia clays, Caddo limestone, Bokchito formation, and Bennington limestone, aggregating nearly 840 feet in thickness. The upper beds are slightly eroded and succeeded by the Silo sandstone, which is in part at least of Dakota age.†

The Goodland limestone is correlated with the entire Fredericksburg—that is, Walnut, Comanche Peak, and Edwards—while the underlying sands are called Trinity. This correlation is no doubt just as erroneous as was the former reference of the Cheyenne sandstone to the Trinity. The fact that a lower Cretacic formation is a basement sand does not make it Trinity in age, since basement sands can be of any age. The combined thickness of the Comanche Peak and Edwards (the Walnut is only a phase of these limestones) on the Rio Grande is in the neighborhood of 700 feet, while in Mexico it is still greater. This shows clearly that the Goodland limestone can represent only a part—that is, the upper part, though probably not the highest part—of the Fredericksburg, and that the so-called Trinity sands are really basal sands of Fredericksburg

* Cragin: Loc. cit., p. 371.

† Taff: Professional paper no. 31, U. S. Geological Survey, Tishomingo and Atoka folios.

age which have overlapped the Trinity. Here, as in the case of the Cheyenne sandstone, the simple application of the principle of progressive overlap will give the right solution of the problem.

The Kiamitia clay is equivalent to the Kiowa shales of Kansas, both being at the Fredericksburg-Washita boundary. The Caddo, Bokchito, and Bennington formations, however, are later Washita beds. Here, then, we have clear evidence that the Dakota retreat, beginning in central Colorado and Kansas at the commencement of Washita time, reached the Arbuckle Mountains region only toward the middle of that period, after nearly 700 feet of additional strata had been deposited in this more southern region.

It is not at all improbable that while the Kiowa (Kiamitia) clays were forming the upper Edwards limestone of southern Texas and Mexico was still being deposited.

In northern Texas the Washita division is about 500 feet thick and consists of clays, marls, and some limestone beds, the whole resting conformably on the Goodland limestone. At the base lie the Kiamitia clays with *Gryphæa corrugata,* while the top is formed by the Grayson marls, which are apparently conformably succeeded by the Dexter sands of the Woodbine (Dakota). In the Austin region the corresponding deposits (Georgetown, Del Rio, and Buda) are chiefly limestones, some of them even chalk of foraminiferal origin; hence it is not surprising to find the series much thinner in that section. The top of the section, moreover, is here marked by an erosion interval, and hence the whole of the Buda (elsewhere 100 feet thick) is not shown. This erosion interval is important as indicating the extent to which the Dakota retreat took place, the Austin region being lifted into dry land.

The Dakota of Texas is known as the Woodbine. In the northern section it is at least 600 feet thick, at Denison about 500 feet, and at Fort Worth about 300 feet. Near Waco it has thinned to 45 feet, and on the Brazos it has disappeared altogether. Hill states that it apparently rests unconformably on the Grayson marls and Main Street limestone of the Denison beds of the Washita division. "The upper beds pass by inseparable transition from sands into sandy clays and finally into the bituminous clays of the Eagle Ford formation. This transition is so gradual that no exact line of separation can be drawn between the Woodbine and Eagle Ford formations. The parting is arbitrarily established at the zone of *Exogyra columbella,* which is considered as the top of the Woodbine formation."* The disconformity at the base of the section can not be great, if it exists at all. Of course, the emergence at the

* R. T. Hill: Twenty-first Ann. Rept. U. S. Geological Survey, pt. vii, p. 296.

beginning of Woodbine deposition (Dexter sands) would allow a certain amount of erosion, probably by the streams which later spread out the Dexter sands. The presence of dicotyledonous plants and the absence of marine organisms indicate that these sands were spread by streams. Sometimes a clay marks the transition from the Grayson marls. The presence of glauconite in the lower beds suggests that at first they were deposited in a shallow sea, and that only during the progress of deposition of the sands did emergence occur. If this is the case, there can be no serious break between the Grayson marls and the basal Dexter sands, and from the description of the sections there appears to be none. False bedded structure is a characteristic feature of these sands, whose thickness is approximately 160 feet.

