

T H E

AMERICAN JOURNAL OF SCIENCE

[F O U R T H S E R I E S .]

ART. XXVII.—*The Middle Ordovician of Central and South Central Pennsylvania*; by RICHARD M. FIELD.

INTRODUCTION.

The geographic position, as well as the faunal and lithological peculiarities of the Ordovician formations of central and south-central Pennsylvania, make it possible to treat their area, for descriptive purposes, as a part of a province within the Ordovician terranes of eastern North America. The sketch-map (fig. 1), copied from the atlas of the Second Geological Survey of Pennsylvania (1),¹ gives an approximate idea of the location and distribution of the formations which are exposed in eroded anticlinal valleys parallel to the northeast and southwest axis of the Appalachians. The map shows all of the formations from the Beekmantown to the Eden, no attempt having been made to plot the exact areal distribution of the Middle Ordovician formations alone. At the time of the Second Geological Survey, all of the limestone above the Upper Cambrian and below the Upper Ordovician was represented by a single color, and called the "Valley limestone." The white numbers on the black areas of the sketch-map refer to the principal sections in the Middle Ordovician which have been studied by the writer and which will be described in detail elsewhere.

The large western area exposed in Bedford, Blair, Center, Clinton and Lycoming Counties contains approximately 840 square miles, the northeastern section at Salona being 105 miles from the Willow Grove section to the northwest. In Center County the Ordovician lime-

¹ Reference numbers in parentheses in the text apply to the bibliography at the end of the article.

stones are separated by the Silurian sandstone of Nittany Mountain into the areas roughly represented by Nittany Valley to the west and Penns Valley to the east. The large eastern terrane located in the rich and beautiful canoe-shaped valley of the Kishacoquillas in Mifflin and Huntingdon counties has an approximate area of 140 square miles.

FIG. 1.

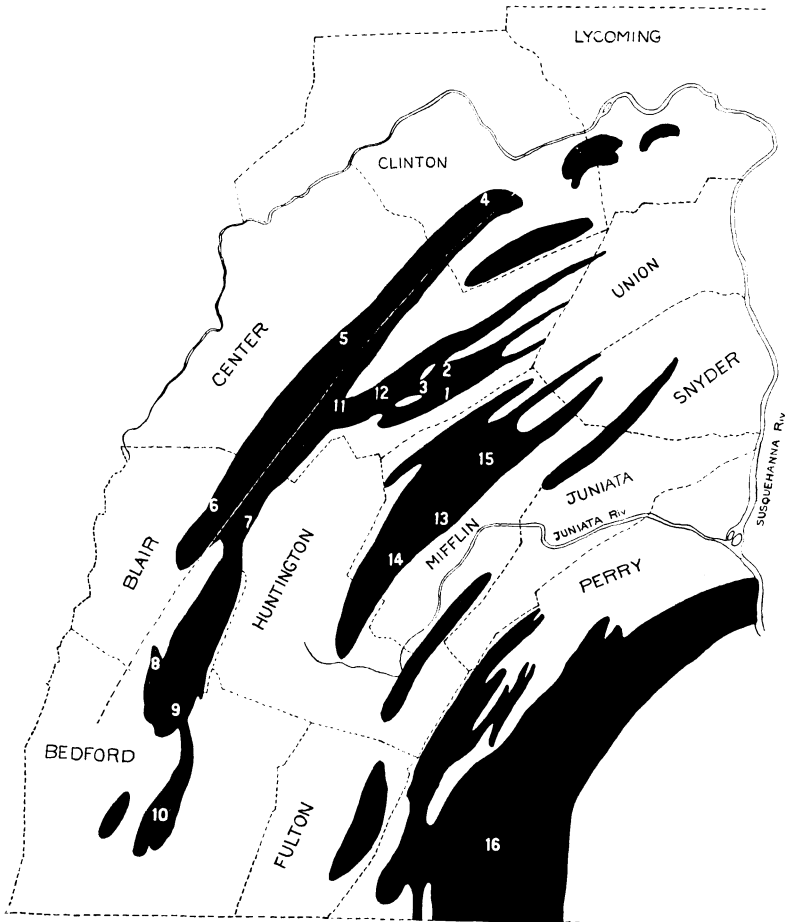


FIG. 1.—Map of Central and South Central Pennsylvania.

The black areas show the distribution of the Ordovician formations in the province. The numbers refer to the locations of the sections as follows:—1. Coburn. 2. Millheim. 3. Spring Mills. 4. Salona. 5. Bellefonte. 6. Tyrone. 7. Franklinville. 8. Roaring Spring. 9. Loysburg. 10. Thorpes Quarry-Willow Grove. 11. Lemont. 12. Center Hill. 13. Reedsville. 14. Belleville. 15. Naginey. 16. Chambersburg.

Complete and well-exposed sections are not numerous within any of the areas, but fortunately the development of quarries along the strike of the purest beds of limestone, which extend through the towns of Tyrone, Bellefonte and Salona, exposes the zones above and below this horizon. The older quarries, where weathering has gone on for some time, furnish the best general collecting ground for fossils. Well exposed sections of the lower Middle Ordovician are to be found in the abandoned road metal quarries of the region. Unfortunately, however, most of the above mentioned sections lie close to the Alleghany Plateau under which the Ordovician limestones of Pennsylvania dip.

To the southeast of the central Pennsylvanian province lies a more or less parallel band of somewhat metamorphosed Ordovician limestones and dolomites which extends through Carlisle, Easton and Port Jervis. The southwestern extension of the easterly belt, on the other hand, the formations of which are metamorphosed, passes through Chambersburg and continues as far as Birmingham, Alabama. Thus the central Pennsylvanian province is the most western extension of the Ordovician formations of the state, and it will also be seen that this province occupies a middle and somewhat isolated position within the Ordovician terranes of eastern North America.

HISTORY.

The earliest reference to the Ordovician of central Pennsylvania appears to be that of Richard C. Taylor (2), who in 1835 noted the fossiliferous beds at the foot of Jacks Mountain. Then there is no mention of it until the publication in 1858 of the First Geological Survey of Pennsylvania by H. D. Rogers (3). In this work, on an excellent colored geological map which is supposed to have been compiled by the Survey but which was probably largely copied from an earlier map of Dr. Henderson's, the Ordovician formations are shown in light-blue and green.

