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CAMBRIAN AND ORDOVICIAN STRATIGRAPHY OF NORTHWESTERN VERMONT.

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INTRODUCTION.

In all of eastern North America there is no more fully developed or more fossiliferous Cambrian system, and none that has a more complicated structure, than that of easternmost New York, and Vermont west of the Green Mountains. It is to the Cambrian and Lower Ordovician stratigraphy and faunas of the northwest portion of the latter area that the present paper is restricted.

History.—The difficulties inherent in the geology of the boundary region between New York and Massachusetts and Vermont gave rise to the "Taconic controversy," which stormed for more than half a century and was "equaled by none in the annals of American geology" (see Merrill, *The First Hundred Years of American Geology*, chapter XII, 1924). The Taconic Mountains have a structure that is exceedingly difficult to unravel, due to folding, mashing, faulting (both normal and overthrust), and metamorphism "to an extent . . . undreamed of" in the pioneer days of American geology. The formations of these mountains were first described by Amos Eaton, more than 100 years ago (1820-1832), and the "Taconic system" was first named by Ebenezer Emmons in 1841 and fully defined by him in the following years. However, the two men who were first to begin to decipher the intricate structure, to give a more correct interpretation to the strata in northwestern Vermont, and to bring some daylight into the Taconic problem were Canadians. The leader in this work was the remarkably gifted director of the Geological Survey of Canada, Sir William Logan, and his helpmate, that born paleontologist, Elkanah Billings. The former, between 1861 and 1863, followed the structural trends from Canada south through Vermont to Burlington, noted in a clear manner in his *Geology of Canada* (1863) the major north-south faulting, the overthrusting of the "Primordial" formations, and how they rested on various members of the

younger Ordovician, and finally in 1865 presented a detailed geologic map of the area south to St. Albans. His associate, with the guidance of local workers in geology, collected the fossils, described the new forms in 1861, making use of those published a few years earlier by James Hall, and then sent his printed results to the one man in all the world who knew most about Primordial fossils, namely, Joachim Barrande of Bohemia. Barrande was already familiar with the Primordial fossils of the United States and Canada and in 1860 had presented a paper about them before the Geological Society of France. Agreeing with the conclusion of Emmons that the Taconic system was older than the Potsdam sandstone at the base of the New York system, Barrande said that the fossils of Parker's farm in Georgia township, Vermont, were undoubtedly of the age of his "First or Primordial fauna," and much older than those of the Olenus zone, which was correlated with the Potsdam sandstone. It was Barrande's papers published between 1860 and 1862 and his letters to Billings and Jules Marcou that confirmed the work of Logan and Billings, and established the age of the fossils of the Taconic system as being older than anything in the New York system. These results of Barrande and of Billings must have warmed the heart of the exiled Emmons, who died in North Carolina late in 1863.

In 1883, Charles D. Walcott began his remarkable and highly successful search for fossils in the Cambrian strata of the Taconic Mountains of eastern New York and in western Vermont, a search that culminated in 1888 in his paper, "The Taconic system of Emmons." Here and elsewhere he recorded the many places at which he or others had found Cambrian fossils, and laid the foundation for all subsequent historical geology of the region.

In 1913, Arthur Keith, of the United States Geological Survey, who had since 1909 been mapping the geology of the Taconic Mountains in southern Vermont and eastern New York, extended his work into northwestern Vermont. In 1921 he wanted paleontologic help, and invited the writer to accompany him. In the course of a motor trip over the geology from Rutland north to Highgate Falls, the writer became so favorably impressed with Keith's methods and views that he insisted that his major results should be published in the *American Journal of Science*. This paper appeared in February, 1923, and in 1932 the same author brought the

matter up to date. Keith's work, joined with that of Logan and Billings and Walcott, has furnished the key that will unravel the detail of the complicated geology west of the Green Mountains. The fossils collected led to a more detailed stratigraphy, and this information, in turn, to a more correct understanding of the exceptional structure of the region. By pursuing these methods, Keith (1923) came to see that the Champlain synclinorium showed "older and lower rocks on the east on account of the general westward overlap and nondeposition of the older beds." But the orderly succession of the formations "is further greatly disturbed by north and south thrust faults with great westward movement. The two principal faults are the Champlain fault, near the east shore of Lake Champlain, and the Green Mountain border fault, along the west foot or border of the Green Mountains." Between these major faults "there are from three to seven faults in any single cross section, and the width of the belt between the faults is only from three to ten miles" (p. 104). Due to these facts it became clear that the formations could be understood only by arranging them into "three sequences, originally far apart east and west . . . now jammed together along great thrust faults" (p. 103). These sequences are the *Western*, west of the Champlain fault, followed to the east by the *Central*, and the *Eastern*.

The purpose of the present paper is to set forth enough of the stratigraphic detail and the fossil evidence to fix chronologically the various geological formations and their sequence. Since 1921 the writer has made ten trips to northwestern Vermont, accompanied at different times by Keith, P. E. Raymond, B. F. Howell, C. O. Dunbar, L. M. Prindle, R. W. Sayles, C. R. Longwell, and Adolph and Eleanora Knopf, with whom the stratigraphic succession and the fossils have been discussed. Some of the results attained are here presented in abbreviated form for the benefit of the visiting geologists at the International Geological Congress of 1933 who will join in the excursion up the Hudson Valley, into the Adirondack Mountains, across Lake Champlain into western Vermont, thence across the Green Mountains and down the Connecticut Valley. A longer paper, with maps, will appear two years hence in the biennial report of the Vermont State Geologist.

The Extraordinary Limestone Conglomerates.—The most difficult of all the formations in northwestern Vermont to interpret are the limestone conglomerates of local distribution

and origin. Three of these are basal conglomerates, one (Rugg Brook) at the base of the Middle Cambrian, one (Mill River) at the base of the Upper Cambrian, and a third (Corliss) beneath the Ordovician. A similar conglomerate occurs in the Upper Cambrian of the Highgate gorge section; this, however, may not be a basal conglomerate but an intraformational one (holds the time of the Mill River), and is discussed in another place. The Corliss conglomerate has great blocks of limestone that originally were parts of local lenses or reef limestones in the Lower Cambrian (Parker) or Upper Cambrian (Highgate) slate, and that measure from 20 to over 120 feet in length. These lenses grew on the mud bottoms of the Cambrian sea. Some of these limestone lenses in their entirety are now also found in the basal conglomerates of the Ordovician. How did these great masses get into their present, younger geological position? The guesses have been many and highly varied.

The best argued paper dealing with similar phenomena is "Paleozoic submarine landslips near Quebec City," by E. B. Bailey, L. W. Collet, and R. M. Field (*Jour. Geology*, vol. 36, 1928, pp. 577-614), which interprets the Quebec limestone conglomerates as submarine bottom slippings caused by earthquakes in a tectonic belt. This explanation may apply in part to the intraformational conglomerate below the Highgate above mentioned, but does not account for the basal conglomerates of the Upper Cambrian and the Lower Ordovician, nor for the one beneath the Middle Cambrian. Here these conglomerates are local accumulations at or near the places where the limestone lentils had grown or to which they had slid during the erosion intervals. The encroaching seas pounded most of these lentils to pieces, but others were preserved in their entirety by being piled over with thin-bedded Upper Cambrian limestones picked up by the shallow seas not far from where these conglomerates are now found. In other words, the land over which these seas encroached was uneven, with low ridges of limestone or dolomite, and here and there stood a reef lentil or a dolomite zone. Where there were no ridges of harder material, only a substratum of shale, the invading Upper Cambrian muds (Highgate) came to lie on the Middle Cambrian shale (St. Albans), and the Middle Cambrian shale on the Lower Cambrian shale; and in the case of the Lower Ordovician invasion the muds of the Georgia series were deposited over the Highgate shale. It is only here

and there that we find these local limestone conglomerates between the various mud formations, and they are most common in the line of strike of the thin-bedded limestones of the Gorge formation where it existed or still exists.