It was apparently during this period of emergence that the erosion at Austin took place. This is believed to be the case, because the succeeding beds of the Woodbine (Lewisville beds) carry a marine fauna, and hence mark the readvance of the sea. The Lewisville beds consist of laminated lignitic sands and clays, interstratified with brown sands, ferruginous sandstones, and argillaceous shelly sandstones, aggregating 100 feet. The fauna of this bed, listed by Hill,* is peculiar, in that it is unknown above or below this horizon. This indicates a considerable period to have elapsed before the readvance of the sea took place. The higher beds of the Woodbine are sands and clays, often fossiliferous, and pass upward into the overlying Eagle Ford formation.

The Eagle Ford formation of Texas is essentially a bituminous clay. It rests directly on the Buda limestone in central Texas, having there become a flaggy argillaceous limestone. The thickness of the formation varies considerably, from 250 feet on the Rio Grande to 600 feet in northern Texas, with varying thicknesses at other points. In the Austin region it is only 30 feet thick, but here only the upper beds of the formation rest upon the post-Buda erosion plane.

In southern Kansas the typical Dakota sandstone is followed by lignitic sands, bituminous shales, and saliferous and gypsiferous shales with marine fossils, followed by 350 to 400 feet of shales and limestones with the typical fauna of the lower Colorado or Benton group, *Inoceramus labiatus* predominating.

In the Front Range region of Colorado these shales (Benton) vary in thickness from 500 to 700 feet, while farther north, in the Bighorn Mountains they increase to 1,300 feet, and in the Black Hills to 1,600 feet.† Throughout most of the region the characteristic fauna with

* Hill: Loc. cit., p. 314.

† N. H. Darton: Bull. Geol. Soc. Am., vol. 15, pp. 379-448. Professional paper no. 32, U. S. Geological Survey.

Inoceramus labiatus begins from 200 to 500 feet below the top of the series, in an impure limestone averaging 50 feet in thickness. This limestone (the Greenhorn) apparently represents the successful accomplishment of the post-Dakota marine invasion, the underlying shales, except in the southern area, showing little if any evidence of marine occupation. In fact, it is not improbable that 800 to 900 feet of the Lower Graneros shales and included sandstones of the northern region are chiefly of non-marine origin, representing the continued deposition of fine material during the period of continued southward retreat and early advance of the sea. This would explain the increase in thickness northward of the Graneros shales. The only fossils recorded from these shales in the northern region are dicotyledonous plants and fish scales.

The Carlisle group overlies the Greenhorn (*Inoceramus labiatus*) limestones and constitutes the upper member of the Benton division. This group consists mostly of clays, with some limestones and sandstones. It is as a whole not very fossiliferous, but certain beds are characterized by *Prionocyclus wyomingensis* and *Prionotropis woolgari*.

The Eagle Ford beds are succeeded by the Austin chalk with a thickness of 600 feet in central Texas, but 1,500 feet on the Rio Grande. In Colorado this series is represented by the Niobrara formation, with *Inocoramus deformis* and *Ostrea congesta*. This is 700 feet thick in southern Colorado, where it rests on about 200 feet of Benton, Northward, in the Black hills, where the Carlisle has a thickness of from 500 to 700 feet, the Niobrara is only about 200 feet thick, thinning to 100 feet toward the northwest.

Above the Niobrara comes a great thickness of clay shales, the Pierre. These have a recorded thickness of 4,000 feet in southern Colorado, increasing to over 7,000 feet in the Denver region, but decreasing to 2,700 feet in the Bighorn mountains and to 1,200 feet in the Black hills. Beds of sandstone become intercalated in the thicker sections, as at Denver, where a bed of sandstone from 100 to 350 feet thick occurs near the middle. The succeeding Fox Hill beds, which are mainly sandstones, have an average thickness of 300 feet or less, though increasing to 1,000 feet in the Denver region. Marine fossils occur, together with plant remains, the whole series grading up into the great non-marine Laramie formation.

