

THE AGE AND CORRELATION OF THE BIGHORN  
FORMATION OF NORTHWESTERN  
UNITED STATES.\*

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INTRODUCTION.

The Bighorn<sup>1</sup> formation is of widespread occurrence in northwestern United States and apparently underlies most of Wyoming, Montana, and southeastern Idaho. Fossils are present throughout the entire formation, but in most outcrops they are not abundant or well preserved, and there seems to be little unanimity of opinion as to their age.

The type locality is on the eastern slope of the Bighorn Mountains where the formation averages about 300 feet in thickness and consists of a thin basal sandstone member (25-30 feet thick), a thick massively bedded dolomite member which forms the conspicuous cliffs of the region, and an upper thin-bedded dolomite member (75-100 feet thick). East of there, in the Black Hills and the Bear Lodge Mountains, the Whitewood "limestone" is lithologically similar to the Bighorn dolomite and contains similar fossils. To the west the Bighorn dolomite has been recognized in the Owl Creek, Absaroka, Cedar and Rattlesnake, Wind River, Gros Ventre, Teton, Salt River, and Snake River ranges of western Wyoming and the Bighole Range of southeastern Idaho. To the southwest outcrops of the formation have been reported from the Green and Labarge mountains of Wyoming, and the Fish Haven dolomite of northeastern Utah and the adjacent part of Idaho appears to be merely a southern extension of it. To the northwest the formation has been identified in the Beartooth and Little Rocky mountains of Montana. In most of these exposures it is from 200 to 350 feet thick, but it is somewhat thinner in the vicinity of Wind River Basin and appears to be entirely absent from southeastern Wyoming.

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<sup>1</sup>The term "Bighorn" has been applied to two different geologic formations. It was used first by Darton in 1904 (Geol. Soc. Am. Bull., 15, p. 394) for the Ordovician strata of the Bighorn Mountains of Wyoming. Later, in 1911, the same term was applied by Malloch (Canada Geol. Survey Mem. 9, p. 36) to a Cretaceous formation of the Bighorn Coal Basin, Alberta. The original usage of the term is retained in this paper.

During the summers of 1925, 1927, and 1929 the writer had opportunity to study this early Paleozoic dolomite on the northeastern slope of the Wind River Mountains, which lie near the center of the region known to be underlain by it. There the formation consists of a thin basal sandstone member (2 to 4 feet thick), here called the Lander<sup>2</sup> sandstone; a thick massive dolomite member which is about 300 feet thick in the northwestern part of the Range but decreases to less than half that thickness in the southeastern part; and a thin-bedded . . . . . upper dolomite member (about 25 feet thick), the Leigh dolomite of Blackwelder.

In the Bighorn Mountains, whence the only extensive collections of fossils from this formation have been studied, the upper thin-bedded dolomite member is abundantly fossiliferous, and the massive dolomite member is moderately so, but fossils are rare and unsatisfactory in the basal sandstone member. In the Wind River Mountains, however, this condition is just reversed; the upper dolomite is very sparsely fossiliferous, and fossils are not very plentiful in the massive member but are exceedingly abundant in the thin basal sandstone. Unfortunately, they are preserved only as internal and external molds, and since the sandstone is moderately coarse-grained small forms are not well preserved and surface detail is generally absent. Nevertheless, the writer has been able to identify most of his fossils with considerable assurance, and, although too much significance can not be attached to any one identification, it is believed that generalizations based upon the entire fauna are reliable, and the fossils obtained are thought to be sufficient to fix the age of the lower part of the Bighorn formation beyond reasonable doubt as Richmond instead of late Black River or early Trenton.

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<sup>2</sup>The name is given for exposures about 10 miles southwest of Lander, Wyoming.

PREVIOUS WORK.<sup>3</sup>

As early as 1873 the presence of the Bighorn dolomite in the Wind River Mountains was recorded by Comstock (p. 428), who designated it "Silurian limestone" and in 1874 (pp. 110-112) referred it to the Niagaran epoch. Somewhat later it was mentioned in the reports and shown on the maps of the Hayden Survey, and in 1894 its nature and distribution were discussed in a general way by Eldridge (pp. 18-19). These early students referred the formation to the Niagaran epoch on the basis of a few corals, such as *Halysites catenularia*, which at that time were thought to occur only in rocks of that epoch. In 1896 Beecher (p. 32) identified a few fossils from outcrops in the Bighorn Mountains and recognized that they might be older than Niagaran, *i.e.* "Trenton or Hudson."