Structure.—To make the discussion of the stratigraphy more easily understandable, we must introduce a little more of the structural relations. In general, the structure of northwestern Vermont, according to Keith (1923), is one of rock slices lying at low angles thrust over one another far toward the west from the east. Of folding very little is seen and most of it is restricted to the incompetent shales. The thin-bedded limestones (lower Highgate) and the shale formations “simply rode along on top of the massive rocks below them which transmitted the thrust” (p. 104).

The formations of northwestern Vermont, as already stated, occur in three sequences, two of them being overthrust sheets. The *Western Sequence* lies wholly west of the Champlain fault (“Logan’s Line”) and remains in its original position (see white area of Fig. 1). East of this substratum occurs the thrust mass known as the *Central Sequence*, separated by another fault from the thrust known as the *Eastern Sequence*, which extends to the foothills of the Green Mountains. Of these, only the two first named are discussed in this paper.

The Western Sequence is shown by McGerrigle (1931) also to include a thrust block previously noted by other geologists, namely, the Philipsburg series, mainly of Canada but extending a little into Vermont (see Fig. 1). It is typically developed in Canada and the formations of this northerly-pitching syncline disappear considerably north of Swanton, Vermont. Hence, the Champlain fault bounds both the Philipsburg and the Central Sequence on the west.

All of the rest of westernmost Vermont embraces the nearly horizontal and undulatory Lower and Middle Ordovician formations that underlie Lake Champlain and outcrop along its eastern and western shores. It is usually more or less highly fossiliferous. Logan and Billings (1863, pp. 274 and 855) were the first to describe the northern area in Vermont and named the western or Ordovician strata the *Highgate Springs series*. McGerrigle says it has here “suffered sharp folding and occasional faulting and thrusting within itself” (p. 183).

North of Highgate Springs the Western Sequence is abundantly fossiliferous, with the Chazy, Black River, and Trenton

limestones represented. Logan also worked out the structure and dated some of the formations in the Fonda quarry shortly to the south of Swanton Junction. Here the Trenton, Black River, and probably the Chazy limestones, occur "in an inverted attitude." The strata dip eastward, with the greatest overturn at the east. There is between 60 and 70 feet of thin-bedded black limestone, with *Calymene senaria* and *Trinucleus concentricus*. Over these lie 80-100 feet of "thick bedded black limestones, with *Columnaria alveolata*, and *Orthoceras Bigsbyi*. After a very small interval of concealment, these are followed by about sixty feet of grey calcareous sandstone, on which rest about 200 feet of dove-grey limestone," thought to be of Chazy age (p. 280). The overlying strata are the overthrust Mallett dolomite of the Central Sequence, and Logan regarded them as "greatly the older of the two" (p. 281). In other words, the Lower Cambrian lies on the Middle Ordovician.

LOWER CAMBRIAN

The Lower Cambrian of northwestern Vermont may be an unbroken sequence beginning with the Monkton quartzite, which is followed, in turn, by the Winooski, Mallett, and Parker formations. The first two of these divisions were united in the old reports under the name of Red Sandrock, and wrongly correlated with the Medina sandstone at the base of the Silurian.

Monkton Quartzite (Keith, 1923). The type locality for the Monkton quartzite is in the township of Monkton, 20 miles south of Burlington, and the formation continues in its typical development to the township of Colchester, about 10 miles north of the city. Still farther north, the formation is more or less absent, due to overthrusting. In its typical development the Monkton is a red formation "varying from reddish-brown through brick-red and purple to light shades of red, pink, buff, and white" (p. 107). Some red or purple shales are interbedded and toward the top gray or pink dolomites are introduced. The only known fossils are fragments of the trilobite *Ptychoparia adamsi*, which ranges, however, through the entire Lower Cambrian.

The Monkton formation originated as fine sand, with very little mud and dolomite, deposited in a very shallow sea with a wide littoral zone; the sandy-beach nature explains why so few fossils are preserved in it. The thickness is unknown, as

FORMATIONS OF THE CENTRAL SEQUENCE.

No younger formations known in Central Sequence.

Lower Ordovician { Georgia slate series, 2000-3500 ft.

2000-3500 ft. } Corliss limestone conglomerate, 0-40 ft.

Break and slight orogeny (Vermont).

Upper Cambrian { Highgate slate, 500-600 ft.

500-700+ ft. } Mill River limestone conglomerate, 0-15 ft.

{ Highgate slate, 0-300+ ft. Highgate alternations of thin-bedded limestone and slate, 85 ft.

(In Highgate gorge)

{ Upper Highgate slate, 220+ ft. Lower Highgate limestone and slate, 85 ft.

{ Upper Gorge intraformational conglomerate zone, 80 ft. Middle Gorge thin-bedded limestone, 140 ft. Lower Gorge dolomite, 80 ft.

Highgate slate, 500 ft.

Milton dolomite, 700 ft.

Break, much of the early Upper Cambrian absent.

Middle Cambrian { St. Albans slate, 0-230 ft.

50-230 ft. } Rugg Brook dolomite conglomerate, 0-20 ft.

Break, most of Middle Cambrian time unrepresented.

Lower Cambrian { Parker slate, 200-300 ft.

1380-1800 ft. } Mallett dolomite and quartzite (?300 ft.), 630-800 ft.

{ Winooski dolomite and marble, 250-400 ft.

{ Monkton quartzite, 300+ ft.

Thrust contact.

Basement unknown.

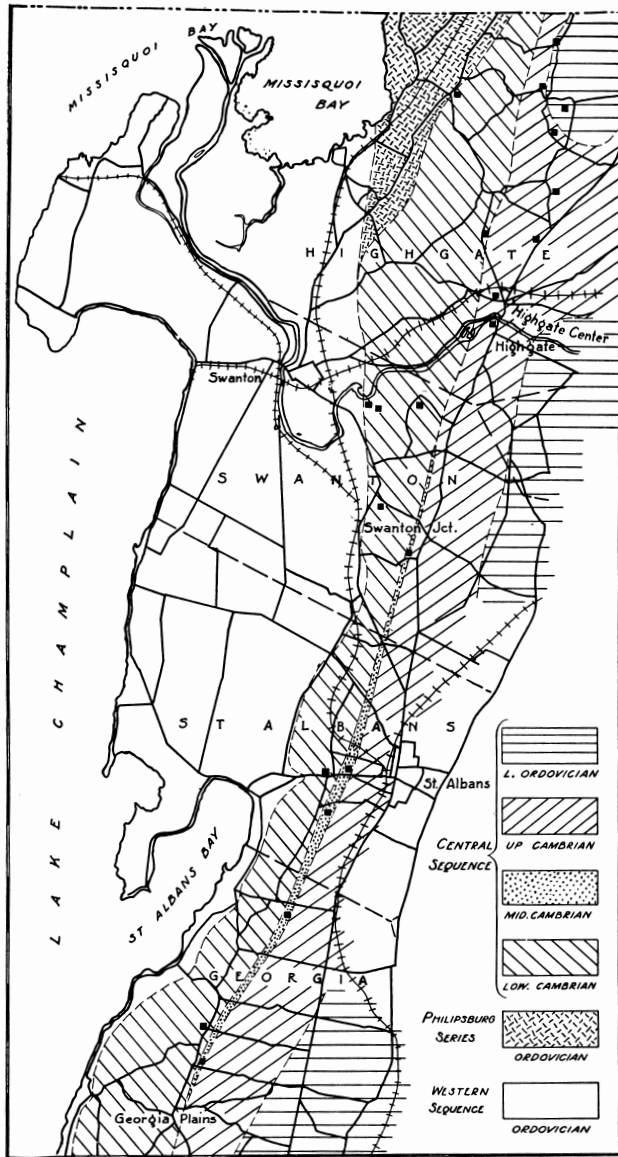


Fig. 1. Sketch map showing roads and railways of northwestern Vermont. Eastern Sequence not shown. Black squares, localities for fossils. Logan's Line (Champlain fault) is at the western edge of the shaded area. Three sides of the frame indicate the miles; at the north is Canada. Based on map of the St. Albans and Milton quadrangles, greatly reduced.