In the northern region the Austin chalk grades up into the Taylor marls and Eagle Pass or Navarro formation. These are the *Exogyra ponderosa* beds. The Taylor marls are about 700 feet thick in southern Texas, and 600 feet in central Texas. The overlying Navarro has a thickness of 4,300 feet on the Rio Grande and consists mainly of sandstones with beds of clay and glauconite and with several coal seams about 1,200 feet above the base. Marine fossils occur almost throughout the series, but Laramie plants have been found in the neighborhood of the coals.

The interpretation of these sections in the light of the principles discussed shows us that the Dakota sandstone represents the deposits between the retreat and readvance of the sea. The retreat, as we have seen, began in Washita time, almost at the beginning of that period. The Washita division itself is the depositional equivalent of the retreatal Dakota sandstone, and hence the lower Dakota is actually of Washita age—of lowest Washita in the northern and of highest Washita in the southern area. The retreat of the sea was considerable, as shown by the unconformity between the Buda and the Eagle Ford and by the thinness of the latter. With the readvance of the sea, a new fauna, an immigrant from Europe, came in; and as the sea continued to advance, the continental sands of the Dakota-Woodbine Graneros were reworked and incorporated as basal deposits of later Cretacic age. The Upper Dakota sandstone is thus of Eagle Ford-Benton age, the return of the sea being finally accomplished in mid-Benton time.

From this it appears that the Dakota sandstone can not be included as a time element of the standard scale, since it represents different time in different localities. This consideration also suggests that the Washita be made the base of the Middle Cretacic, the classification being approximately the following:

		Marine.	Non-marine.
Upper Cretacic-Montanan		Navarro Taylor.	Laramie.
Mid-Cretacic	Coloradoan	Austin. Eagle Ford.	Dakota.
	Unrepresented interval.		
	Washitan.		
Lower Cretacic-Comanchean		Fredericksburg. Trinity.	

If two systems are to be made from the present Cretacic, the Comanchic system would end with the Washitan, and the Cretacic begin with the Coloradoan, the unknown base of which must be looked for in southern Texas or in Mexico.

Non-marine Progressive Overlap

EXPLANATION OF THE TERM

This term is applied to the large structure normally produced during the formation of a great fan or subaerial delta from the wash carried by the streams from the mountains and deposited on the plains adjoining. Such a subaerial fan will, of course, grow year by year; and in so growing the latest deposits, whether derived from the mountains or whether obtained through the reworking of the previously deposited portion, will, as a rule, extend farther out on the plain than did the deposits of previous periods. In other words, each later formation will overlap the previous ones by a margin commensurate with the increase in the size of the fan, and beyond the margin of the previously formed bed it will come to rest directly on the floor of the plain. This overlapping of later formed over earlier beds will, of course, be progressive, if the growth of the fan is continuous. The essential point of difference between this type of overlap and that formed in a transgressing sea is that in the subaerial fan the formations will overlap one another in the direction *away from the source of supply of the material;* while in marine progressive overlap (transgressive) the overlap is *toward the source of supply of the material.* The following diagrams will illustrate this difference, the source of supply in each case being on the left.

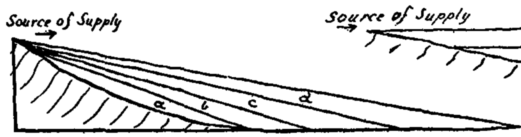


FIGURE 10.—*Non-marine progressive Overlap.*

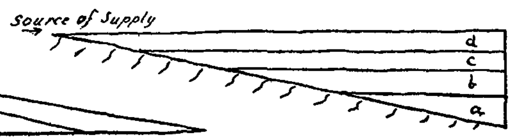


FIGURE 11.—*Marine progressive Overlap.*

The coarsest material of the subaerial fan will, of course, be deposited near the head of the delta. Finer material may be carried out for hundreds of miles across such a delta, as is plainly shown by the delta-plains of the Indus, Ganges, and Yellow rivers. Occasionally pebbles well rounded may be carried out to great distances, and this is especially true of the well rounded pebbles derived from older conglomerates. When the surface of the delta has become very flat, drainage obstructions may take place, in which case swamps and deposits of carbonized plant remains will form. Thus a fossil delta of this type may include coal seams, the tops of which may again be eroded or covered with a moderately coarse river deposit.