In 1904 Darton (pp. 394-396), who had studied this early Paleozoic dolomite in the Bighorn Mountains, called it the "Bighorn limestone" from its outcrops there. He also made the first extensive collections of fossils from the formation, and these were studied by E. O. Ulrich, who regarded those from the lower massive member of the formation as representing a lower Galena-Trenton fauna, and those from the upper beds a Richmond fauna. Since that time fossils have been collected from various localities, and it has been more or less generally accepted that the basal sandstone member of the formation is of late Black River or early Trenton age, the massive dolomite member of Trenton age, and the upper thin-bedded dolomite member of Richmond age. If this were true, there should be a big hiatus between the middle and upper parts of the formation, representing the whole of Eden and Maysville times. No field evidence of such has been recorded. Wilmarth in her correlation chart of the geologic formations in Wyoming (U. S. Geol. Survey, 1925) places the whole of the Bighorn formation in the Upper Ordovician, indicating a disconformity between the upper and middle members only in the Wind River Mountains near Lander, Wyoming. Three summers' field work on the part of the writer in that particular vicinity has failed to reveal evidence of disconformity there. Kirk, in 1922 (U. S. Geol. Survey Bull. 733, p. 25), expressed the opinion that the lower massive Bighorn dolomite is of Richmond age, though without giving

<sup>3</sup> For complete references to papers cited see Nickles' bibliographies of North American geology, U. S. Geol. Survey Bulls. 746, 731, 758, 784, and 802.

his evidence, and the most recent reference that the writer has been able to find on the subject (Bevan, Arthur, Geol. Soc. Am. Bull. 40, p. 440, 1929) adheres to the belief that "the lower part is of Trenton and the upper part of Richmond age."

#### NEW EVIDENCE.

In the southern part of the Wind River Mountains the Bighorn formation lies disconformably between the Gallatin formation of Upper Cambrian age and the Madison formation of Mississippian age, but in the northern part of the Range it is separated from the Madison by a few feet of limestone containing Devonian fossils and thought to be an extension of the Darby formation of the Teton Mountains. The writer's collections of fossils from the Bighorn formation are largely from the basal, Lander sandstone member, but a few forms were found in both of the dolomite members and many others were collected from dolomite talus boulders.

#### *Fauna of the Lander Sandstone and its Age.*

The Lander sandstone, ranging between 1 and 4 feet in thickness, is abundantly fossiliferous. Most of the writer's fossils were collected from loose blocks of the sandstone in the talus since only three actual exposures were found, but the lithology is so distinct that there can be no doubt as to the source of these boulders. The fauna of the sandstone is dominantly molluscan, with a preponderance of cephalopods, but several of the other major groups of invertebrates are well represented. As indicated in the following list, the writer's collections include 1 species of *Receptaculites*, 1 species of *Cyclocrinites*, 7 species of corals, 1 species of worms, 27 species of brachiopods, 13 species of pelecypods, 34 species of gastropods, 50 species of cephalopods, and 1 species of trilobites.

The following fossils were collected from the Lander sandstone in the central part of the Wind River Mountains near Lander, Wyoming. Most of them were found in and near the canyon of Middle Fork of Popo Agie River:

- Receptaculites arcticus Etheridge?
- \*\*Cyclocrinites aff. C. gregarius (Billings).
- \*\*Streptelasma cf. S. angulatum (Billings).
- \*Streptelasma cf. S. breve Ulrich.
- \*Streptelasma corniculum Hall?
- \*\*Streptelasma robustum Whiteaves.

- Streptelasma* n. sp.  
 \*\**Halysites* cf. *H. delicatulus* Wilson.  
 \*\**Halysites gracilis* (Hall).  
     Worm borings.  
 \*\**Dinobolus* aff. *D. laurentinus* Twenhofel.  
     \**Orthis* cf. *O. tricenaria* Conrad.  
     \**Orthis* aff. *O. tricenaria* Conrad.  
     *Orthis* sp.  
 \*\**Platystrophia* cf. *P. acuminata* (James).  
 \*\**Platystrophia acutilirata* (Conrad)?  
     \**Platystrophia* aff. *P. colbiensis mutata* Foerste.  
 \*\**Platystrophia* aff. *P. elkhornensis* McEwan.  
     \**Dalmanella* aff. *D. rogata* (Sardeson).  
     *Dalmanella?* sp.  
 \*\**Dinorthis* aff. *D. carletona* Twenhofel.  
 \*\**Dinorthis* (*Plaesiomys*) cf. *D. subquadrata* (Hall).  
     *Sowerbyella* cf. *S. sericeus* (Sowerby).  
 \*\**Rafinesquina lata* Whiteaves.  
     *Rafinesquina* sp.  
     *Rafinesquina* (*Playfairia?*) n. sp.  
     *Rafinesquina* (*Playfairia*) sp.  
     *Rafinesquina lenta* Troedsson?  
 \*\**Strophomena planodorsata* Winchell and Schuchert.  
     *Strophomena* n. sp.  
     *Strophomena* sp.  
 \*\**Rhynchotrema* aff. *R. anticostiense* (Billings).  
 \*\**Rhynchotrema* aff. *R. argenturbica* (White).  
 \*\**Rhynchotrema capax* (Conrad)?  
     \**Rhynchotrema* cf. *R. increbescens* (Hall).  
     \**Rhynchotrema* cf. *R. ottawaense* (Billings).  
     *Rhynchotrema?* sp.  
     *Clinopistha antiqua* Whiteaves.  
     *Clinopistha* 2 n. sp.  
     \**Ctenodonta* cf. *C. levata* (Hall).  
 \*\**Ctenodonta* cf. *C. recurva* (Ulrich).  
     *Ctenodonta?* 2 sp.  
     \**Cyrtodonta billingsi* Ulrich?  
     \**Cyrtodonta* aff. *C. rotulata* Ulrich.  
     *Clidophorus?* sp.  
     *Vanuxemia?* sp.  
 \*\**Whitella* aff. *W. securiformis* Foerste.  
     *Byssonychia* n. sp.  
     \**Archinacella* aff. *A. cingulata* Ulrich.  
     \**Archinacella* aff. *A. deleta* (Sardeson).  
 \*\**Archinacella* cf. *A. estella* (Billings).  
     \**Palaeacmaea?* 2 sp.  
     *Sinuities* aff. *S. cancellatus* (Hall).  
 \*\**Sinuities* cf. *S. concinna* (Ulrich and Scofield).  
     *Salpingostoma* aff. *S. buelli* (Whitfield).  
     *Salpingostoma?* 2 sp.  
     *Bellerophon* cf. *B. similis* Ulrich and Scofield.  
 \**Lophospira perforata* Ulrich and Scofield?  
     *Lophospira?* sp.  
     *Eotomaria* n. sp.  
     \**Hormotoma salteri* Ulrich?  
     \**Hormotoma trentonensis* Ulrich and Scofield?  
     *Hormotoma* cf. *H. winnipegensis* Whiteaves.  
     *Liospira americana* (Billings).  
     *Liospira* cf. *L. micula* (Hall).

