

ART. X.—*The Mississippian Formations of the Horton-Windsor District, Nova Scotia;* by WALTER A. BELL.

INTRODUCTION.

The paleontological writings of Sir William Dawson early determined the Horton-Windsor district as the type area for two Mississippian series of formations, the Horton and the Windsor. Later controversies that arose between paleontologists on the one hand, and structural stratigraphers on the other, involved the correlation of the older or Horton formation, a circumstance that lends additional interest to the Mississippian stratigraphy of this district.

Previous work.—Among the previous workers who have written on the geology are such famous names as Sir William Logan, Sir Charles Lyell, and Sir J. W. Dawson. Logan visited the area in 1841, fresh from his geological studies in South Wales, where he had so ably established the true nature of Stigmarian underclays. His discovery in the Horton formation of amphibian footprints (*Hylolopus logani* Dawson), in conjunction with the coal-measure appearance of the Horton strata and of the contained flora, led him to consider these beds of Coal Measures age. The gypsiferous or Windsor series was recognized as stratigraphically younger, and fossils gathered at Windsor and submitted to De Verneuil, Keyserling, and Murchison were first regarded as Permian in age. This correlation, however, was doubted by Sir Charles Lyell as long ago as 1843, and he was the first to assign both the Windsor and Horton beds to the lower Carboniferous, a conclusion soon corroborated by Sir William Dawson. For the next fifty years Dawson contributed various papers dealing with the flora, fauna, and stratigraphical relations of these Mississippian rocks. His observations and conclusions are admirably presented in the various editions of his "Acadian Geology."

Later references to the correlation of the Mississippian formations are made by David White, R. Kidston, A. Smith Woodward, L. M. Lambe, H. M. Ami, Charles Schuchert, and J. W. Beede. White (1901) assigned the Horton a Kinderhookian age, with a partial equivalence

¹ Published by permission of the Director of the Geological Survey of Canada.

to the Pocono. The fauna of the Windsor series was considered by both Schuchert (1910) and Beede (1911) to have mainly a Kinderhookian aspect, but certain of the limestones were assigned by Schuchert to the Keokuk or to a somewhat higher horizon.

Scope of the present paper.—The present paper is concerned primarily with conclusions reached after a detailed study of the field relations and of the faunas of the marine Windsor series, begun in 1912. As considerable interest, however, attaches to the earlier Mississippian formations, on account of their terrestrial fluvial origin, a brief description of them is included. These formations, the *Horton* and the *Cheverie*, comprise what has formerly been known as the *Horton series*.

The treatment of the faunas of the Windsor series necessitated the description of more than sixty new species, and the report dealing with these faunas as a whole will be published at a future date by the Geological Survey of Canada. Where new species are mentioned in the present paper, use is made of manuscript names that are subject to revision.

Acknowledgments.—The field work of the present study, which was completed in 1914, was rendered possible by the aid and encouragement extended by the Director and Directing Geologist of the Geological Survey of Canada. The preparation of the manuscript has been done in the laboratories of the Peabody Museum of Yale University, and the writer is particularly indebted to Professor Charles Schuchert of that institution, from whose suggestions the work was originally projected, for constant supervision and inspiration. As Professor Schuchert is personally acquainted with the field, the value of his criticism was greatly enhanced, while the Peabody Museum collection of Windsor fossils gathered by him was generously placed at the writer's disposal.

Thanks are also due to Mr. J. E. Hyde, of Western Reserve University, Ohio, for suggestions made in the field.

Although the work was interrupted by the war, the writer was privileged, when in England, to study the collections of Avonian fossils of the late A. Vaughan, that are preserved in the Sedgwick Museum, Cambridge, and the many courtesies extended him by Professor J. E. Marr, of Cambridge University, are held in grateful remembrance.

Particular pleasure was derived, and benefit received, from direct field observations on the rocks and contained faunas of Lower Carboniferous age in the vicinity of Settle, Yorkshire, and in Westmoreland, under the able guidance of Professor E. J. Garwood, of University College, London, who at the sacrifice of his own pressing affairs cordially exerted himself in the writer's behalf.

Location.—The town of Windsor lies on the estuary of the Avon river some 35 miles in a direct line northwest of Halifax. The district under discussion embraces land with an areal extent of 240 square miles on either side of the estuary and facing north on Minas basin, the southernmost prolongation of the headwaters of the Bay of Fundy. Communications are readily effected with Halifax, Yarmouth, and St. John by means of the Canadian Pacific Railway.

GENERAL GEOLOGICAL RELATIONS.

Pre-Mississippian history.—The Mississippian rocks in the district form an undulating lowland with elevations of less than 250 feet, margined on the west and south by an upland of older crystalline rocks that is peneplaned at an elevation of about 500 feet. The sediments of the upland are intensely folded and regionally metamorphosed, with a cleavage at a high angle to the south, and are intruded by an unaltered batholithic mass of coarse, porphyritic, biotite granodiorite. The altered strata are chiefly dark green, pyritized, banded slates, belonging to the gold-bearing or Meguma series of Nova Scotia, generally accepted as of late Proterozoic or Algonkian age, associated south of the Gaspereau valley with a marginal strip of slates and argillites of Niagaran age which have yielded *Dictyonema retiforme* (Hall). The contact between the two slate formations in the Windsor district is the result of pre-Mississippian faulting, with upthrow on the south, but farther to the west in the Kentville district, a larger mass of Silurian rock is said to follow the Precambrian slates without angular discordance.