The geological map of the Second Survey (4) shows little or no advance over the first, the Lower and Middle Ordovician formations being still undifferentiated and shown in light blue. The county reports, however, contain many references to Middle Ordovician outcrops and

sections, though several of the sections in the present paper are not mentioned in them.

In brief summation, then, of the work on the Middle Ordovician limestones of central and south-central Pennsylvania during the state surveys, it may be truthfully said that Rogers gave a remarkably full and accurate description of the faunas, for his time, but that the Second Survey added very little to what was already known. Hall and Simpson were the chief cataloguers of fossils during this period, but even they did little or nothing to elucidate the Ordovician faunas of central Pennsylvania. To Simpson, however, must be given the credit for the discovery and description of the new and curious trilobite *Homalonotus (Brongiartielli) trentonensis*.

In 1903, Collie (5), in his paper on the Bellefonte section, gave the first detailed and correlative description of the Middle Ordovician limestones and faunas, in part as follows:

“There is apparently no true Chazy present, but rocks containing the fauna of the Stones River Group, which includes the Birdseye zone of New York as its upper member, follow immediately on the Beekmantown. These in turn are followed by the Black River and Trenton Groups, above which follow in order the Utica and Lorraine shales.”

Collie gives a detailed description of the Trenton, which he divides into eight fossiliferous zones, but he does not appear to appreciate the difference in fauna and lithology between the lower and upper limestones. His faunal list for the Trenton of the Bellefonte section is, as a whole, remarkably complete and the writer has been able to add only a few species, but his list of the Stones River species is incomplete, as he failed to report many of the thoroughly critical and distinctive types contained in this formation.

The following year Grabau (6) commented upon Collie's upper Beekmantown as follows:

“Since the fossiliferous horizon below the 2335 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 2500 feet (\pm) of the latter, a 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.”

In 1910 Ulrich (7) discusses the Lower Ordovician (Canadian) limestones and dolomites of the Bellefonte section but writes nothing regarding the Middle Ordovician series. In his correlation tables (op. cit., p. 27) he lists the following formations:—Trenton (Reedsville); Lower Trenton). Black River (Amsterdam; Lowville). Stones River (Pamelia).

In an “Outline of Practicum Work in General Geology,” which Prof. E. S. Moore has privately printed for his class in Geology at Pennsylvania State College, the Middle Ordovician is divided in the following manner:

“Trenton, highly fossiliferous thin-bedded limestone and black to brown shale, 791 feet. Black River: This group includes the Black River and Lowville limestones which are usually pure, blue to grey rocks. The Lowville contains the famous quarry-rock, 182 feet. Stones River, bluish limestone, 260 feet.”

A still more recent paper is that by Professor Raymond (8) in which he says:

“At Bellefonte, Penn. according to the observations made by Mr. Richard M. Field and the writer, a zone of dark limestone, containing such typical Leray (Black River) species as *Columnaria halli* (?) and *Maclurites logani*, is followed by more argillaceous limestone containing *Echinosphærites* and a large number of other fossils. Christiania has not yet been found in the Bellefonte section, but this section does definitely show that the *Echinosphærites* zone is there younger than the Leray-Black River of New York. As shown by Mr. Field, there is essential agreement between the section at Bellefonte and that at Chambersburg and Strasburg, so that all three of these occurrences of *Echinosphærites* may be dated definitely as post-Leray.”

The preceding were the latest data which had been published on the Middle Ordovician of central Pennsylvania at the time that the writer finished his field work in this region. The Bellefonte section has, however, been visited by many geologists and paleontologists, including members of the state and federal surveys, and

until quite recently it was the only section within the region which had been described in detail.

A description of the section at Roaring Spring was published by Butts (9) in 1916. To the *Echinosphærites* zone he gave the name Rodman, and divided the subjacent Stones River into two formations, Lowville and Carlim, the latter a new term proposed for the fossiliferous but less pure limestone below the pure quarry-rock. He also proposed the term Lemont for the upper and less pure part of the Carlim. The facts derived from my study of the section at Roaring Spring do not agree in certain important particulars with Butts' published account; his faunal list is also incomplete and contains certain supposedly characteristic fossils which are only to be found 60 to 90 miles to the northeast. Finally, a study of the Roaring Spring and Bellefonte sections alone can give no adequate idea as to the paleogeography of the area, or its relation to the Ordovician terranes of eastern North America.

DESCRIPTION AND CORRELATION OF SECTIONS.

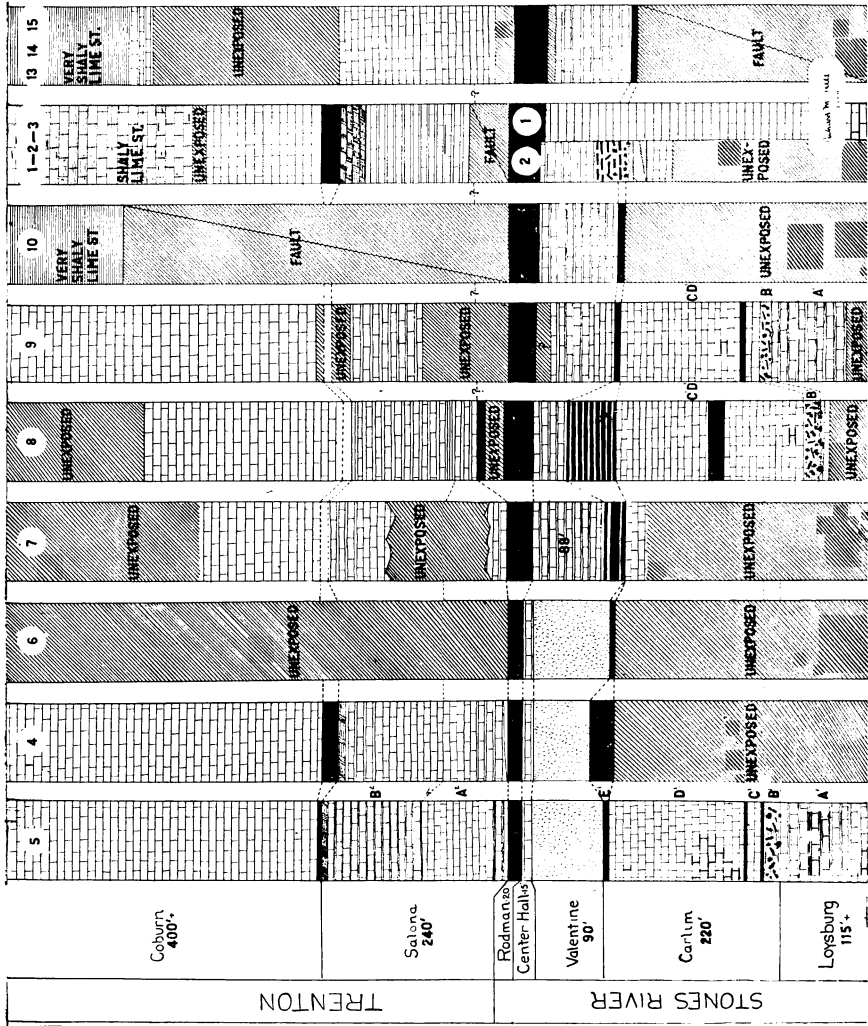
Nine stratigraphic columns are arranged on fig. 2 so as to give a diagrammatic view of the thicknesses and relative positions of the formations, the geographic position of each section being shown by the same number on the sketch-map, fig. 1. These two illustrations, together with the following lithological and faunal descriptions of the formations, will be used in the discussion of the correlation of the sections within the given province. Space does not permit me to give here the complete list of the fauna, which is to be published later, and only those species are mentioned below which are essential horizon markers. The subject in its broadest sense is the paleogeography of central Pennsylvania during Middle Ordovician time.