- \**Liospira* aff. *L. obtusa* Ulrich and Scofield.
- Liospira persimilis* Ulrich?
- \**Ectomaria prisca* (Billings)?
- \**Maclurites crassus* (Ulrich and Scofield)?
- Maclurites* cf. *M. subovatus* (Parks).
- Maclurina* aff. *M. cuneata* (Whitfield).
- Maclurina manitobensis* (Whiteaves).
- Maclurina manitobensis* (Whiteaves)?
- Maclurina* cf. *M. manitobensis* (Whiteaves).
- Trochonema umbilicatum* (Hall).
- \*\**Cyclonema* aff. *C. thalia* (Billings).
- \**Holopea* aff. *H. excelsa* Ulrich and Scofield.
- Subulites* sp.
- Fusispira* aff. *F. elongata* Hall.
- Fusispira* aff. *F. inflata* (Meek and Worthen).
- Endoceras nelsonense* Foerste and Savage.
- \*\**Endoceras fulgur* (Billings).
- Endoceras* 8 n. sp.<sup>4</sup>
- Cyclendoceras* 7 n. sp.
- Billingsites* 2 n. sp.
- Orthoceras?* sp.
- Kionoceras* 2 n. sp.
- \**Spyroceras olorus* (Hall).
- Spyroceras* 2 n. sp.
- Charactoceras?* 2 n. sp.
- Wilsonoceras* 2 n. sp.
- Wilsonoceras* sp.
- Actinoceras* n. sp.
- Paractinoceras canadense* (Whiteaves).
- Kochoceras* 4 n. sp.
- Allumettoceras* n. sp.
- Lambeoceras* 2 n. sp.
- Lambeoceras?* sp.
- \**Beloitoceras plebeium* (Hall).
- Beloitoceras* 2 n. sp.
- Wetherbyoceras?* n. sp.
- Diestoceras* 3 n. sp.
- Dowlingoceras* n. sp.
- Cyrtogomphoceras* n. sp.
- Cyrtogomphoceras?* n. sp.
- \**Encrinurus* aff. *E. vannulus* Clarke.

From the preceding list it is evident that the fauna of this sandstone member contains both Mohawkian and Richmond elements, and if the member were thicker and exposures no more numerous, one might easily be led to the erroneous conclusion that its lower part is Mohawkian in age and its upper part Richmond. Species which may be considered to indicate a Mohawkian age for the fauna are indicated in the above list by an asterisk, whereas those that are generally believed not to occur below the Richmond are indicated by two asterisks. In summary it can be stated that of the above listed 135 forms, 88 are of little value in distinguishing between Mohawkian and Richmond, either because they are represented

<sup>4</sup>The cephalopods are to be described in detail elsewhere.

in the writer's collections only by specimens that are too poorly preserved to permit certain identification, are known only from strata of questionable age, or are known to occur in both Mohawkian and Richmond strata. Of the remaining forms, however, 25 would seem to indicate a Mohawkian and 22 a Richmond age. If correlation were based solely upon a percentage basis the Lander sandstone would be referred to the Mohawkian, and in particular to the Galena. It is well known, however, that the Richmond fauna is a modified recurrence of the Mohawkian fauna, and in this circumstance the new elements of the Richmond fauna are clearly of more significance than "hold-overs" from the older fauna.

It seems probable that the presence of a large *Receptaculites* in the lower part of the Bighorn was one of the main reasons why that part of the formation was identified as Mohawkian; *i.e.* Ulrich, who originally made the identification, thought that the *Receptaculites* of the lower part of the Bighorn formation and that of the Galena of the Upper Mississippi Valley were identical. However, he has since recognized that the two are not conspecific, and recently, Foerste (1924, p. 17) quotes him as stating that "the Richmond of Alaska and the western states contains a species of *Receptaculites* so similar to *Receptaculites oweni* that it has been distinguished only recently," and that *Receptaculites oweni* of the Stewartville member of the Galena is "not precisely similar" to the *Receptaculites* of Manitoba, which is associated with "fossils commonly regarded as indicating Richmond age." It therefore seems that the large *Receptaculites* (up to 8½ inches in diameter) of the Lander sandstone, which the writer is tentatively referring to *Receptaculites arcticus* but which in sandstone molds is indistinguishable from *Receptaculites oweni*, may as well be of Richmond age as of Mohawkian. Indeed, Foerste states in connection with the above quotation that the "common occurrence of a large form of *Receptaculites* is alone sufficient to suggest a later age."