The orogenic disturbance, with granitic intrusion as an end phase, that produced the folding and regional metamorphism of these rocks, affected elsewhere sediments of Oriskany age and represents the outstanding historic event of the whole region. It was named many years ago

by H. S. Williams the *Acadian orogeny*. Although this disturbance must have resulted in a constructional topography of high relief, the basal Mississippian contact in the Windsor district indicates that these mountains were worn down to peneplanation prior to early Mississippian times. Not only do the basal Horton sediments of Kinderhookian age truncate at a flat angle both slates and granite, but there is evidence of pre-Mississippian weathering in the oxidized nature of the slates and in the disintegrated condition of the granite for several feet beneath the contact.

Structure and physiography.—The slopes that connect the lowland with the upland are everywhere steep. In the western margin of the district there is a rise of several hundred feet within half a mile, while the ascent in the south is still more abrupt. The latter was determined to be the erosional expression of a fault, here named the *Butler Hill fault*, that has a stratigraphic throw in the district in the neighborhood of 2,000 feet. As a result, hard crystalline rocks on the south are brought up against very soft rocks of the Windsor series of upper Mississippian age. This fault that margins the Windsor lowland in the south was traced for several miles northeastwards beyond the confines of the district. The border of upland and lowland in the west does not show a response to faulting, but is a sinuous one determined by post-Mississippian folding that has affected the crystalline floor as well. The present main streams, e. g., Gaspereau river, Halfway river, Mill branch and West branch, all of which are tributaries of the Avon river, are located in synclinal valleys that are underlain by Mississippian rocks, whilst the divides between these streams are in the nature of projecting "capets" from the upland developed on the older crystalline rocks. This relation has given rise to the erroneous impression current in the literature that the margin of lowland and upland is an inheritance from an old Carboniferous shore-line.

The lowland of the Windsor district is underlain by rocks of so soft a nature and is so maturely dissected by the Avon river and its tributaries that it is not known to what extent its formation is due to marine planation on the one hand or to subaerial denudation on the other. At present, the lower reaches of the rivers are submerged and an estuarine cycle is in process. Tides of 20-30 feet mean range have resulted, and that these are effective

agents of erosion is evident from the maintenance and rapid undercutting of cliffs. It is only in favored localities, such as over alluvial flats bordering the upper limits

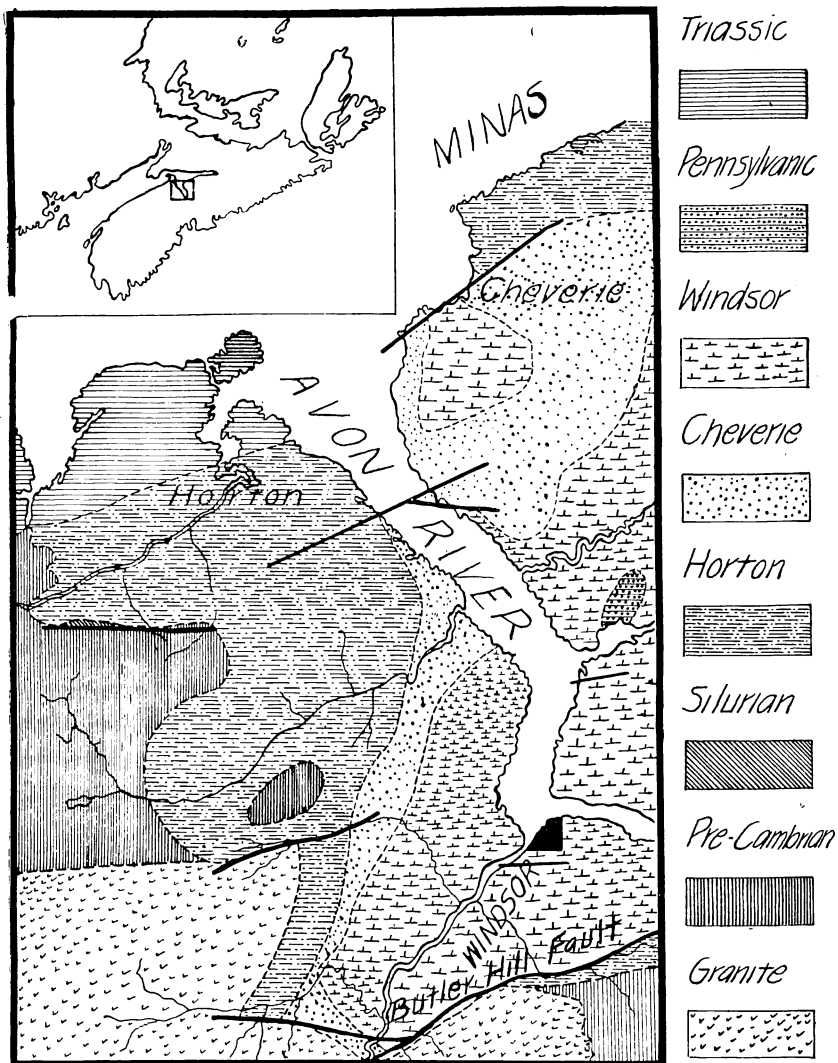


FIG. 1. Geological map of Horton-Windsor district. Scale 4 miles — 1 inch.

of tidal action, that extensive aggradation has taken place, with the formation of estuarine plains such as that of Grand Pré in the north of the district, the historic ground of the early French settlers.

The basal Mississippian sediments belonging to the Horton formation that flank the upland in the west have suffered practically no folding beyond the broad flexures already noted. To the northeast, however, where higher and better laminated strata of the Horton outcrop along Minas basin, they are affected by numerous minor asymmetrical folds and corrugations which have their axial planes inclined to the northwest.