the formation is basally cut off by a thrust fault, but at least 300 feet has been measured by Keith in Colchester township. Northward this formation is either reduced in thickness by thrusting, or loses more and more of its sandy nature and, changing into dolomite, grades into the succeeding Winooski dolomite.

In the Phelps stone quarry in South Burlington the Monkton is a fine-grained red quartzite with some interbedded white or pink thin-bedded layers. Many of the shale partings show sun-cracking and rain-pitting.

Winooski Dolomite and Marble.—This is probably the oldest name for a Vermont formation, due to certain of its mottled dolomites having long been used for marble and floor tilings, also known in the trade as the Swanton mosaic or mottled marble; it has been quarried near Swanton for nearly a century. The type locality for the formation is along the Winooski River and Falls north of Burlington. The formation consists of pink, red, mottled, and gray hard dolomites, more or less siliceous and with beds of quartzite. Its chief internal character is the wavy nature of the thin red mud layers, seen best on old weathered surfaces. The mottling of the marble is due to the shallowness of the sea and the rippled nature of the bottom, which caused the white magnesian limestone to form in the hollows or to be torn up by the storm waves. The thickness is variable between 250 and 400 feet (12 miles north of Burlington).

In the marble beds are rare pockets with *Salterella pulchella* (thought to be primitive cephalopods); and Edson reports having seen in addition *Ptychoparia adamsi* and the brachiopod *Nisusia festinata*. West of Parkers Cobble Walcott found *Obolus crassus*, *Botsfordia caelata*, *Hyalithes americanus*, *H. communis*, and *Hyalithellus micans*.

Mallett Dolomite (Keith, 1923).—The type locality is on Malletts Bay of Lake Champlain 5 miles north of Burlington, where the formation is 800 feet thick. It continues north across the Canadian boundary for several miles. This series consists of massive, light and dark gray sandy dolomites, with as much as one-sixth of the formation made up of fine-grained quartzites that are more or less cross-bedded. "The sand in these beds consists of glassy, rounded quartz grains which stand out in relief on weathered surfaces" (p. 110). This same kind of sand, however, is also seen in all subsequent dolomites and limestones, and in the paste of the limestone con-

glomerates as well. It appears to be wind-blown sand originally derived from pre-Cambrian lands, subsequently weathered out of the Lower Cambrian deposits, and reworked into the younger Cambrian and Ordovician formations. Another feature of the Mallett sandstone layers is their rippled nature, along with channeling and the introduction of well-rounded or angular pieces of dolomite up to 18 inches across. We again see here evidence of very shallow seas and the action of tidal currents.

Shale beds are rare in the Mallett. North of St. Albans the thickness of the formation is highly variable between 100 and 300 feet; this condition appears to be due, however, to local thrusting. The contact with the overlying Parker shale "is usually sharp, but a few sandy beds in each formation seem to make a rather poor transition between the two" (p. 110).

Fossils are exceedingly rare in the Mallett dolomite and most of those recovered are out of decomposed sandstones. East of Highgate Springs Walcott reports *Palaeophycus incipiens*, *Paterina swantonensis*, *Nisusia festinata*, *Scenella varians*, *Ptychoparia adamsi*, *P. teucer*, and *Olenellus thompsoni*. West of Parkers Cobble Walcott found *Paterina swantonensis*, *Hyolithellus micans*, *Ptychoparia adamsi*, and *Olenellus thompsoni*.

Parker Slate (Keith, 1932).—Marcou (1861) called this formation Georgia shale, and Walcott (1886) did the same. Keith (1923) renamed it Colchester shale but in 1932 abandoned the term "because of the poor exposure of the formation in Colchester." It should all the more be abandoned for the reason that the Colchester area has as yet yielded no fossils. In 1932 Keith changed the name to Parker shale after Parkers Cobble on the old Noah Parker farm, the type locality for most of the fossils described by Walcott. The best section is exposed around Parkers Cobble and for some miles to the north along the strike of the formation. In this region the thickness is around 300 feet. Parkers Cobble is 2 miles N. 60° W. of Georgia Center.

The Parker farm, now owned by Mr. Montcalm, was the second place in North America to yield Lower Cambrian fossils. It was Noah Parker himself who gave specimens of *Olenellus thompsoni* and other species found in his road-metal quarry to Rev. Zadock Thompson, and the latter sent them to James Hall, who described them in 1859 but erroneously

regarded them as of the *Olenus* fauna at the top of the Cambrian.

The Parker formation is dominantly one of dark blue micaceous slate with some flaggy sandstone present in the lower part. In the upper Parker there are also local zones of dolomites, the thickest one, about 30 feet, capping Parkers Cobble.

To the north, on Martin Conner's farm, and beneath the Middle Cambrian, occur 70-100 feet of additional micaceous slate and thin-bedded dolomites. These are also thought to be of the Parker formation, since they underlie the Rugg Brook conglomerate, though no fossils have been found in them. In the township of Swanton these local dolomites are more common than elsewhere.

In addition, the Parker slate has local reef limestones (bioherms) "consisting of massive blue marbled limestone, sharply separated from the slate. They are best shown two miles southeast of Swanton, where two of them are surrounded by gray slate. The lenses measure 100 by 60 feet and 105 by 75 feet. . . This limestone very closely resembles some of the boulders in the later conglomerates, and even a whole lens may have become a boulder" (Keith, 1923, p. 111).

At several localities the basal few feet of the Parker slate are conglomeratic, with small inclusions of the older Mallett dolomite, which on exposed surfaces weather out, leaving holes in the slate. Rarely there is a thick basal conglomerate of dolomite blocks. A remarkable occurrence of this kind was noted about 2½ miles northwest of Highgate Center and back of the public school. Here at the top of the Mallett formation is a conglomerate about 20 feet thick which appears to be the basal deposit of the Parker slate, eroded away at this locality but occurring shortly to the east. The conglomerate is composed of angular blocks of all sizes up to 6 feet across, with all of the pieces derived from the underlying Mallett dolomite.

The thickness of the Parker slate is highly variable from place to place, because it is the terminal formation of the Lower Cambrian and has undergone much erosion during the following land interval. The next sea invasion is that of late Middle Cambrian time (St. Albans).

The Parker slate is the only one of the Lower Cambrian formations that is in places richly fossiliferous, but good material is always hard to get because of the metamorphism.