Most of the corals that occur in the Lander sandstone are small cup corals, and their significance is questionable. The forms of *Halysites*, the only compound coral noted, are indicative of a Richmond rather than a Mohawkian age. In fact, the occurrence of *Halysites* below the Richmond is now very doubtful.

Of the brachiopods those forms that are closely related to, if not identical with, *Orthis tricenaria* Conrad, *Dalmanella*

*rogata* (Sardeson), *Rhynchotrema increbescens* (Hall), and *Rhynchotrema ottawaense* (Billings) might be cited as evidence of a Mohawkian age, but on the contrary *Platystrophia acutilirata* (Conrad), *Dinorthis subquadrata* (Hall), *Strophomena planodorsata* Winchell and Schuchert, *Rhynchotrema anticostiense* (Billings) and *Rhynchotrema capax* (Conrad) are usually ranked among the best of the guides to the Richmond. Prof. Schuchert has examined the brachiopods in the writer's collections and has stated positively that they are of Richmond age. All of the genera encountered are common to both Mohawkian and Richmond strata.

Pelecypods are abundant in the Lander sandstone, but only two forms, *Clinopistha antiqua* Whiteaves and *Clinopistha* n. sp., are common. The former is not known to occur outside of Manitoba where its age is questionable, and the latter, of course, has little stratigraphic significance at present. Since only coarse sandstone molds are to be found, most of the diagnostic characters of the pelecypods are not ascertainable, and therefore little detailed stratigraphic evidence can be derived from them.

The same is true for most of the gastropods, but the presence of large maclurinas would in the past have been urged as strong evidence of Mohawkian age, because of their occurrence in the Galena (Stewartville) of Minnesota. Nevertheless, *Maclurina manitobensis* (Whiteaves) was described originally from strata in Manitoba that are now thought to be of Richmond age, and Foerste (1924, p. 17) has recently quoted Ulrich, who originally described the Minnesota specimens, as stating that "the Stewartville member of the Trenton contains fossils that have been identified with Manitoban fossils (notably *Maclurina manitobensis* and *Receptaculites oweni*), but are not precisely similar. The Manitoban fossils are associated with a large *Rhynchotrema* similar to *Rhynchotrema capax*, and other fossils commonly regarded as indicating Richmond age, but no such fossils are found in the Stewartville member, or in any other member of the Trenton in the upper Mississippi Valley." If this is true, then the large maclurinas in the Lander sandstone, being conspecific with those of Manitoba, are really indicative of a Richmond age.

Most of the numerous cephalopods of the Lander sandstone are new, but they undoubtedly belong to a widely distributed Arctic Ordovician fauna that was originally made known by

Whiteaves (1890, 1892, and 1897) from the vicinity of Lake Winnipeg and the adjacent parts of the Red River Valley in southern Manitoba and has recently been described by Foerste<sup>5</sup> from the same localities, from the Nelson River southwest of Hudson Bay, from the head of Frobisher Bay in the southeastern part of Baffin Island, and from Putnam Highland on the western side of Baffin Island, and by Troedsson (1926) from Cape Calhoun on the northern side of Kane Basin in northwestern Greenland. The age of this widespread cephalopod fauna has been a moot question. It was regarded by Whiteaves (1897, p. 135) and Dowling (1900, pp. 35-46) as Mohawkian (chiefly Trenton but possibly in part Black River). Later Bassler (1915, p. 1458) listed its age as "Black River or Richmond" but gave no evidence for his correlations, and Foerste (1924, p. 17) quotes Ulrich as regarding "it as possible that all the Arctic occurrences usually referred to Black River are of later age." Recently Troedsson (in part) and Foerste (op. cit.) have argued for a Richmond age.

Among the very few described species of cephalopods obtained by the writer from the Lander sandstone, *Spyroceras olorus* (Hall) and *Beloitoceras plebeium* (Hall) are known to occur in Mohawkian strata, but *Endoceras fulgur* (Billings) was described from the Richmond. For the most part the numerous cephalopods of the Lander sandstone are similar only to those of the widespread fauna noted above, for which Foerste (op. cit.) has ably presented all the evidence of Richmond age. It now seems to the writer, however, that in this case the final conclusion will have to be based largely on the other groups of invertebrates.

From the preceding discussion it is evident that although Black River and Trenton affinities are present in the fauna of the Lander sandstone, a considerable number of forms with Richmond affinities also occur here. Furthermore, although superficially the majority of the fossils would seem to support the traditional belief in a Mohawkian age, a critical examination of the available evidence seems to belittle the Mohawkian affinities. Also, since the Richmond fauna is a recurring Mohawkian fauna, Mohawkian forms should be expected in the Richmond, but the reverse would be difficult to explain.