The very soft strata of the Windsor series are characterized by numerous small flexures and are broken by many faults that are mainly thrust slips consequent upon stretching of the limbs of the folds. In general, these slip planes dip steeply southwards, and where closely spaced, the strata have isoclinal dips and are locally overturned. Such a complex structure, combined with the presence of thick zones of gypsum and very poor exposures, renders the interpretation of the stratigraphic sequence exceedingly difficult. The stratigraphic throws along the slips vary from several tens to several hundreds of feet.

The northward dip of the axial planes of the folds in the northern part of the district is believed to be due to the influence of the resistant crystalline mass of the Cobequids north of Minas basin, which bulwark is expressed topographically at the present time by the narrow upland known as the Cobequid mountains.

Post-Mississippian history.—The Windsor series of late Mississippian age is the last sedimentary record of marine transgression within the Maritime Provinces prior to the Champlain epoch. The folding that affected the Mississippian rocks took place before the close of mid-Pennsylvanian (Westphalian) time, with the balance of evidence in favor of an early Westphalian orogeny. Rocks of Pennsylvanian age have been entirely removed by erosion from this district, with the exception of a very small patch of sandstone that may represent a faulted inlier. The district was once more reduced to peneplanation before the deposition of the semi-arid terrestrial deposits of Newark age (early upper Triassic).

STRATIGRAPHY AND CORRELATION.

Mississippian sequence.—In descending order the succession of Mississippian formations is as follows:

- Tennessean (Chesterian equivalent).
 Windsor series (marine)..... 1100'+
Disconformity.
- Tennessean (Meramecian equivalent).
 Cheverie formation (terrestrial)..... 600-800' max.
 Characterized by *Estheria dawsoni* Jones and *Leaia salteriana* (Jones & Kirkby).
Disconformity.
- Waverlian (Kinderhookian equivalent).
 Horton formation (terrestrial)..... 2800-3400' ± max.
 Characterized by *Aneimites acadicus*
 Dawson and *Lepidodendron corrugatum*
 Dawson.
Unconformity.
- Silurian and Precambrian slates and Devonian granodiorite.

Horton Formation.

Description.—Broadly the Horton may be divided into a basal feldspathic arenaceous member (650-2,000 feet thick) which carries rare faunal remains, and an upper argillo-arenaceous shale member (300-1,400 feet thick) with abundant Ostracoda and fish scales at various horizons. The feldspathic sediments at the base flank the bordering upland with a present mean dip of the warped contact surface of about 12°. The composition of the immediate contact beds is in direct relation to that of the underlying rock. Where the latter is slate, for example, the lowermost Horton bed of several feet thickness is a compost or agglomerate consisting of angular to subrounded fragments of the underlying rock embedded in a paste of the same material with but occasional pebbles from more distant localities. Above this thin sheet of basal agglomerate the stream-deposited feldspathic grits and arenaceous shales so characteristic of the Horton were laid down. The grits, in which the grain of the matrix ranges from 7 mm. downwards, consist of transparent angular quartz, rounded flakes of dark slate, kaolinite and muscovite. Conglomeratic basal beds carry in addition pebbles of vein quartz, quartzite, or slate. The coarser beds are heavily cross-bedded, whilst the slates are typically marked by ripples predominantly of the current type.

The peculiarity of the succeeding beds lies in the presence of frequent zones of laminated, siliceous, and argillaceous shales, with which are commonly associated ironstone concretions, abundant spheroidal calcareous concretions, and occasional thin argillaceous limestones

with a cone-in-cone structure. Certain beds in these zones are abundantly rich in leperditoid and beyrichioid ostracods, *Spirorbis*, and the scattered scales and dermal bones of palæoniscid fishes. The ostracod beds are of a more argillaceous character, and are more restricted in their vertical distribution, being mainly confined to the middle part of the Horton.

The higher beds of the upper Horton comprise a thick accumulation of finely siliceous shales associated with thick interzones of non-laminated, or but poorly laminated, argillo-arenaceous deposits that break with a characteristic hackly fracture, and that weather frequently to variegated light greenish and buff-yellow colors. An extraordinary feature presented by these beds on their exposed bedding surfaces is a polygonal system of cracking that might readily be mistaken for true sun-cracking. Careful inspection, however, reveals the presence of carbonaceous traces of a dichotomously branching system of rootlets, and not uncommon association with casts of upright tree stems, denoting clearly that they are fossil soils. It is these early soil zones that lend to the deposit its greatest interest. Although they may be observed in their best development in the upper Horton (they are particularly well displayed along the Cambridge shore), their occurrence is widespread both vertically and laterally, and they are eminently characteristic of the whole deposit. In several hundred feet of strata in the upper Horton, fifty-six well marked soil zones were noted, of which seven had associated with them abundant upright tree stems. Additional soils and upright stems were present in the ostracod-bearing division below. The abundance of these upright stems in the horizons in which they occur is evident from the fact that ninety-six were counted in a plot 150 × 15 feet. The stems are small, rarely exceeding 11 inches in diameter, and usually not more than a foot of the height can be traced. As regards the rootlets in the soil zones, their casts and imprints are indistinguishable from the rootlets of *Stigmaria ficoides* of the Coal Measures. It is a striking fact, however, that no creeping "rhizomes" comparable to *Stigmaria* were found anywhere in the Horton formation, while several upright stems had directly attached to them rootlet-like appendages that branched dichotomously. The absence in the Horton of true *Sigillaria* and the association

of these stems with the ubiquitous drift of *Lepidodendron corrugatum* Dawson suggest the strong probability that the upright stems belong to this species. An absence of horizontally spreading *Stigmaria* is in agreement with the arenaceous character of the Horton soils and absence of carbonaceous seams, which point rather to good drainage and lack of permanent swampy conditions before burial.