The formations have been grouped under two main divisions. This has been done for several reasons, it being necessary at present only to draw attention to the fact that the lithology and faunal characteristics of the Salona and Coburn are decidedly different from those of the subjacent Rodman, Center Hall, Valentine, Carlim and Loysburg. The Bellefonte column (No. 5) is placed first because it contains all of the formations from the Loysburg to the Coburn, inclusive. The succeeding

columns are arranged to best illustrate the paleogeography of the province, starting with the Tyrone, Belle-

FIG. 2.—The Middle Ordovician sections of central and south-central Pennsylvania.

The columns are numbered according to the locality numbers on Plate 1. For description of the symbols see the adjacent page.



fonte, and Salona sections (Nos. 4, 5, 6), and extending to the east as far as Reedsville (No. 13). The field evidence suggesting this arrangement will be taken up under the

discussion of each formation in order. The numbers in the left hand column refer only to the thicknesses of the formations in the Bellefonte section. All of the solid black bars below the Valentine designate *Tetradium* beds, and the Rodman is also shown by a solid black bar. The solid black bar at the base of the Coburn indicates the *Parastrophia* zone. Particular horizons are marked by letters, the Stones River series being A¹, B¹, C¹, etc., the Trenton series A², B², etc. Intraformational structures are shown by the pattern as illustrated in B¹.

Loysburg Formation.—The dark and impure, dolomitic limestone which lies between the Beekmantown and the first intraformational zone has been named Loysburg, after the town by that name in the northern part of Bedford county. Collie does not appear to have recognized the existence of this formation, for in his description of the section at Bellefonte he makes no distinction between the lithology and faunal characteristics of the lower and upper Stones River. Butts also does not mention the lowest division of the Stones River group, probably because it is poorly exposed in the section at Roaring Spring. The Loysburg differs from the superjacent Carlisle not only in lithology and paucity of fossils but also in the total absence of the reef-building organisms so characteristic of the latter formation. Only the upper 115 feet are exposed at Bellefonte and the base can not be located with any degree of accuracy. The only other section in which it is well exposed is at Loysburg, where it appears to be somewhat less thick.

Carlisle Formation.—The contact between the Loysburg and the Carlisle is well exposed in the section at Loysburg, where the line appears to be quite sharp between the dark, impure and the light-colored purer limestone. There is no evidence of an interformational conglomerate at the base of the Carlisle, but wherever the base of this has been observed it is characterized by strongly marked intraformational structures, which at first sight suggest a fine-textured basal conglomerate. These structures are the most striking characteristics of the Stones River group and the writer has been able to trace them from New York to Tennessee. It is obvious that the elucidation of these phenomena is intimately connected with the study of disconformities and no discussion of the correlation of the lower Middle Ordovi-

cian formations is complete without their consideration. In 1916 I published a preliminary paper (10) in which an attempt was made to distinguish between interformational and intraformational structures, especially in limestone and dolomite, as follows:

"A review of the literature, as well as of certain examples in the field, has shown that not all intraformational conglomerates are made up of water-worn materials: in fact, certain of them are composed of distinctly brecciated fragments which show no signs of attrition by water transportation, a common characteristic according to most geologists. It may seem strange at first to consider a 'sun-cracked' limestone as a brecciated rock, and yet viewed in cross-section, or at right angles to the bedding plane, the hand specimen or field section will often show a characteristic brecciated structure.

"It is, therefore, proposed to introduce two new terms, *Glomerate* and *Phenoclast*, in describing all those rocks (glomerates) which are of sedimentary origin, coarse, or psephitic in texture, whether or not their "show" constituents (phenoclasts) give signs of attrition and transportation." "*Glomerate*, according to the Century Dictionary, means 'collected into a spherical form or mass.' It is an old English word and rarely used. Conglomerate in its ordinary sense is also defined as 'a rock made up of the *rounded* and *water-worn* debris of previously existing rocks, etc,' (the italics are the writer's). It is proposed to use the term glomerate in a geological sense to mean any sedimentary or clastic rock made up of roughly graded debris formed within itself or from pre-existing rocks. Such a term would cover breccias, conglomerates and certain other rocks of doubtful origin.

"Nauman, in his 'Geognosie,' proposed the term Psephite, but it has never been widely accepted, and probably never will be although it is a useful word in petrology."

"There is as great a need for a term to express the order or size of the constituents in a sedimentary rock as there is for the term phenocryst, which designates a large crystal in the ground-mass of a crystalline rock. *Phenoclast*, from pheno, show, and clast. clastic, broken piece or fragment, is proposed to designate the larger fragments which are easily distinguished from the ground-mass or cementing material. They, the phenoclasts, may be of several orders of size and shape. The term is convenient as it is not always correct to refer to the major constituents of a conglomerate as pebbles, or even brecciated fragments. For instance, in the edgewise glomerates the pebbles and cement are apt to be formed from the same material. Also the shape of the 'pebbles' is hardly pebble-like, neither are the 'pebbles' true brecciated fragments. Their outline is as peculiar and

distinct as is their mode of origin and it is upon the discovery of their origin that the solution of the problem depends. One has but to glimpse at the literature on the subject in order to appreciate the necessity for a reasonably accurate nomenclature.”