<sup>5</sup> Foerste, Aug. F., Denison Univ. Bull., Jour. Sci. Lab., 24, 129-235, 1929; 22, 1-106, 1927; 32, 1-110, 1928; and Michigan Univ., Museum Paleontology, Contr., 3, 25-70, 1928.

These facts have led the writer to the conclusion that the fauna of the Lander sandstone is of Richmond age.

*Fauna of the Massive Dolomite Member of the Bighorn Formation in the Wind River Mountains and Its Age.*

In the Wind River Mountains the massive dolomite member of the Bighorn formation rests conformably on the Lander sandstone where that is present and in one locality, at least, grades downward into it. Therefore there is probably no great difference in the age of the two members, and the differences in their faunas must be due largely to differences in ecology and preservation; *i.e.* with a clearing of the seas, corals became more prominent, echinoderms made their appearance, and mollusks dwindled in importance.

The following fossils were identified by the writer from the massive member of the formation near the central part of the Wind River Mountains:

Receptaculites arcticus Etheridge?  
 Streptelasma corniculum Hall?  
 Streptelasma cf. S. robustum Whiteaves.  
 Streptelasma sp.  
 Halysites gracilis (Hall).  
 Crinoid or cystoid columnals.  
 Dinorthis? sp.  
 Maclurina? sp.  
 Spyroceras n. sp.

Also the following were collected from dolomitic talus boulders and came either from this member or from the overlying Leigh member:

Receptaculites arcticus Etheridge?  
 Streptelasma corniculum Hall?  
 Streptelasma robustum Whiteaves.  
 Streptelasma sp.  
 Columnaria alveolata Goldfuss.  
 Columnaria halli Nicholson?  
 Palaeophyllum stokesi (E. and H.).  
 Calapoecia borealis Whitfield.  
 Calapoecia canadensis Billings.  
 Halysites gracilis (Hall).  
 Circular and pentagonal crinoid or cystoid columnals.  
 Dinorthis? sp.  
 Rhynchotrema capax (Conrad).  
 Rhynchotrema? sp.  
 Catazyga cf. C. headi borealis (Billings).  
 Maclurina? sp.  
 Liospira? sp.  
 Allumettoceras? sp.

*Receptaculites arcticus?*, *Halysites gracilis*, a large *Mac-lurina*-like gastropod, and, locally, small simple corals are the only common fossils in this member, but they occur throughout its entire thickness. In view of the conditions of preservation it can not be stated positively, but it seems probable that the large *Receptaculites* of this member is conspecific with that of the Lander sandstone.

So little definite information is available in regard to Ordovician cup corals that they are really of little stratigraphic significance. *Halysites gracilis*, the only compound coral definitely known to occur in this member, is an excellent guide to the Richmond. The rest of the fossils obtained by the writer from this member are of little significance because they are either fragmentary, very poorly preserved, or entirely new.

Of the fossils obtained from the talus boulders, *Columnaria alveolata* is known to occur in both Mohawkian and Richmond strata, but *Halysites gracilis* and *Palaeophyllum stokesi* are not known to occur below the Richmond. *Calapoecia canadensis* was originally described as coming from the Black River, but Bassler (1915, p. 154) states that "it is possible that the types of *C. canadensis* were derived from the Richmond and not from the Black River." *Calapoecia borealis* was originally described from Cape Harrison, Princess Marie Bay, Greenland, and was thought to come from strata of Niagaran age. Recently, however, it has been recognized in the Cape Calhoun formation of northern Greenland, which is probably Richmond in age.

Of the few brachiopods obtained by the writer from the dolomite, only two have any stratigraphic significance. *Rhynchotrema capax* (Conrad) is one of the best indices known to the Richmond, and a specimen of *Catazyga*, unfortunately very poorly preserved, also suggests a Richmond age.

In summary it can be stated that whereas fossils are not abundant and are generally poorly preserved in the massive dolomite member of the Bighorn formation in the Wind River Mountains, those that were obtained show a Richmond affinity and only such variations from those of the Lander sandstone as might be expected because of different conditions during deposition. The combined faunas of these two members really represent a single faunal zone which is to be contrasted with the upper Bighorn.

*Fauna of the Leigh Dolomite in the Wind River Mountains and Its Age.*

The only fossils obtained by the writer from the uppermost member of the Bighorn formation in the Wind River Mountains are the following:

- Streptelasma cf. *S. corniculum* Hall.
- Streptelasma sp.
- Crinoid or cystoid columnals.
- Trochonema umbilicatum (Hall).

However, it is probable that at least part of the fossils collected from the dolomite talus boulders and listed above came from this member. All of these came from near the central part of the Range.

A single specimen of *Trochonema umbilicatum* is really the only fossil obtained by the writer from this member to which any stratigraphic significance can be attached. Both an internal and an external mold of this specimen are preserved, and therefore the identification is fairly certain. Although this species occurs in the Black River and Trenton, it has also been recognized in Manitoba, Anticosti Island, and elsewhere in the Richmond.

FAUNAS OF THE BIGHORN FORMATION IN REGIONS OTHER THAN THE WIND RIVER MOUNTAINS AND THEIR AGE.