Throughout the formation, broken plant material is common. Larger recognizable fragments are almost exclusively cortical imprints of *Lepidodendron corrugatum* Dawson or of the broken foliage and rachises of the pteridosperms *Aneimites acadicus* Dawson, two species represented by close allies in the American Pocono. In the upper beds, large megaspores (*Spongites glaber* Dawson) 1.2 mm. in diameter are very abundant at certain horizons. A single specimen of *Asterocalamites* cf. *scrobiculatus* Schlotheim was found as a stray fragment, presumably from the upper Horton.

In the restricted fauna the following ostracods are most characteristic: *Jonesina nova-scotica* (Jones), a beyrichioid allied to *Beyrichia colliculus* Eichwald; *Kirkbyina acadica* n. sp., a larger and more quadrate form than *K. reticosa* (Jones & Kirkby); *K.* cf. *scotoburdigalensis* (Jones & Kirkby); *Carbonia* cf. *pungens* Jones & Kirkby.

The fish scales of most common occurrence are assigned to the genus *Elonichthys*, differing from *E. brownii* (Jackson) from the Albert series of New Brunswick, in the possession of nonserrate margins. Maxillæ of *Rhadinichthys* are not uncommon. Rarer remains are jaws and teeth of *Strepsodus*, and selachian spines of the genera *Stethacanthus* and *Ctenacanthus*.

Depositional environment.—Marine conditions are excluded as inconsistent with a widespread extension of rootlets and plant stems *in situ*, an exclusion corroborated by the textural features of the deposits. General uniformity of deposition, carbon content, absence or rarity of desiccation cracking, ferrous condition of the iron content, etc., testify to pluvial conditions. Among the possible terrestrial deposits, a fluviatile accumulation under humid climatic conditions is postulated as most consistent with all the facts. The laminated ostracod-bearing shales may represent temporary lacustrine deposits on the river plain. While the presence of the beyrichioid

Jonesina seems unfavorable to a fluvial or lacustrine origin of the particular sediments in which it is found, the remaining evidence is so overwhelmingly in favor of a terrestrial deposition that it is believed a fresh-water adaptation of this genus must be accepted.

The accumulation and preservation of several thousand feet of terrestrial sediments characterized by abundant soil levels calls for a differential subsidence of the basin of deposition. Two convergent lines of evidence fix the source of material in nearby upland masses lying in a general southwesterly direction. Primarily, the composition of the sediments points unequivocally to the belt of Devonian granites and Precambrian slates and arkosic quartzites of the Meguma series, which outcrop at present for 120 miles to the southwest before they sink beneath the Atlantic. The second line of evidence is presented by the alignment of the current ripples. By plotting the results of many observations, the mean trends indicate the dominance of currents from the southwest.

Correlation.—The plant evidence has been effectively summarized by David White, who correlates the Horton with part of the Pocono, assigning to it a Kinderhookian age. The fish genera *Elonichthys* and *Rhadinichthys* establish the Carboniferous age of the deposits, whilst the ostracods have their nearest allies in the Lower Carboniferous of Europe.

Upper contact.—Although the Cheverie formation succeeds the Horton without *angular* discordance, a marked disconformity is inferred. There is a distinct climatic break and the thick clastic beds at the base of the Cheverie suggest also a marked uplift of the headwater region that was undergoing erosion. Moreover, local mountain-making movements at this time are indicated by heavy conglomerates of Cheverie age in the Moncton area, New Brunswick.

Cheverie Formation.

Description.—The Cheverie formation attains a maximum thickness in the district of from 600 to 800 feet. The basal 300 feet is dominantly made up of gray arkose grits with a subordinate amount of chocolate argillo-arenaceous shale and occasional beds of micaceo-arenaceous shale of a greenish black color. The arkose consists of angular fragments of transparent quartz up to 15 mm. diameter, with angular fragments of feldspar of

like dimension. Biotite mica, little altered, is commonly present in flakes up to 3 mm., and may be in excess of muscovite. The binding material is largely kaolinite which renders the arkose friable. Slate particles are of minor importance. The upper strata of the formation are dominantly purple-red argillo-arenaceous shale with occasional thin zones of greenish micaceous shale or slate-grey argillaceous *Estheria*-bearing shales. These dark shales yield likewise a few plant remains and rare specimens of *Leaia*. The red shales are commonly non-laminated, weather in a hackly manner, and frequently contain small irregular concretionary calcareous nodules.

The phenomena of current ripples and cross-bedding are as widespread in the Cheverie as in the Horton. Channeling of the grit beds into underlying shales is a marked feature, and frequently large torn angular remnants of shale are included in the arkose. Sun-cracking has been observed in several instances, although the exposures are unsuitable for observations of this nature. Striking features of this cracking are the sandy nature of the beds in which it occurs, the relatively great width of the fissures, the coarse infilling, and the fact that the cracked beds have traces of rootlets *in situ* and represent old soils.

Biologically the features presented are a repetition of those of the Horton formation, but are here in a more restricted development consequent to a more advanced degree of subaerial exposure. Rootlets *in situ* are common throughout all the argillo-arenaceous non-laminated shales, notwithstanding the fact that the strata are now dominantly red and practically devoid of other organic remains. The traces of rootlets are, however, less frequent than in the Horton formation, and are most commonly represented by slight color distinctions, with traces of carbon of rare occurrence. At times the oxidation of the carbon took place at the expense of oxygen combined with the iron, giving rise to grey contact zones. Upright stems were observed in one instance in a purple-red shale in which thirty-three stems were counted in a plot 29 × 146 feet. The drift flora is practically restricted to occasional thin seams of dark shale, but the flora so far gathered is of too fragmentary a nature for reliable specific identification. It appears to be more varied than that of the Horton, with sphenopterid types dominant.