The lowest bed of the Carlim was laid upon a consolidated surface. There is no evidence of a basal conglomerate, but the presence of ripple-marks and sun-cracks is conclusive proof that the pure calcareous oozes of the Carlim were deposited under alternating conditions of quiet and agitation. If these basal Carlim sediments had been deposited upon the unlithified Loysburg sediments and under the conditions of agitation which have just been cited, we should expect to find an intimate mixture of the two types near the base of the former; such, however, does not prove to be the case. The distinctly banded character of these rocks, together with the frequent zones of ripple-marked, sun-cracked and glomeratic limestone, are particularly suggestive of shallow-water and tidal conditions. The intraformational glomerates represented by B¹ on fig. 2 are well exposed in the sections at Bellefonte, Roaring Spring, and Loysburg, but in the former section there does not appear to have been much bottom agitation and the glomerate is either the direct or indirect result of organic activity. The Carlim here begins almost immediately with numerous thin beds of *Tetradium*, and the growth as well as the destruction of this peculiar and little understood organism has functioned to an important degree in the formation of a typical bioglomerate. The evidence presented in this section indicates that at times conditions were quiet enough for the growth of a thin veneer of the colonial organism, *Tetradium syringoporoides*, but that sometimes the bottom was sufficiently agitated to break up the colony, together with the cementing muds, and deposit the whole material in the form of a fine-textured, intraformational conglomerate in which are also found the remains of other attached and vagrant benthonic species. In the section at Loysburg there are first a few inches of light-colored, banded limestone, then a thick zone of mud-cracked, ripple-marked limestone and glomerate beds which alternate with thin zones of *T. syringoporoides*. The ripple-mark is quite even, with an amplitude of not more than 1 to 2 inches; moreover, it is decidedly symmetrical and appears to belong to the

oscillation rather than the current type. The nature of the ripple-mark, together with the thin mud-cracked layers and associated edgewise glomerates, all indicate that the lower 30 feet of the Carlim were deposited in relatively shallow water and that at times the beds of ooze were exposed to the direct action of the sun and air, the edgewise glomerates being probably formed by the rising of the tide upon the previously mud-cracked flat. The presence of only a few Tetradia-bearing beds in the lower Carlim, and the fact that they become increasingly abundant toward the top of the formation show either that the water was becoming slightly deeper, causing the bottom to become less agitated, or, that the Tetradia were gaining firmer hold upon the low-lying platform and gradually creating a broad-bedded reef more and more resistant to the waves. It appears as if the latter possibility were more in accord with the field data than the former.

In the section at Bellefonte, the middle and most of the upper Carlim, except for the final 10 feet, contain very few Tetradia, but Bryozoa are abundant and appear to have formed a sea-mat upon which a rich fauna of trilobites flourished.

In the upper Carlim of the section at Loysburg, both *Girvanella* and Tetradia occur in solid beds, giving this part of the formation a decidedly "reef" aspect. Mention should also be made of the occurrence of the compound coral, *Columnaria* sp.? (closely related to *C. halli*), which is found associated with *Maclurites logani* just below the *Beatricea* zone. This coral has been found only in the sections from Center Hall to the west. In the section between Center Hall and Reedsville it is particularly abundant, heads from 2 to 3 feet across being closely packed together in their original position of growth; in fact, at this particular spot one would have no difficulty in believing that he was looking at a fossil coral reef. *Columnaria* is not, however, particularly abundant in the other sections, and was not found at all at Roaring Spring and Loysburg. The Carlim varies considerably throughout the area, but in all sections it is particularly characterized by the presence of such colonial and gregarious organisms as Tetradia, Bryozoa, and *Girvanella*. That these variations are dependent upon geographic position will be more clearly

brought out after considering the conditions under which the superjacent formations were laid down.

The Carlim is closed with a zone (E') of shaly, impure limestone, which is well shown in the foot-walls of all the quarries. This zone is somewhat variable in thickness and has been traced from Salona to Tyrone, a distance of over 90 miles. It contains a regular mat of *Tetradium fibratum* and *Beatricea gracilis*? The upper layer which forms the parting plane between the Carlim and the Valentine was particularly well exposed in the Bellefonte quarries in 1917, where approximately one-quarter of an acre of ripple-marked and mud-cracked limestone was displayed on the steep foot-wall of the largest quarry.

Valentine Formation.—I have named the pure quarry-rock, which follows the Carlim, from a small hamlet and forge near Bellefonte which are not shown on the county map. The Valentine family was prominent in the early mining industry of central Pennsylvania, and it seems fitting that this valuable bed of limestone should receive its name.

Collie makes no distinction between the pure quarry-rock and the overlying fossiliferous formations, all of which he has grouped under the rather indefinite term of "Black River."

The Valentine does not occur in the section at Roaring Spring, although Butts intimates that this section is identical with those on the Tyrone-Salona line. The contact of this unfossiliferous formation with the underlying *Tetradia* and *Beatricea* beds is sharp and clean-cut, but its upper beds merge almost imperceptibly into the superjacent Center Hall. The field relationships of the Valentine will be discussed more fully after the descriptions of the Center Hall. It is simply stated here that this formation occurs as a lens in the upper Stones River beds and is gradually replaced by them to the east.

An examination of the thin section of the Valentine limestone shows that the ground-mass is made up of minute crystals and granular particles of calcium carbonate, which are barely distinguishable under a magnification of 380 diameters. There is no evidence of stratification except under high powers. Throughout the ground-mass are scattered larger grains of calcite, some of which are large enough to be seen macroscopically.

A few scattered particles of the tests of trilobites are

present but they are exceedingly rare and their worn and comminuted appearance suggests that they have been carried some distance. In the finer portions of the ground-mass the grains of calcium carbonate are somewhat obscured by a thin brown film which has the appearance of being either iron-oxide or carbonaceous material. It is interesting to note that, aside from speculations upon this "brown film," there is no evidence which would lead one to suppose that the pure limestone of the quarry beds had been formed by organic agencies.