On the Parker farm, bedding and cleavage are alike and most of the fossils collected for Walcott were obtained here through quarrying in two different places. From one place or another the following species have been described from the Parker slate: *Palaeophycus incipens*, *P. congregatus*, *Dactyloidites asteroides*, *Rustella edsoni*, *Micromitra (Paterina) bella*, *Kutorgina cingulata*, *Nisusia orientalis*, *N. festinata*, *Microdiscus parkeri*, *Mesonacis vermontana*, *Olenellus thompsoni* and var. *crassimarginatus*, *Paedumias transitans*, *Olenoides marcoui*, *Bathynotus holopyga*, *Ptychoparia adamsi*, *Acrocephalites (?) vulcanus*, *Protypus hitchcocki*, and *Corynexochus capito* (formerly wrongly identified as *Protypus senectus*).

On the northeast side of Parkers Cobble, Howell found loose a small piece of rotten dolomite that has *Archagnostus walcotti* ? MS. and *Corynexochus capito*. It is not surely known that these fossils are out of the upper dolomites. The last-named fossil is, however, certainly a Lower Cambrian guide species, and as for the agnostid, it is now known that these later Cambrian trilobites make their appearance in both America and Europe in the latest Lower Cambrian.

In a road-metal quarry 1 mile N. 15° W. of Highgate Center was found in the uppermost Parker slate the oldest known graptolite, *Dictyonema schucherti* Ruedemann MS. Higher, there is an erosional unconformity, and in the basal intraformational conglomerate of the Upper Cambrian occur *Acrothele*, and commonly *Acrotreta sagittalis taconica*. The conglomerate is followed at once by the massive Upper Cambrian dolomite (lower Gorge) with all of the Middle Cambrian absent. Therefore, there is a great stratigraphic hiatus at this place; how much of the Parker formation is removed can not be told, but apparently considerable. It is, consequently, all the more interesting to note the early appearance of the graptolite, the next record being in the latest Cambrian.

MIDDLE CAMBRIAN.

Paleontologists had long been looking for the Middle Cambrian in northwestern Vermont, but had failed to find anywhere in the St. Lawrence geosyncline any evidence of the Paradoxides or other Middle Cambrian faunas. The surprise was therefore great when a local collector, Mr. G. E. Edson, of St. Albans, found such forms in the outskirts of that city, and still greater when Walcott (1908 and 1910) determined the

fossils to be of the Atlantic realm and of the Acadian geosyncline. How this sea got into northwestern Vermont from the Atlantic source remains an unsolved puzzle.

The Middle Cambrian of Vermont consists of the St. Albans slate and its basal Rugg Brook dolomite conglomerate, which Keith thinks should be regarded as a separate formation.

St. Albans Slate.—The type locality for the St. Albans formation is Adams pasture on the western outskirts of the city. It was for the strata of this place and the wider area about St. Albans that Marcou (1861) founded his St. Albans group, a term to which Walcott directed attention in 1891 (p. 281) and which he used in 1910. As we now see, the term embraced not only Middle but Upper Cambrian (Highgate) as well. Howell, in 1929, restricted the term to the Middle Cambrian portion of the original definition.

Mr. Edson found Middle Cambrian fossils in Adams pasture both in the Upper Cambrian limestone conglomerate (Mill River) and in loose blocks of slate on either side of it. State Geologist G. H. Perkins, learning of these specimens, borrowed them to show to Walcott, who pronounced them to be of the *Paradoxides* fauna. This discovery was announced by Perkins in his Biennial Report for 1907-1908. Keith, in preliminary mapping of the area in 1923, did not know what to do with this find, but in the summer of 1922 Howell had relocated Edson's locality and found more than 100 specimens of this Middle Cambrian fauna, most of them in situ. In September, 1924, Keith, Prindle, and Schuchert found two other localities where Middle Cambrian fossils occur in place. The first of these was about 1½ miles southwest of St. Albans on Martin Conner's land, and the next 4 miles northeast of the city near the Rockledge estate. This, then, fixed the presence of Middle Cambrian beneath the Upper Cambrian slate (Highgate) in northwestern Vermont.

The St. Albans formation consists almost wholly of blue-black sandy micaceous slate; rarely a bed is very limy, making impure limestones, and there are also thin layers and lenses of sandstone and an occasional dolomite up to 6 feet thick. The greatest thickness, 250 feet, is in the Mill River-Rugg Brook area, 3 miles to the southwest of St. Albans. Farther south the formation thins away rapidly, but 1 mile south of Parkers Cobble 57 feet of the slate is still present, bounded by the Rugg Brook and Mill River conglomerates. In Adams pasture the thickness appears to be greater than 200 feet,

the uncertainty being due to lack of exposures. To the northwest of Rockledge the thickness is about 60 feet, and this, or a smaller amount, continues north for a few miles; but the formation is absent in the well-exposed section of the Highgate gorge. The varying thicknesses are due to the erosion interval following the deposition of the St. Albans slate. The accompanying map (Fig. 1) shows the distribution of the St. Albans formation.

The St. Albans slate is underlain basally in at least three places by the *Rugg Brook dolomite conglomerate*, which weathers a salmon color and which is usually less than 20 feet thick. These three localities are on Rugg Brook, on Conner's farm, and near Rockledge. The formation name is a new one, and the type locality is on Rugg Brook, less than 3 miles to the southwest of St. Albans. The dolomite blocks, up to 2 feet across, are out of either the Parker or the Mallett formation, and rarely there are also pieces of the Winooski red dolomite. The paste is the usual round-grained sand cemented by dolomite. The upper limit of the St. Albans slate is locally easily ascertained when the Mill River limestone conglomerate is present, making the basal member of the Upper Cambrian (Highgate). When this conglomerate is absent, it is very difficult to define the upper limit of the St. Albans slate, but usually the younger Highgate is so decidedly banded as to help to differentiate the two slate series. No fossils are known in the Rugg Brook conglomerate.

The fauna of the St. Albans slate (about 20 species) is characterized by the trilobites *Centropleura* (related to *Paradoxides*) and *Elyx*. Neither genus is known elsewhere in North America. The common fossils are *Agnosti* and *Lingulella*. The entire fauna marks the time as of latest Middle Cambrian.

From the facts recited above, it is seen that there is a long time break between Middle and Lower Cambrian, and that this interval represents a loss of record, the length of which is equivalent to the early and middle portions of the Middle Cambrian.

Howell will, in the near future, describe the fauna of the St. Albans formation, most of which is new, in the Biennial Report of the Vermont Geological Survey. The unpublished species are: *Lingulella vermontana*, *Spinagnostus franklinensis*, *Grandagnostus vermontensis*, *Hastagnostus angustus*, *Armagnostus megalaxis*, *Conoides edsoni*, *Champlainia recti-*

margo, *Micragraulus decorus*, *Solenopleura vermontensis*, *S. franklinensis*, *Elyx longæ*, *Elyx* sp., *Centropleura vermontensis*, *Paradoxides* sp. (very rare), and *Ptychoparia* (?) *convexa*.

UPPER CAMBRIAN.

The presence of Upper Cambrian in northwestern Vermont was suspected since at least 1861. In 1886 Walcott found a few fossils of this age near Highgate Center and elsewhere, but even then the evidence was not fully convincing. In 1921 Keith found fossils in lower Highgate limestone in the village of Highgate Center, which Walcott pronounced to be Upper Cambrian. Finally, on July 5, 1922, Keith, Sayles, and Schuchert found in the Highgate gorge a series of thin-bedded limestones, a few of which were replete with comminuted trilobites that demonstrated the presence of a varied Late Cambrian fauna. Most of this material has been described by Raymond (1924).