Another type of non-marine overlap is that connected with a retreating seashore, in which case the overlapping of the non-marine beds will be, not on the old plain surface, but on previously deposited and all but contemporaneous marine beds. Along the border line the two, marine and non-marine, will blend, and it will appear as if the non-marine overlies the marine, though in reality it is more a replacement of the one by the other. The following diagram will make this clear:

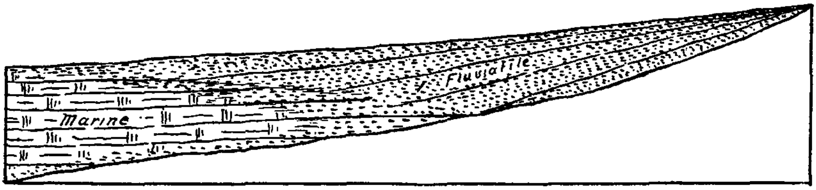


Figure 12.—*Overlap Relation of marine and non-marine Beds.*

EXAMPLES OF NON-MARINE PROGRESSIVE OVERLAP

Chemung-Catskill.—A typical example of the last described type of overlap is seen in the case of the Catskill and Chemung formations of New York and the northern Applachians generally. Here the non-marine Catskill begins in Portage time as the Oneonta, and is gradually but progressively pushed westward and northwestward until it has reached the very summit of the Chemung. Thus in the Ithaca region the red sedimentation of the Catskill type does not begin until upper Chemung time. In the Olean region farther west it begins in the Cattaraugus beds above the Chemung (Devono-Carbonic transition). Thus, while the Chemung is fully developed in western New York, it is absent in eastern New York and Pennsylvania, where the Catskill type of sedimentation alone occurs. Between these two points both are seen, the non-marine always overlying the marine. This relationship is shown in the following diagram:

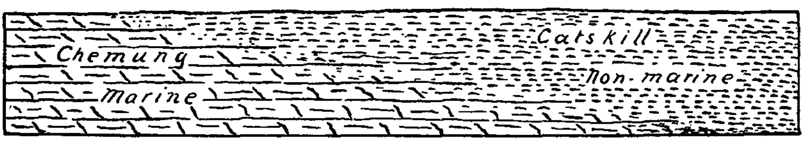


Figure 13.—*Overlap Relation of marine Chemung and non-marine Catskill Beds.*

The Pocono.—This is the lowest of the Appalachian Lower Carbonic formations and represents the continued non-marine sedimentation from the Appalachians northwestward to the western Pennsylvania region. The original easternmost extension of this formation, as of the preceding and succeeding non-marine formations, has been removed by erosion; so that we find at the present time only portions which originally were accumulated at some distance from the highlard which furnished the material.

That the Pocono is non-marine is shown by the absence of fossils, except as noted below. The fact is further indicated by the relationships of the strata, which conform to the non-marine type of overlap. The source of the material of this formation was in the Appalachian oldlands on the southeast, as is shown by the decreasing coarseness toward the northwest, and by the fact that no land capable of furnishing the material of this rock existed in Ohio, western New York, or Canada, which were extensively covered, at the time of the formation of the Pocono, by marine Devonic strata, many of them limestones. The characters of this formation will be best shown by two sections from the eastern area.

I. *Section of the Pocono in the Northern Anthracite Fields, in Wayne County, Pennsylvania, about 10 Miles South of the New York Line.**

	Feet
8. Sandstone	40
7. Shale and sandstone	200
6. Massive sandstone	125
5. Shale and current bedded sandstone	265
4. Griswold Gap conglomerate	35
3. Sandstone and shale, imperfectly exposed	150
2. Sandstone and sandy shale	200
1. Mount Pleasant conglomerate	25
Total	1,040
0. Catskill.	

Beds 1 to 3 are regarded by White as transitions from the Catskill.