In addition to *Estheria dawsoni* Jones, which is common, there is a *Leaia* of rarer occurrence, a very significant fact, as *Leaia* elsewhere in America is eminently characteristic of the Pennsylvanian.

Depositional environment.—The same features that denoted a fluvial environment in the case of the Horton are here repeated, some of them in accentuated forms. Thus channeling, sun-cracking, fresh feldspars, little altered biotite, oxidized iron content, etc., are dominant properties of the Cheverie that give a unity to the deposit and differentiate the formation as a whole from the underlying one. As the material itself has been derived from the same general land mass that supplied the Horton detritus, it is reasonable to attribute climatic influence as the main control of the chemical and textural features of the sediments. Tumultuous current action at recurrent intervals in the basal arkose mass, in conjunction with the presence of soil beds at like intervals, would call for rhythmic pronounced accessions of water flow and a sufficiently high level of the ground water in the river flats during the intervals to favor a vegetable growth. From a study of present-day climates, it would seem necessary to postulate a warm temperate semi-arid type to fulfill all the requirements. That extreme arid conditions were wanting is evidenced by the absence of pebbles. The presence of nodules of reddish calcium carbonate in the red soil beds of the upper part of the formation suggests homology with the "kankar" in the alluvium of the Indo-Gangetic plain.

Correlation.—The stratigraphical position of the Cheverie formation between the Horton below of Kinderhookian age and the Windsor series above of Chesterian age does not closely define its position in the Mississippian. It is the addition of an eremopterid flora and the distinct climatic break that have led to the inclusion of the Cheverie in the lower Tennessean rather than in the Osagian. The break between the two terrestrial formations, the Horton and the Cheverie, is believed to be greater than that between the terrestrial Cheverie and the marine Windsor.

Windsor Series.

Description.—The Windsor series comprises a well defined unit of marine deposits laid down under peculiar

environmental conditions. There are three and probably four zones of calcium sulphate deposits (gypsum and anhydrite), averaging roughly 50 feet each, separated by varying amounts of brick-red argillaceous shale and fossiliferous limestone with subordinate thin dolomitic sandy shales, oölites, and calcareous algal bands. In amount, the gypsum and anhydrite may make up some 10 per cent of the total estimated thickness of 1100 feet, with red shale 50 per cent and calcareous beds 40 per cent. Estimates of the thicknesses of this series, however, must be considered as but very rough approximations, owing to the poorness and isolated nature of the exposures, and to the presence of numerous fault slips of which mention has been made. The sequence of faunal zones presented here is necessarily dependent on the writer's interpretation of the structure, and is not advanced as an established fact. Better and less broken sections may be found elsewhere in the province that will necessitate a considerable revision of the following succession. The sequence as given below is radically different from that presented by Hartt (1867) and in Dawson's "Acadian Geology."

- Upper Windsor or *Martinia* zone. Characterized by
Martinia opertacosta n. sp.
 Subzone D. Characterized by *Caninia dawsoni* (Lambe) 460'±
 Subzone C. Characterized by *Dibunophyllum lambei* n.
 sp. 270'
 Lower Windsor or *Composita* zone. Characterized by
Composita dawsoni (Hall & Clarke).
 Subzone B. Characterized by *Diodoceras avonense*
 (Dawson) 265'±
 Subzone A. Basal limestone and *Sanguinolites* phase. . 95'±

The Windsor beds disconformably overlie the Cheverie formation. The basal member is a fine calcareous quartzite whose upper surface is locally marked by interior molds of the valves of a *Sanguinolites*. Commonly both valves are attached and flatly opened. A thin conglomeratic development with limestone pebbles, probably of an intraformational character, follows the basal arenaceous bed, and is succeeded by platy brecciated limestone which carries calcite vugs and occasional nodules of pyrolusite and manganite of secondary origin. This manganiferous mineralization is of such widespread occurrence at this horizon that it is probable that the manganese content was originally disseminated in the limestone at the time

of deposition. The subzone terminates with a thick band of anhydrite and gypsum.

Subzone B is characterized by the presence of two limestones that are extremely fossiliferous, and as they outcrop in the vicinity of the town of Windsor, they afford a rich collecting ground. The lower or *Maxner limestone* is about 80 feet in thickness, the upper or *Miller limestone* about 35 feet, the two being separated by a second band of gypsum. The fauna is common to the two limestones, but the association is somewhat different. The Maxner limestone is characterized particularly by the abundance of *Diodoceras avonense* in its upper portion and by the great profusion of individuals of species of *Dielasma* and *Composita* in which the brachidia are excellently preserved within the hollow interiors. The Miller limestone is characterized by an abundance of *Aviculopectens*, bryozoans, and productids.

Subzone C is best exposed on the Avon estuary at Windsor in the neighborhood of the bridges. The section, however, is broken by a number of important faults. The lower part of the subzone has frequent oölitic, algal, and sandy dolomitic beds that are sparingly fossiliferous, but in the upper part some 20 feet of platy blue limestone furnishes abundant *Martinia* and *Productus*.

Subzone D has a thick gypsum member at its base, in which are a number of thin calcareous seams crowded with ostracods and with the foraminifer *Nodosinella*. The upper beds are best exposed at the mouth of Kennetcook river, where 100 feet of thinly bedded blue-grey limestones carry a fauna which is more normally marine than any which preceded it. Cup corals become abundant here for the first time, there is a greater variety of brachiopods, and the molluscs are mainly confined to the Bellerophontidæ.