A few marine invertebrates have been identified by Tomlinson (1917, p. 130) from the basal sandstone member of the Bighorn formation in the Bighorn Mountains. Although only one form, *Receptaculites oweni*, has been identified specifically, the general nature of the fauna seems to be more or less like that of the Lander sandstone and suggests a correlation therewith. A few fish plates have also been identified by Walcott (Darton, 1906, p. 29) from the sandstone member in the Bighorn Mountains, and they are conspecific with those occurring in the Harding sandstone of Colorado. The fauna of the latter has never been studied thoroughly, but it is stated by Walcott (1892, p. 159) to be lower Trenton or Black River in age. This conclusion, however, is based in part on the occurrence of a supposed "Trenton fauna higher up in the section," *i.e.* in the Fremont limestone. Walcott also lists this latter fauna (pp. 159-162), and although his identifi-

cations are now nearly 40 years old and the fossils need to be reexamined in the light of present-day knowledge, the fauna seems to the writer to be merely a southern extension of the Richmond fauna of the Bighorn formation.

A considerable number of fossils from the massive dolomite member of the Bighorn formation in the Bighorn Mountains has been studied by Ulrich (Darton, 1906), and a few forms have been listed from that member by various authors from the Wind River, Owl Creek, Teton, Little Rocky, Cedar and Rattlesnake, and Absaroka mountains. A form of *Halysites*, probably *Halysites gracilis*, seems to be the only ubiquitous fossil noted. Most of the identifications given are of such a general nature that they are of little detailed stratigraphic value. Among the forms listed by Ulrich (op. cit.) from this massive dolomite member in the Bighorn Mountains, *Receptaculites oweni*, *Streptelasma corniculum*, *Dinorthis pectinella?*, *Holopea excelsa?*, and *Maclurina manitobensis* might be considered to indicate a Trenton affinity, as originally postulated by Ulrich (Darton, 1905, pp. 47-48). However, as explained above, the *Receptaculites* identified as *Receptaculites oweni* and the *Maclurina* identified as *Maclurina manitobensis* now appear to be conspecific with Manitoba forms but not with Minnesota forms, and therefore actually to indicate a Richmond instead of a Trenton age. *Streptelasma corniculum*, in common with most of the other Ordovician cup corals, is of little stratigraphic significance. Both of the other species that appear to indicate Trenton affinity are identified with uncertainty. Furthermore, such forms as *Halysites gracilis*, *Dinorthis subquadrata?*, and *Rhynchotrema capax?* indicate a Richmond age.

A large fauna has been identified from the upper dolomite member of the Bighorn formation in the Bighorn Mountains, but only a few more or less problematical fossils have been listed from any of the other localities in which the member is known to outcrop. There seems to be no doubt that the fauna of this member in the Bighorn Mountains is of Richmond age, as originally postulated by Darton (1904, p. 396). However, Blackwelder (1913, p. 610) found in the Gros Ventre Range, in rocks which he confidently referred to the Bighorn formation, "a small collection of fossils containing not only the usual corals and fragmentary brachiopods and mollusks, but also several species of trilobites. This faunule is referred to the Richmond fauna by Mr. Ulrich, but in the

estimation of both Dr. Kindle and Dr. Stuart Weller it is of Niagaran age." The writer has not had an opportunity to examine the fossils collected by Blackwelder or to visit the locality from which they came, but if they are of Niagaran age, the strata in which they were found can not be considered as part of the Bighorn formation.

The lower part of the Bighorn formation has generally been correlated with the Galena of the Upper Mississippi Valley, as both consist in the main of two or three hundred feet of coarse-grained rough-weathering dolomite, and their faunas contain elements that superficially appear to be strikingly similar. The age of the latter has been accepted as Trenton, but it has recently been questioned by Ulrich,<sup>6</sup> who states that "some of the beds that have been assigned to the Galena in Wisconsin are older than Trenton, whereas others are younger than the Maysville of Ohio." The exact correlation of the Galena and the source of its fauna are at present unsettled problems, and the writer agrees with Ulrich, who in connection with the above quotation states that "a special paper needs to be written about the Galena." It will perhaps suffice here to state that the fauna of the lower Bighorn, although superficially somewhat similar to that of the Galena, is distinctly younger than it. This statement is based upon the occurrence in the former of such characteristic Upper Ordovician forms as *Halysites gracilis*, *Palaeophyllum stokesi*, *Strophomena planodorsata*, *Dinorthis subquadrata?*, and *Rhynchotrema capax*; none of which is present in the Galena.

#### CONCLUSION AS TO THE AGE OF THE BIGHORN FORMATION.

From the preceding paragraphs it is evident that the Lander sandstone, the basal member of the Bighorn formation in the Wind River Mountains, contains a large and varied fauna that is a southern extension of a widespread Arctic fauna of Richmond age. The available evidence indicates that the Lander sandstone is to be correlated with the basal sandstone member of the Bighorn formation in the Bighorn Mountains. The fauna of the massive dolomite member of the formation is nowhere large, and fossils are for the most part poorly preserved, but those that have been studied from various localities are indicative of a Richmond age and show only

<sup>6</sup> Ulrich, E. O., Ordovician trilobites of the family Telephidae and concerned stratigraphic correlations: U. S. Nat. Mus. Proc., 76, p. 78, 1929.

such variations from those of the Lander sandstone as might be expected because of different conditions during deposition. The uppermost member of the formation, a thin-bedded dolomite, has yielded numerous fossils only in the Bighorn Mountains, where its fauna is of undoubted Richmond age. Two distinct faunal zones are represented in the Bighorn formation; the lower one is characterized by the presence of *Receptaculites arcticus?* and *Maclurina manitobensis*, the upper by *Paleofavosites asper*.