II. *Section at Pottsville.*†

	Feet
6. Sandstone, more or less conglomeratic	521
5. Slate	22
4. Sandstone, with much conglomerate	726
3. Sandstone with little conglomerate	240
2. Sandstone, variegated	409
1. Red, gray, olive, and yellow sandstone, with some shales and conglomerates, transitional from Catskill	525
Total	2,443
0. Catskill.	

On the Susquehanna the formation is 2,000 feet thick. It becomes coarser toward the southeast, the pebbles in Maryland being sometimes

* Stevenson: Lower Carboniferous of the Appalachian basin. Bull. Geol. Soc. Am., vol. 14, 1903, p. 18. (Slightly altered.)
I. C. White: Second Geol. Survey of Pennsylvania, G 5, 1881, p. 56.
† Stevenson: Loc. cit.

three-fourths of an inch in length or over. In this region* interbedded fossiliferous shales occur, showing the proximity of the sea and its occasional invasion of the growing Pottsville fan. In Huntingdon and Bedford counties, Pennsylvania, where the thickness of the formation is from 1,100 to 1,200 feet, and where it is mostly sandstone, a shaly layer with marine fossils (Spirifer, Rhynchonella, and productoid forms) has been discovered 400 feet above the base of the series. This and the Maryland sections are about in a line parallel to the front of the growing fan, as shown by the correspondence of the thickness.

In tracing the Pocono northwestward, we find that in the northwestern part of Lycoming county, Pennsylvania, it consists of 665 feet of current-bedded sandstones, with a one-foot seam of coal lying 80 feet above its base. In the northwest of Lycoming county its thickness is reduced to 350 feet and it is still a current-bedded sandstone. In Potter county, Pennsylvania, we have 330 feet of sediments, with a thin layer of coarse sand or conglomerate, the Shenango, at the top. Westward from this the pebbles become flat, like those of the underlying Chemung sandstones. In McKean county, Pennsylvania, the Pocono is not much over 200 feet thick, the Shenango being 40 feet. In most of these northwestern sections intercalated strata with marine fossils show the presence of the Waverly sea, which laved the front of the great Pocono fan and into which its edge dipped. Downward these beds grade into fossiliferous Lower Carbonic strata, which are the contemporaneous deposits of the eastern end of the Waverly sea. The margin of this sea was gradually pushed westward by the growing fan, as shown by the character of the deposits.

If we glance for a moment at the contemporaneous marine deposits of the Ohio-Michigan area we find that the coarseness of the material decreases toward the northwest. Many sandstone beds, like the Berea, die out in northern Michigan, while beds like the Logan change from conglomerates to sandstones. This indicates the Appalachian source of the material, even of the marine deposits, showing that the streams which built the subaerial fan also supplied the material for the bordering marine strata.

In the summary given by Stevenson† of the Pocono, the vital fact is brought out that the thinning of the Pocono in northwestern Pennsylvania and in West Virginia is due "apparently in part" to "loss of the lower beds." The significance of this fact is best stated in Professor Stevenson's own words:

"The Pocono of Pennsylvania, Ohio, Kentucky, and Virginia has been regarded by most geologists as Lower Carboniferous throughout. The Pocono of

* Maryland Geological Survey, Garrett county, p. 168.
† Stevenson: Loc. cit., pp. 39, 40.

the eastern outcrops in Pennsylvania has been accepted as the equivalent of that in the western counties, as though the westward decrease were due merely to lessened thickness in each of the subdivisions. It must be clear, however, . . . that the loss in thickness is due very largely to disappearance of the lower members of the section, as is the case also southward from central Kentucky and southern Virginia, so that in Alabama and much of Tennessee only the uppermost beds remain. A new correlation appears to be necessary."*

The general change in the character of the sediments from conglomerates and coarse sandstones in the east to shales in the west is also emphasized by Stevenson. The relationships of these deposits may be expressed in the following diagram:

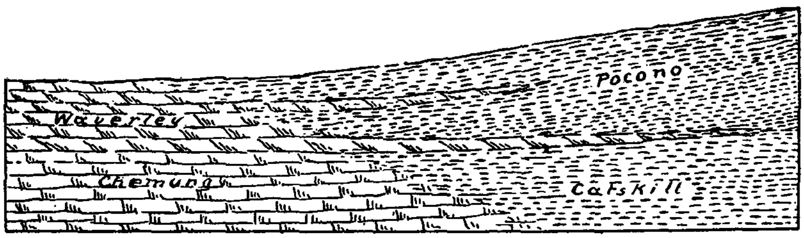


FIGURE 14.—*Relation of Waverley and Chemung Formations to the Pocono and Catskill.*

The Mauch Chunk.—The Mauch Chunk period of Appalachian history seems to have been a period of more stationary conditions, accompanied by some subsidence, as shown by the fact that fine sediments characterize the formation throughout, and also by the presence of extensive marine limestones. In the northern Appalachians heavy non-marine sediments still accumulated. Thus in the type region 2,168 feet of red shales, with some sandstones in the upper part, constitute this formation. A little north of Mauch Chunk, Pennsylvania, the formation of this name has a thickness of 3,342 feet and consists almost wholly of red shales.

In the Broad Top region of Huntingdon county, Pennsylvania, the basal part of the Mauch Chunk consists of 141 feet of shales and sandstones, followed by 49 feet of limestone (Greenbrier), and this by 910 feet of sandstones and shales. In northeastern Lycoming county, 30 miles from Mauch Chunk, the base of the formation consists of 120 feet of shales, followed by 75 feet of marine limestone and 150 feet of shales. In northwestern Lycoming county the basal beds have been reduced to 80 feet, while the upper beds are only 20 feet thick, the intervening limestone measuring 50 feet. In Potter and in McKean counties only the upper beds are present, decreasing from 70 feet in the first to 50 feet in the second, and finally dying away westward as a coaly black shale.

Southward from the type region of non-marine sedimentation the marine phase thickens. Thus on the Potomac, in the Maryland Alleghenies, the formation is 1,107 feet thick and consists at the base of 227 feet of Greenbrier limestone resting directly on the Pocono, followed by 800 feet of shales, mostly red. Southward, in Pendleton county, West Virginia, the Greenbrier limestone at the base is 325 to 400 feet thick, and is followed by gray and brown sandstones and shales and red shales (Canaan shales), with a thickness of 1,250 feet. These shales, however, are in all probability only partly non-marine.

The Mauch Chunk thus seems to present two periods of non-marine fan-building separated by a period of partial subsidence. Non-marine (fluviatile) sedimentation appears to have been continuous in eastern Pennsylvania throughout. In both periods the greatest accumulation of non-marine sedimentation was in the east, and the members overlapped westward and northward. A diagrammatic section will make this clear.

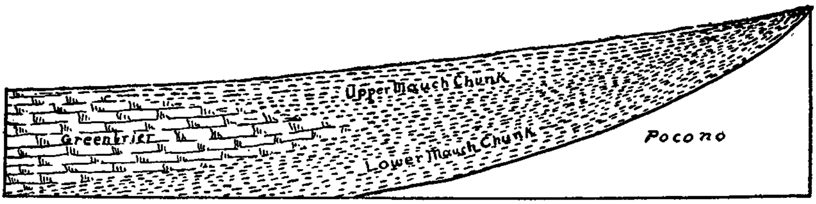


FIGURE 15.—*Relation of the Upper and the Lower Mauch Chunk and the Greenbrier.*

The upper Mauch Chunk fan represents the recovery of the land after the Greenbrier subsidence. With this recovery corresponds the presence of coarser sands in the upper Mauch Chunk in the eastern region, where non-marine sedimentation was uninterrupted. That the land was low and streams sluggish is indicated by the fact that the surfaces of the beds are marked by ripple-marks, sun-cracks, rain-drop impressions, and foot-prints of vertebrates—all signs of floodplain deposits.