The following generalized lithological section illustrates the rhythmic recurrence of mud deposition with chemical and organic deposits:

D. Kennetcook limestone.....	100'+
Gypsum and anhydrite with <i>Nodosinella</i> bands.	
Red shale, etc.	
C. Avon River limestone	45'+
Gypsum? and red shale.	
Dolomitic and calcareous shales and sandstones,	
oölites, algal and <i>Modiola</i> bands.	
B ₂ . Miller limestone	35'

Gypsum, anhydrite, and red shale.	
B ₁ . Maxner limestone	80'
Gypsum, anhydrite, and red shale.	
A. Basal limestone, conglomerate, and quartzite.	

Environmental factors.—As interbedded chemical deposits and red argillaceous shales form so prominent a feature throughout the Windsor series, it is evident that the biotic conditions were decidedly abnormal, a fundamental fact that must be borne in mind in comparative studies with other faunas. The most significant factors of the Windsor seas were shallow waters, probable high temperatures, and varying salinities, culminating at intervals in conditions intolerable to a bottom life. These unfavorable conditions were not confined to local pools, but were of widespread extent in the Windsor basin.

The shallow-water conditions that prevailed were doubtless maintained by progressive subsidence in a manner analogous to the previous differential movements that controlled the terrestrial deposition in the basin. A "barrier" of some sort certainly existed against free communication with the outer sea, and it was more probably a tectonic upwarp due to the same differential movements than a depositional sand or gravel bar or a current barrier established by differential salinities or by controlling winds alone. The Windsor sea, moreover, was of a geosynclinal Paleozoic type and not a shelf sea in the nature of the present Rann of Cutch. There is, furthermore, no evidence at hand for complete isolation, and the "breaks" in the sequence are in the nature of diastems or minor disconformities. Stages of extreme shallowness took place in the middle of the epoch, as attested by dolomitic sands, algal bands, oölites, *Modiola* bands, etc., which beds are characterized by peculiarly restricted faunules, whilst the nearest approach to normal marine conditions was reached in the late life of the sea.

Desiccation rarely proceeded beyond the precipitation of gypsum or anhydrite, but this alone would demand, since there were no marked volume contractions, a surface inflow from the outer sea of four to nine times the volume of water in the basin under conditions in which the evaporation would approximately balance the accessions.

The times of gypsum or anhydrite deposition were not the only ones that prohibited the establishment of an

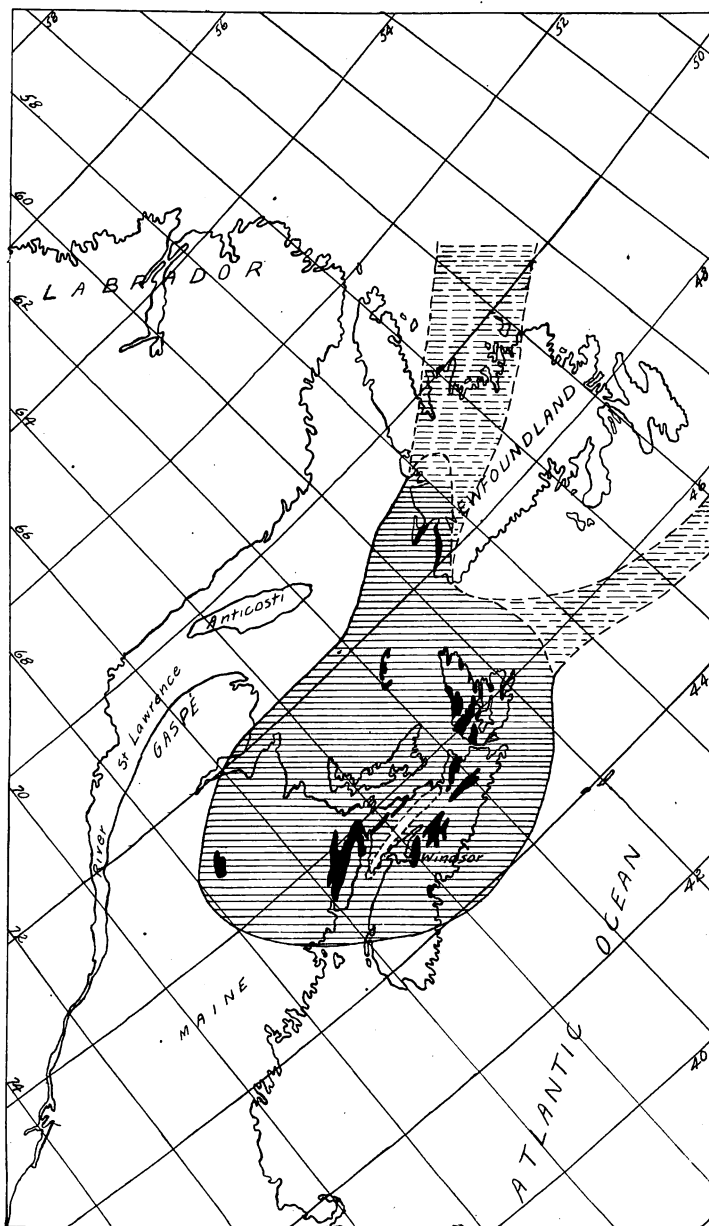


FIG. 2. Hypothetical extension of Sea in Lower Windsor time.

indigenous fauna, as red shales make up nearly one half of the total mass of the sediments, and so far as known are barren of fossils. In this case the extreme muddiness of the waters, combined with probable high temperatures (warm seas at this time are indicated by abundant reef corals in western Europe), was equally deleterious to animal life.