The following analysis of the quarry-rock shows the total amount of variation which has been encountered in several hundred samples taken during the quarry operations of the last few years and collected along the quarry line from Bellefonte to Tyrone:

SiO ₂	0.62%	.....	0.94%
(Al, Fe) ₂ O ₃	0.32	.....	0.40
CaCO ₃	97.81	.....	97.60
MgCO ₃	1.27	.....	1.06

The Valentine limestone is so low in silica that it cannot be used for cement. Its purity makes it extremely valuable for chemical purposes, little or none of it being used for flux or the manufacturing of structural materials. It is interesting to consider the analysis given by Vaughan (12) for the finely divided calcareous muds occurring in the Marquesas and Bahamas lagoons:

	Bottom sample, east side Marquesas lagoon, Florida	Bottom sample one mile west of west end of South Bight, Bahamas
SiO ₂	1.18%	0.29%
(Al, Fe) ₂ O ₃	0.37	0.15
MgCO ₃	2.88	2.72
CaCO ₃	95.57	96.84

Vaughan's description of the finely divided muds from the stagnant area of the South Bight and also from the flats one mile to the west of the west end of the South Bight is particularly significant. He mentions Drew's researches, in which the latter found that the mud off Andros Island contained 160,000,000 bacteria (*Pseudomonas calcis*) per cu. cm. but was characterized by almost complete absence of other organisms. Drew states

that the carbonate mud was probably formed by the metabolism of the bacteria. I have examined this material in the lagoons at Tortugas and find that it is not quite so pure in every case but is apt to contain large quantities of minute animal matter such as the tests of Foraminifera, etc. It is very plastic, sun-cracks readily, and when exposed to the air for a short time becomes exceedingly hard, so hard in fact that it can not be easily dissolved again in water. Its chemical and physical characteristics are quite similar to those of the limestone in the unfossiliferous zones of the Stones River group, and I believe that a careful study of the shoal-water deposits off the southeast coast of Florida, especially in the region of the Bahamas, will yield valuable data for comparison with those of the Lower Paleozoics.

“On the west side (of Andros Island)” according to Vaughan “there is an enormous flat, which is over 60 sea miles wide along an east and west line, and on it the maximum recorded depth is three and one-half fathoms.

“It is probable that, especially during the summer months, the temperature of the shoal waters is higher than on the surface of the ocean where the depths are greater. Such an increase in temperature would cause the water to lose CO_2 and produce precipitation of CaCO_3 . Surface agitation of the water would accelerate the loss of CO_2 and thereby increase the rate of precipitation of CaCO_3 .”

“From the foregoing discussion it is obvious that there are at least three cooperating factors tending to produce precipitation of CaCO_3 , viz: (1) Ammonifying bacteria, (2) concentration of salts in solution through evaporation, (3) expulsion of CO_2 by increase in temperatures. As these factors have not been evaluated, a satisfactory solution of the complicated problem awaits further research” (op. cit., pp. 273-274).

Although the Valentine limestone has not the characteristic “Birdseye” appearance, the thin, thread-like particles of pure calcite which are clearly seen in the hand specimen may be evidence of the former existence of a marine plant, or Nullipore, which flourished at the time of the deposition of the fine, limy muds. The lack of any definite organic structures, however, either in the hand specimen or under the microscope, makes this hypothesis even more indefinite than that regarding the Lowville of New York. It is therefore suggested that the original oozes out of which the Valentine limestone resulted may have been formed, partly at least, by the metabolism of some low form of organism similar to

Pseudomonas calcis. The validity of Vaughan's speculations regarding the precipitation of calcium carbonate by inorganic agencies is not yet fully established, and these agencies may also ultimately prove to be important factors in the formation of both calcium and magnesium carbonates.

Center Hall Formation.—In order to procure fresh quarry-rock uncontaminated by the talus which accumulates from the argillaceous limestones of the hanging-wall, the American Lime and Cement Co. has sunk a shaft in the purest, upper beds of the Valentine, and is now removing considerable rock by the stoping method. The width of the stope is at present limited by the shaft in the basal beds and by a much less pure zone which it does not pay to quarry. The line of contact between the pure and impure zones above is shown to be gradational, and the upper beds are fairly fossiliferous, the most important fossils being *Columnaria* nov. sp., *Maclurites logani*, and one or two species of simple corals. *Columnaria* has been observed on the hanging-wall of the northernmost quarry at Bellefonte but it does not appear to be as abundant at this horizon. To this narrow zone, which occurs above the Valentine and below the highly fossiliferous and lithologically dissimilar Rodman, I have given the name Center Hall, after the village of that name in Penns Valley. The Center Hall formation is only a few feet thick along the Tyrone-Salona line, but it appears to thicken eastward, possibly replacing the upper beds of the Valentine. It is impossible to state definitely at the present time whether or not the Center Hall can be distinguished from the upper Carlisle in the eastern sections. There is good evidence, however, that it can not be distinguished at Thorpe's Quarry.

The taxonomic problem of the Stones River formations is a serious one, which will have to be solved, not only for this area, but for numerous sections throughout the Appalachian geosyncline. If one were describing a single section along the Tyrone-Salona line he would be correct in giving formational names to the pure "quarry-rock" and the thin but exceedingly distinctive zone directly underlying the Salona (basal Trenton). Neither of these formations, it is true, is of mapable thickness, but the Valentine is of great commercial importance and therefore should be shown at least on the economic sheet of a geologic folio. The term Rodman has already been

adopted by the United States Geological Survey without a clear or sufficient definition, the description of the formation not being that of the type locality. The propriety of the use of the term Center Hill, strictly from the point of view of the map-maker, is perhaps open to argument. It must be remembered, however, that the ultimate goal of the stratigrapher is not a more or less neatly drawn columnar section but a comprehensive view of the paleogeography of the area in which he is at work, and failure to recognize certain zones in the Bellefonte section would lead to an incorrect picture of the upper Stones River sea.

Summary of the Stones River Reef.—The stratigraphical relationship of the Carlim and Valentine formations strongly supports the hypothesis that the former was a "bedded reef" or shallow-water platform upon which flourished, from time to time, dense mats of colonial organisms, while the latter represents the deposits of a broad lagoon, or shallow-water shelf, protected from the action of the open sea. The columnar sections of fig. 2 indicate that the Valentine thins out in a southeasterly direction and that its place is taken by an increased thickness of the Carlim. Figure 3 is a diagrammatic cross-section in a southeasterly direction from Bellefonte through Pleasant Gap and Center Hill to Reedsville. Although the Lemont, Center Hill, and Coburn sections lie respectively to the southeast and northwest of this line, they have been projected upon it for the sake of producing all the evidence upon one diagram.