The fossils of the Greenbrier in southern Pennsylvania and Maryland correspond to those of the Maxville of Ohio. The Maxville is separated from the Logan by an interval of erosion, which may correspond to early Mauch Chunk sedimentation in the east; for the beginning of a new fan on an older one indicates either an increased supply of detritus or a period of elevation. The fineness of the lower Mauch Chunk is, perhaps, more in harmony with the theory of a renewed elevation of the region, which in the western area permitted the post-Logan erosion. A part of the upper non-marine Pocono probably also suffered erosion during this time. It may perhaps be further surmised that the change indicated was not due to an elevation in the east, but rather to an elevation of the western region, which gave the surface of the Pocono fan so gentle a slope that the streams no longer were able to carry to this western area the detritus derived from the east; and so they dropped it nearer the source, building up a new fan, but this time of fine materials. However this may be, the presence of the Greenbrier limestone shows a widespread subsidence, and the fossils of this limestone show that this took place at the beginning of Chester time.

It seems likely that the post-Logan elevation, which in Michigan was accompanied by the formation of gypsum beds (lower Grand Rapids), gave an impulse to the southeastward transgression of the Mississippian sea, and that during this period the Cumberland ridge above outlined was finally submerged. The elevation was felt in the Mississippian valley, since a pronounced line of erosion exists at the top of the Warsaw, which is followed by only the highest Saint Louis limestone, resting with a basal breccia on it. Southward in the Mississippi region this interval becomes less; and southeastward, in the southern Appalachians, it disappears altogether, the Saint Louis and succeeding Chester beds being of great thickness. Since this seems to be the case, the Greenbrier-Maxville readvance apparently came from the southeast, where continuous deposition was going on. The readvance reached the Iowa-Mississippi region and northern Kentucky in Saint Louis time; but central Ohio, Michigan, and Pennsylvania only in Chester time. This explains the greater thickness of the Greenbrier in Maryland and West Virginia. The retreat of the sea after the temporary advance into Pennsylvania was followed there by the formation of the upper non-marine Mauch Chunk fan, but transgressive movements seem to have continued over the southern Appalachian region.

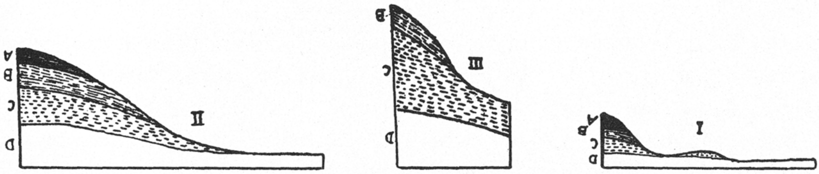
The Pottsville.—The Pottsville of the Appalachians represents even a better case of non-marine progressive overlap than either of the preceding examples. The series has been worked out in great detail by the Pennsylvania geologists, and the relationships of the beds to each other have been fully discussed by Stevenson,* and, with special reference to the overlap shown by them, by David White.†

One of the pronounced characteristics of the Pottsville is the well known abundance of conglomerates and coarse cross-bedded sandstones. Coal beds and layers of coal plants are common, but marine fossils are rarely found. As has been convincingly demonstrated by Stevenson and David White, the lowest beds of the series—that is, the Pocahontas division—is found only in two areas, and those the most easterly of the series. The first is in the type region of central eastern Pennsylvania, and the other is in southwestern West Virginia and adjoining Virginia. The next higher series, the Raleigh-Bon Air (middle Pottsville), is especially well developed in the southern Appalachians, where it extends through Alabama, eastern Tennessee, Kentucky, and West Virginia. In eastern

* Stevenson: Loc. cit.

† David White: Bull. Geol. Soc. Am., vol. 15, 1904, pp. 267-282.

Pennsylvania the overlap was not very great at this time. The next higher division, the Sharon (Sewell), extended into western Ohio and northwestern Pennsylvania, while the higher beds, the post-Sharon, extended still farther. The following diagrams, copied from David White's papers, show these relationships:



FIGURES 16 I-III.—*Relations of Pocahontas (A), Raleigh-Bon Air (B), Sewell (C), and post-Sharon (D), interpreted as overlapping marine series (according to White).*

White assumes that this transgression was that of a water body transgressing northwestward, and he so labels it. At the same time he recognizes the fact that most of the formations are either conglomerates or coarse sands, and that these various clastics rest in most cases directly on marine limestones or shales. He further recognizes erosion in this region preceding the advent of the Pottsville sediments.