The Upper Cambrian is the most varied in fauna and lithology of the three Cambrian divisions. In the near future it will become the type area for interareal correlations in all eastern North America, because of its many fossils, not all of which by far have been collected or described.

In three places the Upper Cambrian has a basal limestone conglomerate (Mill River). When this local member is not present, as was said earlier, it is very difficult on lithologic grounds to distinguish the Highgate slate from the Middle Cambrian.

The Upper Cambrian occurs in three facies. The most prevalent one is the youngest division, the banded Highgate slate. South of Milton, the older Upper Cambrian occurs in massive-bedded dolomites (Milton) that pass unbroken into the younger regulation Highgate slate. About Highgate Falls and to the north, the facies is again very different, since here there is a lower massive dolomite, followed unbroken upward by a thick series of thin-bedded dark blue limestones, magnesian limestones, black slate, quartzites, and intraformational slabby conglomerates, all of which are combined into the Gorge formation (Missisquoi of Keith, in part). Higher are thick limestone conglomerates with blocks up to 10 feet across; these are also regarded as of the Gorge formation. Then follows a series of alternating impure limestones and shales in thin beds of about equal thickness (lower Highgate), and

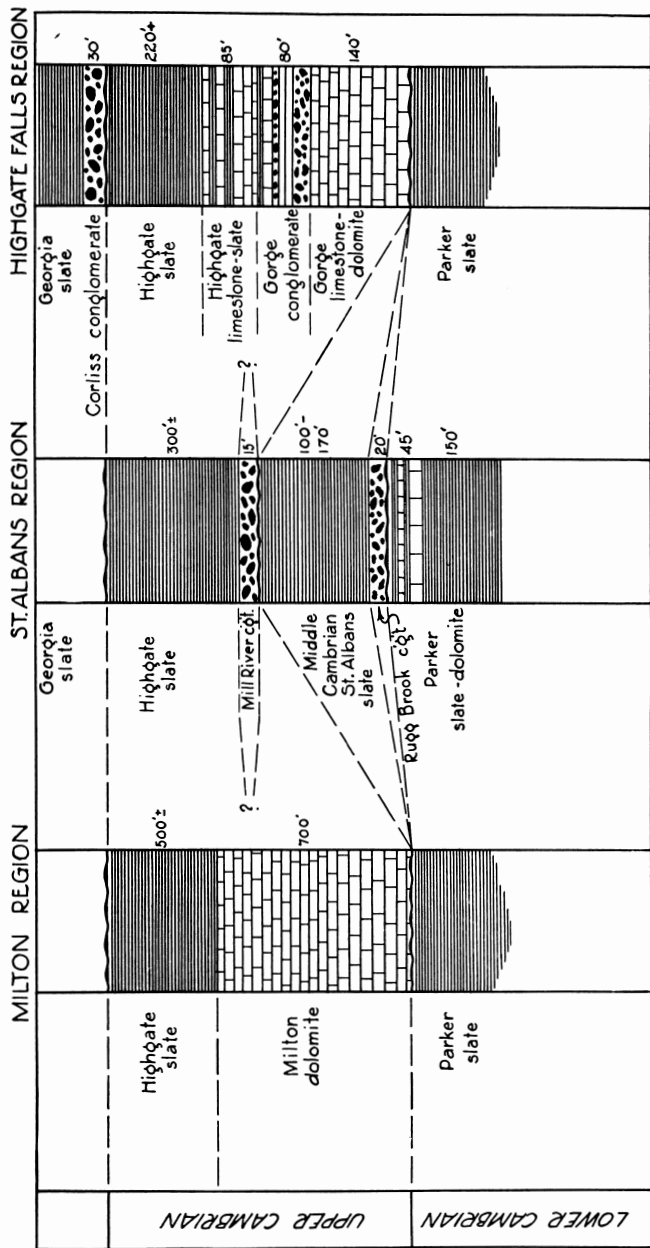


Fig. 2. Three sections to show the relations of formations to each other in the area of Middle Cambrian outcrops. Not drawn to scale.

these pass into the regulation banded Highgate slate at the top of the Upper Cambrian. In places the banded slates are absent, and this appears to be due to subsequent erosion. We will now take up these various members in more detail, but the reader is advised first to study Fig. 2.

Milton Dolomite.—The typical area for the Milton dolomite of Keith (1923) is in Milton township “about three miles west of Milton village. The formation consists almost entirely of massive dolomite,” and appears to be the oldest part of the Upper Cambrian in Vermont. It lies upon the Parker slate and the two formations are separated by an erosion interval. The Milton varies in color “from dark bluish-gray or steel-gray through light gray to buff . . . Beds of sandy dolomite are fairly common.” The formation has much scattering black chert which stands out on weathered surfaces, along with “white quartz knots, or geodes with quartz crystals” (pp. 112-113). There are also thin local wavy layers of *Cryptozoon*. Another peculiarity is the large content of intraformational angular dolomite and dolomitic sandstone pebbles. The greatest thickness of the formation, according to Keith, is 700 feet, but the writer thinks the amount may be much less.

In the original account of the Milton, Keith regarded it as of Upper Cambrian age though he had found no fossils in this formation. Ulrich was the first to find these in the typical area during the summers of 1930 and 1931, and they confirmed Keith's reference. In his later field work, Keith continued more detailed mapping north to the Canadian border, and, finding so many similar dolomites, confused some of them, and in his paper of 1932 applied the term “Milton dolomite” to a much thinner dolomite (about 30 feet) in the upper part of the Lower Cambrian (Parker). All of these Lower Cambrian “Miltons” must be excluded and the term restricted to the original intention, namely, to the dolomites west of Milton and of Upper Cambrian age, and to their equivalents.

In the summer of 1932, Longwell, Dunbar, and Schuchert studied the Milton dolomites $3\frac{1}{2}$ miles in a straight line southwest of Milton village and about $\frac{3}{4}$ of a mile west of the landmark Cobble Hill (860 feet high). It was in these dolomites that Ulrich, Bridge, and Ruedemann found their silicified fossils, and many more were obtained by the writer subsequent to the visit mentioned above. These collections yielded the following species, nearly all of which are very different from the upper Gorge fauna found to the north of St. Albans.

Brachiopods are the common fossils, such as *Syntrophia* ? *calcifera* and *Huenella* cf. *battis* (rare). Of gastropods but a single specimen of *Sinuopea* was found, and trilobites are also rare, with *Richardsonella* present. None of these species occur in the upper Gorge formation, but we agree with Ulrich that the Milton fossils are of Late Cambrian age, as are also those of the Gorge formation.

At another locality $4\frac{1}{4}$ miles in a straight line southwest of Milton village and $\frac{1}{4}$ mile east of Allen Brook, Ulrich and Bridge, and subsequently Longwell and Schuchert, found in abundance, in a thin bed of a decidedly sandy dolomite, the well-known Upper Cambrian brachiopod *Lingulepis acuminata*. These upper Milton strata are very sandy through a thickness of at least 150 feet, with interbedded sandstone in beds up to 10 feet thick, along with horizons of brecciated dolomite and sandstone in which the angular pieces range up to 18 inches across. This is evidence of shallow waters, and of storm waves, tearing up the bottom.

Above these dolomites and sandstones there follows to the east a long sequence of the banded Highgate slates, which pass beneath Cobble Hill with its capping of older dolomite (this is of the Eastern Sequence in thrust relation), and then reappear along the east base of the hill. The thickness of these slates may be greater than 500 feet.