The basal beds of the Carlim were laid down upon the Loysburg platform in very shallow water, as is indicated by the abundance of mud-cracks, ripple-marks, and edge-wise glomerates previously mentioned. During the early stages of the accumulation of the formation, conditions were suitable for the growth of attached colonial as well as other benthonic types which at times formed mats or beds of appreciable thickness and considerable area. *Tetradium syringoporoides*, *T. fibratum*, *T. cellulosum*, *Girvanella*, and numerous species of Bryozoa were important reef-building types.

In the closing stages of the Carlim, Columnaria became relatively more abundant toward the continental side. Toward the west, or open sea, conditions were apparently not suitable for the growth of the reef, and the pure

oozes of calcium carbonate which now form the Valentine were laid down. The absence of fossils in this deposit may be attributed to the nature of the bottom, which at any stage of its growth was unsuitable for fixed or vagrant benthos.² The lagoon or off-reef phase appears to thicken slightly to the southeast, the white line on the sketch-map showing the approximate easterly limit of the purest limestone. It has already been pointed out that the extreme southerly sections (Nos. 8, 9, 10) do not contain the Valentine.

The evidence favors the belief that these sections lie to the east of the original area of the purest limestone, as shown by the dotted extension of the white line on the sketch-map.

Toward the close of the Valentine phase of deposition, the calcareous sediments became less pure. A few corals, including *Columnaria*, and the gastropod *Maclurites logani* reappear. This thin zone, which can be distinguished from the highly fossiliferous beds of the Rodman, is only distinctly observed along the Tyrone-Salona line. It signifies the brief return of Carlim conditions and necessitates a distinct formational name only in the sections where the Valentine is present.

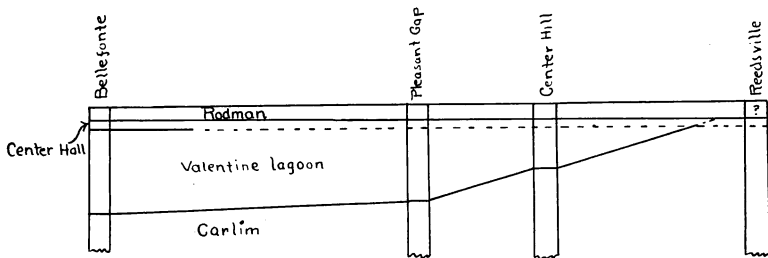
Rodman Formation.—The highly fossiliferous limestone of this persistent northeast and southwest zone is considerably less pure than the subjacent formations. It contains many Bryozoa and other types of attached benthos, as is evidenced by the plates of crinoids and also the abundant remains of pelmatozoan stems. The formation is best observed in the west but its lowest beds have been observed as far east as Reedsville. Its fauna and lithology are taken to represent the closing phase of Stones River time. The descriptions of the new species in the prolific and peculiar fauna listed below have already been written and will be published later. The species are: *Streptelasma profundum*, *S. corniculum*, *Echinospherites aurantium*, *E. aurantium suecica*, *E. grandis*, *Hemiphragma ottawaense*, *Dalmanella rogata*, *Orthis tricenaria*, *O. disparilis*, *Pianodema subæquata*, *Leptæna* n. sp., *L. charlotta*, *Plectambonites* n. sp., *Oxoplecia* n. sp., *Tetranota obsoleta*, *Omospira laticincta*, *Bumastus porrectus*, *B. transversalis*, *B.* n. sp., *Illænus*

² My recent examination of the lagoons in the Tortugas group bears out this theory.

angusticollis, *I. americanus*, *Thaleops ovatus*, *Encrinurus tuberculosus*, *Calymene senaria*.

Salona Formation.—The black argillaceous limestones which follow the Rodman are decidedly different from it lithologically as well as from all of the lower Stones River formations. They appear to attain their maximum thickness at Salona but there is evidence that they also thicken slightly to the east. Although this formation contains a few characteristic fossils such as *Conularia trentonensis*, *Endoceras proteiforme elongatum*, etc., it is principally characterized by *Brongiartiella trentonensis*, another species of the same genus and several new species of *Isotelus*. The lowest beds of the Salona contain *Cryptolithus tessellatus*, and its upper beds bear large symmetrical ripple-marks with an amplitude of

FIG. 3.



from one and one-half to two feet. It is closed in all sections by several feet of finely cross-bedded limestone, exceedingly poor in fossils. The Salona undoubtedly belongs to the Trenton group, but since it is decidedly different from the superjacent limestone both faunally and lithologically, and is in fact a phase peculiar to the central Pennsylvanian province alone, the writer has decided to give it a distinct formational name. Salona is a village in the Mill Hall gap and opposite the best exposure of the Trenton in the whole province.

Coburn Formation.—The upper Trenton limestone is both faunally and lithologically different from the lower Trenton or Salona. It has thus been recognized as a distinct formation and named after the town of Coburn whose location has already been described. This formation begins in all sections, where exposed, with a well-defined zone of *Parastrophia hemiplicata*. The lower and

middle beds are made up of alternations of crystalline, highly fossiliferous limestone and black shaly limestone. There is usually no sharp distinction between the Coburn limestone and the superjacent Reedsville shale, the beds toward the top of the former becoming increasingly shaly and finally merging into the latter formation. The upper beds of the Coburn, which are particularly characterized by *Plectambonites* and *Cryptolithus tessellatus*, become increasingly shaly toward the southeast. At Coburn the typical crystalline and highly fossiliferous beds are thinner than at Bellefonte and the upper beds of this formation are made up of very shaly limestone which is characterized by an abundance of *Cryptolithus tessellatus*. The crystalline beds of the Coburn therefore appear to thicken to the west but on the contrary become increasingly shaly as they approach the old upland of Appalachia to the east.

CORRELATION WITH THE MIDDLE ORDOVICIAN FORMATIONS OF EASTERN NORTH AMERICA.