Faunal selection.—Unfavorable biotic conditions would affect various organisms differentially. They would be particularly prohibitory to the establishment of certain groups of greater sensibility, such as the corals, and it is not surprising that colonial corals have not been found in the Windsor deposits and that cup corals are very meagrely represented and gain only a temporary footing in the more normal marine waters of late Windsor time. An analysis of the Windsor fauna shows that of 104 species belonging to 63 genera, 48 species representing 22 genera are brachiopods, and 36 species representing 25 genera are molluscs. The fauna, therefore, as determined by the physical environment is essentially a molluscan-brachiopod one.

The composition of a faunal assemblage, however, is dependent not only on the direct environmental factor but on the available routes of migration. While the Windsor faunas show very little in common with the Mississippian faunas of interior America, there are clear affinities with the faunas that inhabited the seas of western Europe at this time. Accordingly, absentees in the Windsor faunas may likewise be absent or illy represented in the Avonian (Lower Carboniferous) faunas of the North Atlantic province with which direct migratory relations were established. This factor alone might account for the meagre representation of crinoids as mere stem fragments, for the absence of blastoids, and of such specialized bryozoans as *Archimedes* and *Lyropora*.

Correlation with the Viséen.—In correlating the Windsor faunas it is natural to turn in the first place to their nearest allies, the Lower Carboniferous faunas of western Europe. To the Belgian geologists, who were among the first to illustrate these faunas, we are indebted for the recognition of two major faunal divisions, the Tournaisien below and the Viséen above, corresponding approximately to the Waverlian and Tennessean, respectively, of the American sequence. In recent years, British palaeontologists, led and inspired by the admirable studies of

A. Vaughan, have worked out in great detail the faunal sequence in their Lower Carboniferous or Avonian rocks (Vaughan 1905, 1915; Garwood 1912; Dixon 1911). While opinions differ as to the placement of the division line between the Tournaisien and Viséen, there is general agreement as to the faunal successions throughout the British and Belgian field. The northern part of the British Isles, however, is characterized by an arenaceous or abnormally marine facies and much remains yet to be done on the correlation of the beds that make up the Calciferous and Limestone series of Scotland. The latter facies is rich in the Mollusca as contrasted to the coral-brachiopod faunas of the calcareous or "Mountain limestone" facies.

In comparing the Windsor faunas with the Avonian faunas of England, the affinities are seen to lie with the upper Avonian or Viséen rather than with the lower Avonian or Tournaisien. The presence in the lower Windsor zone of abundant *Composita* of the "ficoides" form, associated with *Productus* of the type of *cora* and *corrugato-hemisphericus*, is in striking conformity with the faunal assemblage in the middle Viséen (S_2) of the Avonian sequence. Of the Mollusca, which dominate the lowest fauna at Windsor, there are species identical with or closely allied to species from the *Lower Limestone* series of Scotland, or from the Redesdale limestone of Northumberland, both of which are well up in the Viséen. Thus, *Sanguinolites parvus* n. sp. is probably synonymous with *S. striatogramulatus* Hinde from the Redesdale; specimens of *S. tricostatus* identical with Portlock's species from the Redesdale limestone occur at Windsor; *Lithodomus lingualiformis* n. sp. is very close to *L. lingualis* Phillips from the Viséen of Castleton; *Murchisonia compacta* is identical with *M. compacta* Donald from the *Upper Limestone* series of Dalry, Scotland.

The upper or *Martinia* zone at Windsor is characterized by the entrance of a clisiophyllid cup coral belonging to the genus *Dibunophyllum*, which is an early form of the type of *Dibunophyllum* aff. ψ Vaughan, as well as by the abundant occurrence of *Martinia* of the *M. glabra* form type. Both of these genera are characteristic Viséen genera, and *Dibunophyllum* especially has been found a good index to the upper Viséen of England. The following species from the upper limestone of Windsor afford additional links on which a correlation of the

Windsor *Martinia* zone with the lower part of the *Dibunophyllum* zone is based.

Zaphrentis minas Dawson is distinctly of the type of *Z. enniskilleni* Edwards & Haime. In England this group ranges from the upper Tournaisien to the upper *Dibunophyllum* zone, but is especially characteristic of the Viséen.

Lophophyllum avonense n. sp. In Europe, *Lophophyllum* attains its maximum in strata of upper Viséen age, or in beds immediately succeeding, although it is found sparingly in the upper portion of the Tournaisien.

Tabulipora acadica n. sp. is a dendroid trepostomatous bryozoan that is very abundant near the base of the Kennebec limestone. It is characterized by the thinness of the peripheral zooecial walls, which nevertheless show a distinct moniliform structure. *Tabulipora* is essentially a Viséen genus, and *T. tenuimuralis* Lee from the Eelwell limestone, Lowick (= D₂?), agrees with the Windsor species in the tenuity of its walls.

Avonia spinifercardinata n. sp. is very close to *Productus longispinus* Sowerby.

Chonetes politus, the only *Chonetes* yet gathered from the Windsor beds, is identical in all respects with McCoy's species from the base of the *Lower Limestone* series of Scotland.

Spirifer bisulcatiformis n. sp. is indistinguishable from *S. bisulcatus* var. *oystermouthensis* Vaughan from D₂-D₃ Gower (Dixon 1911). The *bisulcatus* type of *Spirifer* occurs rarely in the middle Avonian but has its maximum in the upper Viséen.

Martinia opertacosta n. sp. This species lacks dental plates and has the shell structure of a true *Martinia*.

Phillipsia howi Billings. This species has been correlated by Vogdes with *P. meramecensis* Shumard, on the evidence of pygidia only. Several cranidia, however, found by the writer, one of which is still attached in a crushed rolled specimen, determine the Windsor species to belong to the gens of *P. eichwaldi* Fischer, which occurs in the *Lower* and *Upper Limestones* of Scotland and at Bolland, Yorkshire.