Mill River Limestone Conglomerate (Howell, 1929).—At three widely spaced localities the Mill River limestone conglomerate is seen to overlie the fossiliferous beds of the Middle Cambrian (St. Albans) directly but with an erosional unconformity. The typical locality makes a bluff to the east of Mill River about $3\frac{1}{2}$ miles southwest of St. Albans. Another place is in Adams pasture on the western outskirts of St. Albans and the third is to the west of the Rockledge estate 4 miles north of the city.

In general, the Mill River conglomerate resembles the younger Corliss conglomerate (Swanton of Keith, 1923), but a close examination shows that it has none of the slabby dark blue fossiliferous limestones of the Gorge formation, which are so characteristic of the Corliss conglomerate. It is composed almost wholly of angular fragments of the bluish-white limestone lentils that formed in the Lower Cambrian (Parker slate). Some of these blocks are 20 feet across. There are also, rarely, small angular pieces of Mallett or some other dolomite of the same nature, up to 8 inches long. Fossils of

St. Albans and even of Lower Cambrian age have been found in this conglomerate in Adams pasture and at this place there are also white basal sandstones made up of the usual reworked, wind-blown sand.

The thickness of the Mill River conglomerate is everywhere less than 15 feet and in places less than 5 feet.

Highgate Slate.—This formation was named by Keith (1923). It "extends from Canada into the town of Milton, a distance of 25 miles. Its principal development is in the township of Highgate, where it forms a broad area" (p. 114). The formation "consists in the main of dark gray or black slate, usually well banded and with pronounced cleavage" (1932, p. 375). There are also beds of sandy dolomite usually a foot or so thick, though locally in the higher Highgate they may be 10 feet thick. From south of Highgate Falls to the Canadian border the lower part of the Highgate slate consists of interbedded thin layers (1 inch up to several inches) of blue limestone, gray dolomitic beds, and shale, giving the formation a striped character, and, where folded, a picturesque appearance. Locally, the Highgate becomes a thin-bedded gray limestone series with very little shale, and such zones are from a few feet up to 30 feet or more thick. "Strong folding has magnified the apparent size of the formation, which seems to be 500-600 feet thick" (Keith, 1932, p. 376).

The banded nature of the Highgate slate was best seen where the highway was widened in 1922 going up the little hill from South Gore school. Here the cleavage is at right angles to the bedding of the dark slate, and it showed in a very striking manner the extraordinary banding, consisting of thin, yellowish-white laminae of fine silt or clay. There may be as many as seven silt bands in the space of three-eighths of an inch. A specimen of this slate was given to W. H. Bradley, of the United States Geological Survey, who informed the writer that this banding is not a case of varves, as Keith and Sayles had thought, but of lamination due to storm waves or current action.

The Highgate slate usually makes the top of the Cambrian in Vermont, and it normally overlies either the Milton or the Gorge formation. Curiously, however, throughout the area of the Middle Cambrian the bottom of this slate directly overlies the latter, the Gorge formation being absent here. On the other hand, from a mile or more south of Highgate to

the Canadian border the Highgate slate is underlain by the Highgate thin-bedded limestone (lower Highgate), followed by the Gorge formation; south of Georgia Center, however, the Highgate slate rests without apparent break on the Milton dolomite. These occurrences are interpreted as being due to warping at the close of the Upper Cambrian, producing a high area during late Cambrian time from Georgia Center north to near Highgate Falls. Over this region no Milton and only a part of the Gorge formation, was deposited, but the Highgate slate is present and lies directly on the Middle Cambrian (St. Albans slate). When the Lower Ordovician sea invaded this part of Vermont, it pounded to pieces what remained of the Gorge formation, along with, here and there, a Lower Cambrian or Highgate limestone lentil; accordingly, it was this material that was collected into local piles by the waves and currents to make the Corliss conglomerate. In other words, the Gorge formation of the north is, at least in part, the equivalent of the Milton dolomite of the south; originally it was a case of change in facies from massive dolomites into the northern thin-bedded dolomites and limestones interbedded with black dolomitic shale, making the Gorge formation.

Limestone Reefs or Bioherms.—Marble-like oval or mound-shaped growths are often seen in the Highgate slate, usually varying in longest diameter from 15 feet to upward of 100 feet, and in thickness up to 10 feet or more. They are often conspicuous white objects in the landscape. One on the Rockledge estate measures $170 \times 110 \times 8$ feet; and another mass 90×50 feet may be a part of it; 4 miles southwest of St. Albans there are four in close association, the smallest 15×10 feet and the largest $140 \times 120 \times 10$ feet; nearby, one in the forest is 200 feet long and 80 feet wide; and $1\frac{1}{2}$ miles north of Highgate Center is the largest example, about 600 feet long. They occur throughout the Highgate slate, most commonly in the upper half, and the largest one is in the zone of the thin-bedded Highgate limestones. All are homogeneous masses of a light blue limestone that show no bedding. They appear to be of algal growth in thin sheets or in vertical columns, and in the hollows of a reef there may occur comminuted trilobites. Four miles southwest of St. Albans good specimens of a new genus of trilobites were collected in one of these lentils and will be described by Raymond. These

organic growths have recently been named *bioherms* by Cumings (1932).

Some of these reef limestones are enclosed in their entirety in the basal Ordovician (Corliss) conglomerate, and others were broken into angular masses of all sizes.

Lower Highgate Fauna.—As long ago as 1886 Walcott obtained fossils from the Highgate formation. He describes *Protorthis wingi* as occurring $\frac{1}{4}$ mile south of Highgate Falls (1912, p. 743). This is a minute orthid, and the writer has collected it in limestones in a roadside quarry about $1\frac{1}{4}$ miles south of the Falls.

At various places about Highgate Center and to the north, the writer and others have collected trilobites that have been described by Raymond (1924). These come from the lower or thin-bedded limestone part of the Highgate formation. There are eleven species in the following genera: *Agnostus*, *Hypagnostus*, *Leptopilus*, *Cholopilus*, *Leiostegium* (2 spp.), *Marywillia*, *Lloydia* (2), *Hemigyraspis*, and *Pilekia*.

Of these species, only two occur below in the Gorge formation, namely, *Lloydia seelyi* and *Marywillia triangularis*. "On the other hand, the most common species, *Leiostegium puteatum* and *Pilekia extenuata*, belong to genera which are characteristic of the Lower Ordovician, as does *Hemigyraspis*. The specimens of *Lloydia saffordi* are large and closely comparable to those found in the Beekmantown at Philipsburg, Quebec: and *Cholopilus vermontanus*, as well as *Lloydia saffordi*," occur in the equivalent formation, the Georgia of Keith. "So far as can be judged from the trilobites . . . the Highgate would be termed Ordovician rather than Cambrian but would be placed about on the border between the two" (Raymond, 1924 A, p. 200). The field relations, however, show unmistakably that the Highgate lies beneath the Lower Ordovician, and furthermore, that the two formations are separated by an orogenic time and erosion interval that removed considerable of the higher Highgate series (Vermont orogeny).

Highgate Falls Sequence.