It was pointed out in the first part of this paper that the central Pennsylvanian province occupied, geographically, a somewhat intermediate position between the New York, Mohawkian, or Middle Ordovician terranes on the northeast and those of similar age at Chambersburg, Pennsylvania. The presence in the Carlim of *Bathyrus* (cf. *B. extans*), *Columnaria* (cf. *C. halli*), *Maclurites logani*, and other characteristic fossils previously listed, shows this formation to lie above the Beekmantown and below the Trenton. Since the term Black River has now become very indefinite when applied outside of New York State, and since the formations subjacent to the Trenton throughout the central and southern Appalachians are found to vary both faunally and lithologically, I have followed Ulrich in the use of the term Stones River for the pre-Trenton group which lies above the Beekmantown. Although the Salona contains one genus, *Brongiartiella*, which has not been found anywhere else in the Trenton of North America, the rest of its fauna is upper Middle Ordovician in aspect. The Coburn, on the other hand, contains a long list of typical Trenton fossils.

These two formations have, therefore, been placed under the group name of Trenton.

There is no doubt that the above rough correlation is warranted, but the manner in which the separate formations of central Pennsylvania are to be correlated with the neighboring ones is still open to question. The principal argument concerns the location of the dividing line between the Stones River and the Trenton groups: Shall the Rodman be placed at the top of the Stones River or at the base of the Trenton?

Stones River.—The formations above the Loysburg and below the Rodman, i. e., Carlim, Valentine and Center Hall, have been shown to be related in age and mode of origin. The Valentine thins to the east and its beds are successively replaced by the upper beds of the Carlim, the younger of which appears to be synchronous with the Center Hall at Bellefonte. Collie has stated that the Stones River group includes the fossiliferous, fairly pure limestone which follows the Beekmantown, and the superjacent quarry-rock which he likens to the Birdseye zone of New York State. He makes no mention of the Center Hall, however, and what is more important, he also makes no mention of the thin but highly characteristic faunal zone above the pure quarry-rock. Recent and more intensive study of the Appalachian province shows that there is considerable variation in the limestone of Stones River age. If the Carlim is a bedded reef and the Valentine a lagoon or offshore phase, we may account for the slight lithological and faunal variations to the north, south and west as due to such local conditions as distance from shore, presence or absence of marine currents, character of the underlying formations, and possible disturbing influence of large rivers bearing argillaceous or siliceous impurities. To ascribe a different age to each phase is a doubtful proceeding in view of even the little that we know regarding the varied distribution of bottom types in the south Atlantic coral latitudes.

The characteristic fossils of the Carlim are shown in the following table:

Carlim	Murfreesboro	Pierce	Ridley	Lebanon	Carters Creek
Cancellospongia n. sp.....(U)*	X
Streptelasma profundum.....(U)	X	....
Columnaria n. sp.....(U)	X
Tetradium celluloseum.....(L-U)	X?	....
Tetradium syringoporoides....(L-U)	X	....
Cryptophragmus antiquatus.....(U)	X	....
Rafinesquina minnesotensis.....(L)	X	....	....	....
Protorhyncha ridleyana.....(L)	X	....	....	....
Zygospira recurvirostris.....(U)	X	....
Pterotheca sp.....(U)	X	....
Liospira vitruvia.....(L)	X	....	....	....
Liospira progne.....(L)	X	....	....	....
Thaleops sp.....(U)	X	....
Pterygometopus callicephalus....(U)	X	....
Leperditia fabulites.....(L-U)	X	....	....	....

* L stands for lower and U stands for upper Carlim.

On strictly faunal data the lower Carlim should be correlated with the Pierce and the upper Carlim with the Lebanon and Carters Creek formations in Tennessee. Columnaria n. sp. and one or two peculiar sponges recently discovered are particularly important horizon markers.

It can now be definitely stated that the typical Leray-Black River does not occur in the central Pennsylvanian province.

The thin zone of slightly less pure limestone which occurs above the Valentine and thickens appreciably to the east is neither faunally nor lithologically particularly different from the Carlim except that it does not contain Tetradium. Were it not for its separation from the Carlim, at Bellefonte, by the intermediate zone of the Valentine, there would be difficulty in distinguishing it from the lower formations.

The recent discovery of the peculiar faunal zone which occurs between the Center Hall and the Salona, and which Butts has named Rodman, introduces an entirely new element into the discussion of the correlation of the

central Pennsylvanian and neighboring provinces. The fauna of the Rodman does not occur in central New

	Rodman of Penn.	Chambersburg		Elsewhere
		Marion Penn.	Strasburg Va.	
Nidulites favus.....	.....	M-U	.....	?
Zittelella varians.....	X	.....	L	Stones River
Receptaculites occidentalis.....	X	L	.....	Stones River and Trenton
Echinosphærites aurantium.....	X	L-U	L-U	Middle Ordovician
Echinosphærites aurantium suecica.	X	L-U	L-U	?
Echinosphærites grandis.....	X	L	.....	?
Orthis disparilis.....	X	L	.....	?
Orthis tricenaria.....	X	L	.....	Stones River and Trenton
Plectorthis trentonensis.....	X	.....	L	Trenton
Glyptorthis n. sp.....	X	L	.....	Stones River and Trenton
Dalmanella n. sp.....	X	L	.....	?
Dinorthis pectinella.....	X	L	.....	Stones River and Trenton
Plectambonites n. sp.....	X	L	.....	?
Leptaena n. sp.....	X	L	.....	?
Leptaena charlottæ.....	X	L	.....	Stones River
Leptaena n. sp.....	X	?	.....	?
Rafinesquina alternata.....	X	L	.....	Stones River and Trenton
Christiania trentonensis.....	.....	U	.....	?
Oxoplecia n. sp.....	X	L-U	.....	?
Parastrophia hemiplicata.....	.....	L	.....	Trenton
Protozyga exigua.....	X	L	.....	Stones River and Trenton
Cryptolithus tessellatus.....	.....	U	.....	Trenton
Ampyx sp.....	.....	L-U	.....	?
Illænus consimilis.....	?	L?	.....	Stones River
Illænus americanus.....	X	L	L	Trenton
Illænus angusticollis.....	X	L	.....	Stones River
Pterygometopus callicephalus.....	X	L	.....	Trenton
Ceraurus pleurexanthemus.....	X	L	.....	Stones River and Trenton

*L stands for lower Echinospærites zone, M for middle or Nidulites zone, and U, for upper Echinospærites zone of the Chambersburg.