#### CORRELATION OF THE BIGHORN FORMATION.

Darton (1906, p. 555) has correlated the thin basal sandstone member of the Bighorn formation in the Wind River Mountains with the basal sandstone member of the same formation in the Bighorn Mountains and with the Harding sandstone near Cañon City, Colorado. He (1904, pp. 434-435) has also correlated the massive dolomite member of the formation with the Whitewood "limestone" of the Black Hills of southwestern South Dakota and the Bear Lodge Mountains of northeastern Wyoming and with the Fremont limestone of the Front Range of Colorado; and Blackwelder (1913, p. 609) states that extensions "into central Utah, and even Nevada on the west might be suggested."

The writer's study of the faunas has confirmed most of Darton's correlations but suggests that both of the dolomite faunas of the Bighorn are represented in the Fremont limestone. In addition it indicates the correlation of the Fish Haven dolomite of southeastern Idaho and northeastern Utah with the Bighorn dolomite. Very little information is available in regard to the fauna of the latter formation, but it seems probable that it represents both of the dolomitic members of the Bighorn formation.

The uppermost member of the Bighorn formation, the Leigh member, according to Blackwelder (1918, pp. 419-420), extends "from the Teton Range eastward at least to the middle of the Wind River Mountains and north into the Absaroka Range." To this the writer would add that this member seems to be the time equivalent of the upper dolomite member of the Bighorn formation in the Bighorn Mountains.

The Montoya limestone of southern New Mexico and trans-Pecos Texas is a southern extension of the Fremont limestone and the Bighorn dolomite. Two faunal zones are present in

it, and the fossils of each are strikingly similar to those of the corresponding zone in the Bighorn formation. Beach Mountain, near Van Horn, Texas, is the southernmost point from which this widespread Arctic fauna has been recorded. However, since the Montoya formation is about 250 feet thick there and, with the exception of 30 feet of sandstone near its base, is composed of limestone, it seems probable that the sea in which it was deposited extended southward at least into the northern part of Chihuahua and Sonora.

The Beaverfoot formation of the Beaverfoot-Brisco-Stanford Range of southeastern British Columbia and adjacent parts of Alberta corresponds to the Bighorn formation of Wyoming, and both of the faunal zones of the latter appear to be represented in the former. Farther to the north along the Rocky Mountains, in the Tigonankweine Range of west-central Mackenzie, a few fossils were obtained by Keele (1910, p. 37) that appear to represent the upper faunal zone of the Bighorn formation.

In Alaska an Upper Ordovician fauna seems to be widespread. Collections made by Collier (1902, pp. 20-21), Kindle (1911, pp. 344-346), and Steidtmann and Cathcart (1922, pp. 25-26) in the Port Clarence limestone (Ordovician and Silurian) of Seward Peninsula show that both faunal zones of the Bighorn formation are represented there. A few fossils obtained by Eakin (1918, p. 25) in the Cosna-Nowitna region of central Alaska indicate the presence of Upper Ordovician there, but the collection is so meager that it is not possible to state which faunal zone is represented. Prindle (1913, p. 42) obtained two small collections of fossils from the White Mountains near Fairbanks, Alaska, that likewise indicate the presence of Upper Ordovician strata there but nothing further. In northeastern Alaska along the Lower Ramparts of the Porcupine River, Kindle (1908, p. 323) obtained two small collections of fossils both of which appear to represent the same faunal zone and should probably be correlated with the lower massive dolomite member of the Bighorn formation. Along the Yukon-Alaska international boundary between the Porcupine and the Yukon rivers, Cairnes (1914, pp. 67, 69) obtained three small collections of Upper Ordovician fossils. One is so meager that it is of no significance; one of the others appears to represent the

upper faunal zone of the Bighorn formation, whereas the third appears to represent the lower.

Hume and Foerste (1926, pp. 59-72) have recently described two small collections of fossils from the North Arm of Great Slave Lake which indicate the presence of both faunal zones of the Bighorn formation there, and a few species that unfortunately are common to both zones have been collected by Tyrrell (1897, p. 54F) from a small island in Nicholson Lake, which lies midway between Great Slave Lake and the northern part of Hudson Bay along the Dubawnt River a few miles above Dubawnt Lake.