At Highgate Falls beneath the highway bridge occur massive dolomites in a low arch showing about 15 feet of thickness and making the top of the falls and dam. Downstream or west of the falls there is more of the same kind of dolomite but in a greatly disturbed condition and faulted off at the

Highgate slates below. They are all of a thrust series of thin- and thick-bedded gray dolomites, rarely an intraformational dolomite conglomerate, and thin zones of black slate. A part of the nearly horizontal thrust plane is clearly visible for several hundred feet along the north bank of the river. The age of these dolomites is not proved by any fossils, but as their lithology is very much like that of the dolomites to the west at the base of the Upper Cambrian, it is believed that they are of the same age, namely, lower Gorge.

Downstream, and structurally beneath these upper dolomites, occurs the most varied and most highly fossiliferous, and, therefore, the most interesting, Upper Cambrian exposure, not only of northwest Vermont but of all eastern North America. The descending sequence, including over 600 feet of strata, somewhat generalized, is as follows:

Upper Highgate banded dark-blue slate with infrequent thin beds of dolomite, and, toward the base, limestone and rarely limestone conglomerate. Thickness about 220 feet with the top faulted off.

Lower Highgate interbedded thin zones of limestone and shale with some limestone conglomerates. About 85 feet thick.

No apparent break occurs in this part of the section, even though the nature of the next older zone appears to call for a break in deposition at their base. If there is no break here, some convulsion seemingly took place during the time these conglomerates were being laid down, possibly an earthquake that caused a rock slide on the sea bottom. One does not, however, see much evidence of crumpling of the strata such as submarine rock sliding would surely make. Possibly the area was being faulted, resulting in either submarine cliffs or an island that the sea undermined, toppling the dolomites into an intraformational conglomerate. That crustal movement was going on at the time when these conglomerates were forming, is attested by the change from dolomites into muddy and sandy deposits, along with the making of the many zones of intraformational slabby limestone conglomerates. The entire sequence of the Upper Cambrian here ranges from wholly dolomitic deposits through a long transition of thin-bedded dolomites, limestones, quartzites, and intraformational conglomerates (which become very frequent in the beds immediately beneath the great conglomerate zone) into a final long series of banded mud deposits, the typical Highgate slates.

The extraordinary degree of banding in these slates is indicative of shallow seas, and the disturbed depositional condition is seen in the constant introduction of the dolomitic and sandy silts that make the innumerable light-colored bands in the dark blue shales of the Highgate slate. Furthermore, crustal unrest is also shown in the fact that where the younger Corliss limestone conglomerate is best developed, there the Gorge formation is absent. The latter formation apparently stood above sea level when the Lower Ordovician transgression took place, and this sea pounded most of the Gorge formation into the Corliss conglomerate.

Gorge Formation.—This unsatisfactory (for want of a local geographic term) new name is applied to all the strata in the Highgate gorge beneath the Highgate formation. As stated earlier, there is no break with the Highgate, nor is there an apparent break anywhere within the Gorge formation. The Gorge formation is naturally divided into three divisions on the basis of the nature of the strata, as follows:

Upper Gorge (Intraformational?) Conglomerate.—Without apparent break, the Highgate thin-bedded limestones continue downward into a layer of small-pebble intraformational conglomerate (1 foot), banded black slate (6 feet), and sandy dolomite (6 feet). Beneath is the upper great conglomerate seen near the electric powerhouse (10-15 feet). Then come thin-bedded dolomites and limestones, shale, and sandy beds (12-15 feet) with an erratic block of gray dolomites 5 feet thick and 10 feet long, succeeded below by massive blue-gray dolomite in five or six beds with intraformational slabby dolomite pieces (15 feet). Lower still is another great conglomerate bed (26 feet), the whole making a thickness of about 80 feet.

The two great conglomerate zones consist of angular blocks of dolomites, limestones, sandstones, etc., of all sizes up to 10 feet across. It should be added here that Keith (1932) correlates these conglomerates with the Mill River. This may be so, but the writer regards them as local intraformational conglomerates and not basal ones as is the Mill River conglomerate.

Middle Gorge Formation (Missisquoi of Keith, 1924).—This division consists of thin-bedded dolomites, limestones, intraformational flat-pebble conglomerates of dolomite and limestone pieces, and black dolomitic slate. In the lower part

are thick beds of sandstone. The richest fossil zones occur in this division. The thickness is 162 feet.

In beds of limestones at three different levels, the middle Gorge formation abounds in fragmented trilobites indicating a late Upper Cambrian age. As these fossils are very different from those of the Milton dolomites (which, however, appear to hold the same stratigraphic position farther south), the name Milton can not be extended to the strata of the middle Gorge.

Keith, in Raymond (1924, p. 137), called this series of beds Missisquoi, but later on that term was seen to have been applied by the Vermont Geological Survey to a formation on the east side of the Green Mountains. It is unfortunate that this very appropriate name can not be used for the strata in the Highgate gorge.

(We may digress here a little to say that 3½ miles north of St. Albans and 5 miles south of Highgate Falls, and beneath one of the finest exposures of the Corliss conglomerate anywhere, is exposed a limited outcrop in situ of the middle Gorge formation with trilobites. This outcrop is the most southern one of the Gorge formation. Raymond identifies here *Agnostus innocens* and *Plethopeltis*. In the conglomerate lies an erratic or moved limestone lentil about 50 feet long and resting directly on the Gorge limestone above mentioned.)

Middle Gorge Fauna.—From the three fossil beds much material has been collected, and Raymond (1924) has described most of it. There are 45 species of trilobites from these three beds and of these 36 proved to be new. These species occur in the following genera: *Agnostus* (3), *Pseudagnostus*, *Pero-nopsis*, *Phalacroma* (2), *Idiomesus*, *Pseudosalteria*, *Phoreotropis* (2), *Zacompsus*, *Onchonotus*, *Asaphiscus*, *Phylacterus* (2), *Blountia*, *Maryvillia*, *Lloydia*, *Plethopeltis* (5), *Stenopilus* (2), *Corynexochus*, *Acheilus* (2), *Apatokephaloides* (2), *Dikelocephalus*, *Saukia* (3), *Richardsonella* (2), *Hungaiia*, *Iliaenurus* (3), *Platycolpus*, *Ptychaspis*, *Keithia*, and *Ambo-nolium*. Of brachiopods, there are *Huenella* n. sp. (related to *H. simon*), *Lingulella* sp., and *Schizambon* n. sp.

These trilobites, Raymond (1924) says, are "distinctly of the facies of the Upper Cambrian of interior North America, as indicated by the presence of *Saukia*, *Dikelocephalus*, and *Iliaenurus*, and the absence of any European animals except *Agnostus trisectus*" (p. 198). They correlate in time best "with the Franconia and St. Lawrence formations" of the

upper Croixian series. There is also considerable similarity between the Gorge fauna and that of the Saratogan formations of New York and New Jersey. Further connection exists with the conglomerate faunas at Levis, Canada. Upon the whole these trilobites of the Gorge are of "the upper part of the Upper Cambrian" (p. 199).

Lower Gorge Dolomite.—Massive dolomite, more or less replete with thin-bedded black dolomitic inclusions, making the whole series conglomeratic. No fossils have been seen in the Highgate gorge. At the base is a massive, intraformational, decidedly conglomeratic dolomite with some blue slate bands, the whole about 8 feet thick, half of which is beneath the river. The entire division has a thickness of about 80 feet.

This same basal conglomerate is again seen 1 mile north in a straight line, and here it is in contact with the Parker slate of the Lower Cambrian, so that we may infer the same contact in the Highgate Falls gorge. For the fossils that occur there in this dolomite, see page 364.

LOWER ORDOVICIAN.