York, it does occur, however, in the Chambersburg area (No. 16), the nearest outcrop to the southwest.

In the following table the fauna of the Rodman is com-

pared with those of the Chambersburg at Marion, Pennsylvania and at Strasburg, Virginia.

It will be noticed that except for the absence of *Ampyx* in the Rodman, this formation is more readily correlated with the lower than the upper Chambersburg. As *Ampyx* is found in both the lower and upper Chambersburg and is entirely absent in the Rodman, it is really of no correlation value. On the other hand, since *Christiania* and *Cryptolithus* occur only in the upper Chambersburg, and the majority of the Rodman types are also found only in the lower Chambersburg, I believe that these two zones are of the same age and that beds representing the *Nidulites* zone and the upper *Echinosphærites* zone are absent in central Pennsylvania.

Ulrich has placed the strata at Chambersburg, which contain the two *Echinosphærites* zones and the intervening *Nidulites* zone, in the Black River (Stones River), while Raymond (op. cit., p. 252) assigns the same zones to the Trenton. My own study of the problem shows that of certain species in the Rodman, previously listed, five are Trenton, eight are Stones River and Trenton and four are confined to the Stones River alone. The large number of *Illænidæ* present give the Rodman a somewhat "Black River" appearance. The absence of *Cryptolithus* and the fact that this trilobite does occur at the base of the Salona would seem to preclude this horizon from the Trenton. It is true that there are always from 40 to 100 feet of Trenton below the lowest *Cryptolithus* beds in New York State and elsewhere, but Raymond himself places the Athens (Normanskill) below the Trenton in spite of the fact that this formation contains *Cryptolithus*. Whether or not the whole of the Chambersburg belongs in the Stones River group may be open to question. It is fairly obvious, however, that the lower Chambersburg and the Rodman are of the same age. When the Valentine is absent, as at Roaring Spring, the difference in lithology between the Rodman and the Salona is certainly much greater than that between the Rodman and the Carlisle, and it is for this reason, as well as on account of the fact that the fauna of the Rodman is neither more Stones River than Trenton in general appearance, that I prefer to place the Rodman at the top of the Stones River group.

Trenton Group.—Collie has placed all of the limestone above his "Black River" in the Trenton, stating that the fauna is decidedly Trenton in aspect. The Salona

or basal Trenton has been shown to be distinguishable, both lithologically and faunally, from the upper Carlism and Coburn. The fact that the first *Cryptolithus* zone occurs at the base of the Salona and not in the Rodman probably indicates the base of the Trenton group. Raymond (op. cit., p. 295) has correlated these beds with the 20 feet of Hermitage in Kentucky, principally because of the occurrence of *Cryptolithus* at the base and of *Orthis tricenaria* and *Dinorthis pectinella* throughout. The succeeding formations of the Trenton group in Kentucky, i. e., Bigsby, Catheys, etc., are not comparable either lithologically or faunally to the Coburn.

The recent discovery of the *Parastrophia hemiplicata* zone just above the cross-bedded and ripple-marked Salona is a fair indication of the beginning of the Middle Trenton of New York State.

There are three *Parastrophia* zones in the New York Trenton, at the base, middle, and near the top. The oldest or lowest species of the genus is somewhat similar to the primitive type, *P. pristina*, found below the Rodman. The two species which are found in the middle and upper zones are not distinguishable but both are similar to the species found at the base of the Coburn. *Platystrophia*, common in the middle and upper, and *Rafinesquina deltoidea* in the upper Trenton of New York, are absent in the Coburn. Collie reports a *Platystrophia* from the section at Bellefonte but I have been unable to find it in any of the sections.

The following composite section of the New York Trenton is copied from Raymond. (Op. cit., p. 253.)

Utica shale with *Cryptolithus* at top.

g.	Trenton.—Light-grey, coarse-grained coquina in thick beds. <i>Rafinesquina deltoidea</i> , <i>Hormotoma trentonensis</i> and other fossils	20 feet
f.	Thin-bedded, blue limestone with shaly partings. <i>Rafinesquina deltoidea</i> the common characteristic fossil	92 "
e.	Thin-bedded, blue limestone with shaly partings. <i>Prasopora simulatrix</i> and other common Trenton fossils abundant	100 "
d.	Thin and thick-bedded limestone, dark in color and fine grained. <i>Diplograptus amplexicaulis</i> a common fossil	35 "
c.	Thin-bedded, dark limestone with <i>Triplecia extans</i>	

	and other fossils. (<i>Parastrophia hemiplicata</i> occurs in this zone at Rathbone Brook, New Port, New York State. Fide T. C. White)	20 feet
b.	Thin-bedded, dark limestone with some interbedded, coarse-grained layers. <i>Cryptolithus tessellatus</i> the characteristic fossil. <i>Trematis terminalis</i> , <i>Platystrophia trentonensis</i> , <i>Calymene senaria</i> and many other fossils present	41 "
a.	Thin-bedded, grey limestone with an abundance of <i>Dalmanella rogata</i> , and some other fossils	32 "
		346 feet

The 400 feet of the Coburn compare very favorably with the 155 feet (beds c to e, inclusive) of Raymond's section. Since beds f and g are characterized by *R. deltoidea*, which fossil is absent in the Coburn, it appears as if the shale deposition began earlier in the Pennsylvanian province. The lower 72 feet of the New York section (lower Trenton) differ from the Salona in lithology and also in the absence of *Brongiartiella trentonensis*. The lower Trenton of Kentucky as described by Ulrich (op. cit., p. 1) may be summarized as follows:

Hermitage formation.—Thinly-bedded to medium-bedded, fine-grained to granular limestone and shale	50 feet.
Thin, evenly bedded, argillaceous and siliceous, blue layers of limestone, separated by seams of blue or greyish shale	20 feet.

None of the fossils listed by Ulrich from this formation are particularly characteristic of the Salona. In Foerste's list (13) *Cryptolithus* is shown to occur in the Hermitage.

For the present it seems best to refer the Salona to the basal Trenton. Thus the first 234 feet of Raymond's composite section of the New York Trenton is comparable to the 640 feet of the Trenton group in Pennsylvania. The Salona is placed at the base of the Trenton group and the Rodman at the top of the Stones River, but with the admission that this conclusion may be only temporary and is largely dependent upon conditions as found only in the central Pennsylvanian province.

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