In southern Manitoba the Dog Head limestone (Lower Mottled) seems to correspond to the Lander sandstone; the Cat Head limestone and the Selkirk limestone (Upper Mottled) to the massive dolomite member of the Bighorn formation; and the Stony Mountain formation to the upper Bighorn. The Nelson River limestone of northeastern Manitoba apparently corresponds to part of the Red River formation and in a general way to the lower faunal zone of the Bighorn formation, whereas the Shamattawa limestone probably should be correlated with the Stony Mountain formation and the upper part of the Bighorn. It should be mentioned for the sake of completeness that Wilson (1909, p. 35) found two corals on Little Current and Drowning rivers, tributaries of the Kenogami southwest of Hudson Bay, that indicate the presence of Upper Ordovician strata.

The fauna of the Liskeard formation of Lake Timiskaming, which has recently been described by Hume (1925, p. 18), is very similar to that of the lower faunal zone of the Bighorn formation. The upper Bighorn contains a considerable number of species in common with the Vauréal formation of Anticosti Island and the Paleozoic outlier near Lake St. John. The lower part of the Vauréal formation (Twenhofel's zones 1 and 2) and the English Head formation of Anticosti Island probably are approximately contemporaneous with the massive dolomite member and the basal sandstone of the Bighorn formation, but there is little striking similarity between their faunas, and there was probably no direct migration between the two regions in early Richmond times as appears to have occurred in late Richmond times.

The fauna described by Schuchert (1900, pp. 143-177) from southeastern Baffin Island, that described by Kindle

(1896, p. 456) from drift in an adjacent region, and that described by Foerste and Hussey<sup>7</sup> from Putnam Highland on the western side of Baffin Island all seem to correspond rather closely to the lower fauna of the Bighorn formation. A large number of fossils has recently been described by Troedsson (1926, 1928), from the Cape Calhoun series of northern Greenland. This fauna is strikingly similar to that of the lower Bighorn and contains at least 25 or 30 species in common with it. However, it is possible that both faunal zones of the Bighorn formation are represented, as the fossils were collected mainly from the talus at the base of high limestone bluffs and stratigraphic details are not available.

Several expeditions have collected Upper Ordovician fossils from Ellesmere Island. Etheridge (1878, pp. 568-639), studying fossils collected from Cape Louis Napoleon, east-central Ellesmere Island, was the first to recognize the presence of Ordovician ("Lower Silurian") there, but since then Holte-dahl (1913, pp. 9-11; 1917, p. 7) has recognized a good many Ordovician forms from Norman Lockyer Island in Princess Marie Bay, some 40 miles southwest of Cape Louis Napoleon, and a few from Havenfjord (Harbour-Fjord) in the southern part of Ellesmere Island; Whitfield (1900, pp. 19-22) has described a few forms from Cape Harrison, Princess Marie Bay, that now appear to be of Upper Ordovician age; and Foerste<sup>8</sup> has described two species of *Kochoceras* from the same general region. These fossils are all very similar to those occurring on Baffin Island and northern Greenland, and they should all be correlated tentatively with the lower fauna of the Bighorn.

In addition to the localities referred to above, sporadic occurrences of Ordovician fossils have been recorded from many of the islands of the Canadian Northwest Territories. For the most part only very meager collections were obtained; the localities from which they came are more or less uncertain; they were not collected by trained geologists, so that little stratigraphic information is available, and mixtures of Ordovician and Silurian forms are not uncommon; and many of them have not been adequately described or figured and the only published identifications are old. Therefore, correlations are, to say the least, difficult and uncertain.

<sup>7</sup> Foerste, Aug. F., and Hussey, Russell C., Michigan Univ., Museum Paleontology, Contr., 3, no. 3, 19-75, 1928.

<sup>8</sup> Foerste, Aug. F., Denison Univ. Bull., Jour. Sci. Lab., 23, 5, 63-67, 1928.

Nevertheless, a few fossils which in general seem to be of Upper Ordovician age and probably are to be correlated with parts of the Bighorn formation have been described from King William, North Somerset, and North Devon islands and Boothia Peninsula by Haughton (1860, pp. 53-58), Høltedahl (1912, pp. 1-11), and Foerste (1921, pp. 247-306); from Igloodik Island by Foerste<sup>9</sup>; from Southampton Island by Schuchert (1914, pp. 472-473); from Akpatok Island by Whiteaves (1899, pp. 433-434); from Cape Chidley by Schuchert (op. cit., p. 468) and Foerste (op. cit., pp. 1-110); from Melville Island by Schuchert (op. cit., p. 474); and from Wellington Channel by Foerste (1921, pp. 302-304).

RÉSUMÉ—THE ARCTIC RICHMOND OF NORTH AMERICA.

From the preceding paragraphs it is evident that in early Richmond times a shallow sea, bringing with it a very characteristic fauna, spread southward from the Arctic Ocean over the northern half of Alaska and all but the extreme eastern and western parts of Canada, including the Canadian Shield. It narrowed to the south but extended clear across west-central United States and probably into the northern part of Mexico.

In early Richmond times there was no open migration between this sea and the sea that engulfed eastern North America, but in late Richmond times the seas seem to have coalesced, and the contrast between this Arctic fauna and the faunas of eastern United States largely disappears. There appears to have been open migration between the Anticosti Island region and that of Manitoba and Wyoming and between the latter and the region of Michigan, etc., only in late Richmond times.

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<sup>9</sup> Foerste, Aug. F., Denison Univ. Bull., Jour. Sci. Lab., 23, 67-70, 1928.