Allorisma sulcatiforme n. sp. is perhaps identical with *A. sulcatum* Fleming from the Redesdale limestone and the *Limestone* series of Scotland.

Aviculopecten dissimilis Fleming, from the *Limestone* series of Scotland and from the Four Laws limestone of

Northumberland, occurs in the upper Limestone of Windsor.

Correlation with the American Tennesseean.—The dissimilarity of the Windsor faunas to those of like age in the Mississippian basins of America was early noted by Dawson and subsequently confirmed by Schuchert and Beede. Dawson, moreover, clearly perceived their European alliances and attributed their isolation from the western faunas to the existence of an Appalachian mountain barrier. The difficulties of correlating a fauna which is dominantly a molluscan one are well exemplified by the fact that Beede, who described faunas of this age from the Magdalen islands, was impressed with the Devonian or early Mississippian aspect of some of the pelceypods, whilst earlier paleontologists, e. g., Meek and Newberry, emphasized their Permian appearance. In the present correlation, reliance is placed rather on the occurrence of several brachiopods and bryozoans that either hold a limited range in, or make a definite entry into, the Mississippi Valley basin.

In the upper Windsor zone, several species belonging to *Martinia*, *Composita*, and *Productus* present evidence of an age synchronous with some part of the Chesterian group. *Martinia opertacosta* n. sp. is a form closely allied to *M. contracta* (Meek & Worthen). *Composita obligata* n. sp., common in, and characteristic of, the upper Windsor limestones, is so close to *C. subquadrata* (Hall), a characteristic Chesterian species, that it may well be specifically identical. *Productus (Avonia) multiplexseptum* n. sp. is likewise probably specifically equivalent to *P. parvus* (Meek & Worthen) from the Ste. Genevieve and Chesterian groups. Thus there is direct evidence of Chesterian affinities. Indirectly, the same conclusion is reached, as the fauna of the upper zone at Windsor correlates with that of a lower *Dibunophyllum* age in the European time-scale.

The lower fauna at Windsor, while it likewise indicates Chesterian affinities, is seemingly an earlier expression and may be in part equivalent to the Ste. Genevieve. The Compositas, which are extraordinarily abundant in individual representation, belong mainly to two species of European stock, and while the productids of the *cora* and *semireticulatus* types are too plastic for correlation purposes, they likewise are closer to the European species. The occurrence in the fauna of a true *Diaphragmus* is the

most suggestive character, as this genus makes its first appearance in the Ste. Genevieve and the *D. montesana* Ulrich (1917) is close to the Windsor *D. tenuicostiformis* Beede. The bryozoans afford additional evidence in their Chesterian affinities. Thus *Batostomella exilis* (Dawson) and *B. cf. abrupta* Ulrich are two species, associated in abundance in the Miller limestone, that are almost indistinguishable in their external and internal characters from *B. spinulosa* and *B. abrupta* Ulrich. The fenestellid of most common occurrence, *Fenestella lyelli* Dawson, reveals close analogies with *F. elevatipora* Ulrich, while *Septopora parva* n. sp. has the small delicate zooarium of *S. delicatula* Ulrich associated with a like arrangement of accessory pores on the reverse surface. It is concluded that the Chesterian affinities of this lower Windsor fauna are too strong to assign to it as low a position as the St. Louis, and it is provisionally referred to the Ste. Genevieve.

Climatic correlation.—The semi-aridity characteristic of Tennessean time in Nova Scotia during the deposition of the Cheverie and Windsor formations is in agreement with conditions of semi-aridity in Pennsylvania during Mauch Chunk time and in Michigan during the deposition of the Michigan series.

BIBLIOGRAPHY.

- Beede, J. W.—1911.—The Carbonic fauna of the Magdalen islands. New York State Mus., Bull. 149, 156-186.
- Dawson, J. W.—1855.—Acadian geology, 1st ed.; 2d ed., 1868; 3d ed., 1878; 4th ed., 1891.
- Dixon, E. E. L.—1911.—The Carboniferous succession in Gower (Glamorganshire) with notes on its fauna and conditions of deposition. Quart. Journ. Geol. Soc., London, 67, 477-567, 4 pls.
- Garwood, E. S.—1912.—The Lower Carboniferous succession in the north-west of England. *Ibid.*, 78, 449-586, 13 pls.
- Hartt, C. F.—1867.—On a sub-division of the Acadian Carboniferous limestone with a description of a section across these rocks at Windsor, Nova Scotia. *Can. Nat.*, new ser., 3, 212-224.
- Schuchert, Charles.—1910.—Paleogeography of North America. *Bull. Geol. Soc. America*, 20, 551.
- Ulrich, E. O.—1917.—The formations of the Chester series in western Kentucky and their correlates elsewhere. *Kentucky Geol. Surv. and U. S. Geol. Surv.* (joint pub.).
- Vaughan, Arthur.—1905.—The paleontological sequence in the Carboniferous limestone of the Bristol area. *Quart. Journ. Geol. Soc.*, London, 61, 181-307, 3 pls.
- 1915.—Correlation of Dinantian and Avonian. *Ibid.*, 71, 1-52, 7 pls.
- White, David.—1901.—Some paleobotanical aspects of the upper Paleozoic in Nova Scotia. *Can. Rec. Sci.*, 8, 273-274.
- 1913.—Excursion in eastern Quebec and the Maritime Provinces: the Horton flora. 12th Internat. Geol. Congress, Guide Book No. 1 (issued by the Geological Survey of Canada), 144-146.