Unconformity Between Cambrian and Ordovician.—A slightly angular unconformity between the Highgate and Georgia series was discovered by Keith in 1922 on the Oliver Grandge farm $4\frac{1}{2}$ miles N. 10° E. of Highgate Center and $\frac{1}{2}$ mile south of the Canadian boundary. Both formations dip from 10° to 15° east. Here the Georgia series, of a shallow syncline, rests with erosional unconformity on the lower Highgate alternations of limestone and slate beneath, and all of the higher Highgate banded slate is absent. One foot above the unconformity occurs an impure limestone that when well weathered yields an abundance of Lower Ordovician fossils.

This same unconformity, but exposed over a wider area, is again seen 1 mile to the north in Canada at the falls of Rock River on Lot 123, where a country road crosses the river. Here the decidedly cleaved Georgia series lies unconformably on the folded and non-cleaved lower Highgate thin-bedded limestone and slate member. The bedding in the Highgate strikes N. 10° E. and dips 20° E. The bedding in the Georgia slate strikes N. 45° E. and dips about 10° S.E., while the cleavage dips steeply (about 45°) S.E. (Longwell).

Five miles south of Highgate Falls the basal Ordovician conglomerate (Corliss) lies on the upper Gorge formation, with its higher part and all of the Highgate series eroded away prior to the introduction of the sea that laid down the Georgia sequence.

Probably the best place to see this unconformity is 1 mile west of Georgia Center, where there is a low arch of the Highgate formation (here there is slate both above and beneath a thick and local dolomite) trending north-south and made at the close of the Cambrian (Vermont orogeny). It was then eroded and the Corliss conglomerate laid across the different beds of the Highgate indicated above. Accordingly, the Georgia slate and the Corliss conglomerate rest on different beds of the Upper Cambrian and the conglomerate has fossiliferous pieces of the older formations. The erosion is, therefore, so considerable, according to Keith (1923, p. 136), "that we must conclude that there was important tilting and perhaps even some folding."

Corliss Conglomerate (of Keith, 1932 = Swanton conglomerate of Keith, 1924).—Locally, beneath the Georgia series lies the Corliss conglomerate, composed, in the main, of small pieces of slabby limestones derived out of the upper Gorge formation. Very rarely have fossils of the Middle and Lower Cambrian been found in it. There are also pieces of a sandy dolomite present and these appear to be of local dolomites in the higher Highgate. Probably from one-eighth to one-fourth of the Corliss consists of large angular pieces of the Highgate limestone lentils up to 10 feet across, and locally the conglomerate has formed around an entire and unmoved lentil, as at Rockledge. The type area for the Corliss conglomerate is at Corliss Ledge, about 5 miles northeast of St. Albans.

The "Swanton" conglomerate makes its appearance, according to Keith (1923), about 8 miles south of St. Albans, and extends with interruptions to near Highgate Falls. "The conglomerate is well shown in the eastern part of the township of Swanton, for which it was named." This term is now abandoned because the name was used earlier by Perry (1867) for a slate series in this same region. The largest exposures occur about a mile west of Georgia Center, and it was this occurrence that Walcott (1886, p. 17) noted as his division 9 of the Georgia section, defining it as a gray limestone with some bands of argillaceous shale having an "aver-

age dip 60° S.E." (this is, however, the cleavage). Many of the beds of limestone, he says, "appear to have been broken up into fragments and recemented in situ," and the whole formation is 1,700 feet thick. The Corliss conglomerate, however, nowhere exceeds 30-40 feet in thickness. The limestone pieces are cemented together by lime or dolomite paste which is replete with round grains of etched sand. In places there is so much sand present as to make local sandstones anywhere up to 2 or 3 feet thick.

Fossils of the Corliss Conglomerate.—Among the smaller pieces of this limestone conglomerate may often be seen slabs with Gorge formation trilobites. Among these Raymond identifies *Stenopilus pronus*, *Maryvillia triangularis*, *Plethopeltis* sp., *Blountia* sp., etc. Brachiopods are much rarer. Very rare are Middle Cambrian limestone pieces with fossils.

Georgia Slate Series.—Keith (1923) restricted the old term Georgia (1861) to this series, with the typical area in the eastern part of Georgia township, about Georgia Center. The series here "forms a belt three miles wide, and its thickness is likely to be over rather than under 2,000 feet" (p. 123). From here it outcrops nearly continuously to the Canadian border. The Georgia slate is mostly a dark blue-gray fine-grained slate that is everywhere strongly cleaved, and folded as well. It is not, as a rule, well banded but otherwise resembles the Highgate slate, excepting that it is usually lighter in color. No fossils have been found in the type area of the Georgia series, but such have been obtained in two places shortly to the south of the Canadian border.

Logan (1863) referred these slates to his Quebec series. The old term, "Georgia terrane" has ever since 1861 been used so variously that it would seem best to discard it altogether; however, for the present the writer will follow Keith and use Georgia for these Lower Ordovician slates.

Lower Ordovician Faunas.—At a place 4 miles north of Highgate Center and about 75 feet above the base of the Georgia series, in a limy sandstone, first Keith and then Dunbar and the writer collected a number of brachiopods. These, as identified by G. A. Cooper, are: *Archaeorthis hippolyte*, *A. cf. electra*, and *Finkelburgia* sp. They are of Lower Ordovician time. One-half mile farther north on the Oliver Grandge farm and at the very base of the Georgia series, quite a number of fossils were collected by Dunbar, Keith, and the writer. Here Cooper identifies of brachiopods *Orthidium*

n. sp. cf. *O. gemmicula*, *Syntrophina* sp., *Archaeorthis* sp., and *Clarkella* n. sp. The trilobites, identified by Raymond (1924), are as follows: *Cholopilus vermontanus*, *Petigurus cybele*, *Gignopeltis rara*, *Hystericurus mammatus*, *Pilekia eryx*, *Lloydia saffordi*, *Bellefontia obtecta*, and *Pliomerops* sp. indet. The same author says that this is clearly a Beekmantown fauna. "The genera Bellefontia and Pilekia would indicate a horizon very low in the Lower Ordovician; there is nothing to indicate a correlation with any member near the top of the Beekmantown" (p. 200).

OROGENIC TIMES.

The earliest orogeny (a slight one) took place at the close of the Cambrian. It is described on page 377.

To the west of the Green Mountains in Vermont there are no strata now present younger than the highest Middle Ordovician (Canajoharie shale), and all are involved in the thrusting and folding of the region. Farther north, in southern Quebec, there is, however, a very thick younger series of Ordovician age, and southeast of Montreal occur the latest strata of this system (Richmondian). Younger formations do not occur in this general region, but to the north, on the island of St. Helen's in the St. Lawrence River opposite Montreal, there is volcanic agglomerate yielding late Lower Devonian and early Middle Devonian fossils. This agglomerate appears to lie unconformably upon late Middle Ordovician strata. On the other hand, to the east of the Green Mountains in Quebec (Lake Memphremagog) occur Silurian and Devonian formations, with an abundance of fossils, that also lie in unmistakable angular unconformity on Ordovician strata. These younger formations are likewise folded, and apparently by the Acadian orogeny of Late Devonian time. Accordingly, we may conclude that Vermont west of the Green Mountains probably was subject to very intense folding and thrusting at the close of the Ordovician (Taconian movement), but may have undergone further crustal movement, without thrusting, in Late Devonian time (Acadian movement) when the entire Acadian and New England regions were again subjected to intense orogeny. For further discussion of these orogenic times, see Schuchert (1930), Schuchert and Longwell (1932), and Keith (1913).

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