The material of the Pottsville beds shows that they were derived from disintegrating crystalline material. Their coarser and more undecomposed character in the Appalachian region indicates this to have been the source of the material. The utter want in the northwestern region of any area which could have supplied this material makes this conclusion unassailable; for, as has already been stated, the successive beds lie on either marine limestones or shales or on finer non-marine sediments. *These must have constituted the shore at successive periods of transgression* if a Pottsville sea transgressed northwestward, and they should have constituted the source of the material of the Pottsville beds. Such is not the case, as is well known; for the pebbles of the conglomerate are quartz pebbles and the sand is composed chiefly of quartz grains.

We are, then, compelled to consider the crystallines of the Appalachians as the source of the material of these beds. These beds, therefore, overlap *away from the source of supply,* and hence they can not, by any manner of reasoning, be referred to marine or even lake deposits. To refer them to either is to ignore fundamental principles of deposition; yet all or nearly all writers have thus referred them in the past.

A significant fact in connection with the recognition of these beds as river deposits is the remarkable rounding of all the pebbles of the conglomerates. This rounding explains their removal so far from their place of origin, for perfectly round pebbles can be rolled hundreds of miles by streams. It also shows that they have been subject to an enormous amount of river wear. Of course, the accumulation of these pebbles is the result of continued selection by the rivers of the most rounded pebbles. Since such rounding implies, as above stated, a very long period of river wear, it is not surprising that only quartz pebbles survived the ordeal. Pebbles of more destructible material were ground to sand or decomposed during the process. Thus the remarkable purity and roundness of the quartz pebbles of these conglomerates, so entirely inexplicable on the hypothesis of a transgressing sea, is exactly what might be expected in the case of extensively transported river material.

Since the latest Pottsville beds are overlapped by the Kanawha in northern Ohio, it is more than probable that the Pottsville is entirely absent in Michigan and other western areas, except where represented by equivalent marine strata. Thus the Saginaw formation of Michigan and the Mansfield of Indiana and the Mississippi valley is most certainly post-

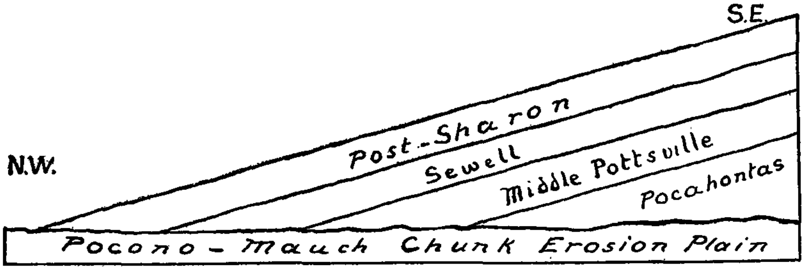


FIGURE 17.—*Diagram illustrating Relationships of Members of Pottsville Formation.* Diagram is based on the theory of non-marine progressive overlap (fluviatile).

Pottsville, limiting that formation according to the standard of the typical Pottsville area. The Saginaw formation of Michigan is indeed now recognized as probably of the age of the Mercer group, which in turn is correlated by White with the later Kanawha. This and the later coal-bearing beds of eastern United States also show evidence of non-marine progressive overlap. They appear to be the remnants of one or more series of fans built out from the Appalachian highlands by streams flowing northwestward, the later members of each fan overlapping the earlier ones of the same series.

Other examples.—Non-marine series, overlapping away from the source of supply, and therefore of fluviatile origin, are to be found in other formations of North America. Among them may be mentioned the Upper Silurics of the Appalachians, the Laramie, and the non-marine Tertiaries of the Great Plains region. The Potomac and Newark formations will probably also show this type of structure when they are studied in greater detail. Wherever it is found, the fluviatile origin of the strata involved is established by it beyond contravention.

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Types of sedimentary overlap

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Notes