

ART. XVII.—*The Silurian Section at Arisaig, Nova Scotia* ;
by W. H. TWENHOFEL. With a correlation note by CHARLES
SCHUCHERT.

[Contributions from the Paleontological Laboratory of Yale University.]

WHILE much has been written concerning the Silurian strata at Arisaig and they have often been studied, no section appears in the literature assigning the fossils to their proper horizons. The intermediate position that the fossils of these strata hold in respect to those of the United States and Europe has made such a section particularly desirable. In the summer of 1908 the writer, in the interest of the Peabody Museum of Yale University, had the opportunity of making a zonal collection of fossils from this extensive Silurian section and of studying in detail its stratigraphy.

The writer is under many obligations to Professor Charles Schuchert, without whose assistance in the analysis of the fossils the preparation of this article would have been impossible. He is also much indebted to Mr. Alex. J. McDonald and family, in particular, and to the people of Arisaig, in general, for many favors accorded him during his stay with them.

Review of the Literature.—To the writer's knowledge, the first person to give any definite statement of the geology of northern Nova Scotia was Abraham Gesner, who published in 1836 a work entitled: "Remarks on the Geology and Mineralogy of Nova Scotia." He divided the rocks of the province into Primary Rocks, Trap Rocks, Clay Slate, and Red Sandstone; the last underlying the northern and northwestern areas (1836:1)*

The first reference to the Arisaig rocks is found in a paper published by J. W. Dawson in 1845, who described the section as follows: "The section between M'Caras brook (top of section) and Arisaig is occupied by dark shales and thin layers of limestone with a few beds of reddish shale and conglomerate. The rocks dip southwest, but become much fractured as they approach Arisaig" (1845:3). He considered them of Silurian age.

The first paleontological work on the section appears to have been done about 1850, as in that year Dawson stated that a small collection of fossils from the upper horizon had been sent to James Hall, who expressed the opinion that they belonged to the age of the Hamilton and Chemung groups (1850:351), and statements to this effect appear in his *Acadian Geology*

* References are to the list of papers at end of this article.

(1855 : 315). In later papers he modified this view and considered that the strata were the time equivalents of the Clinton to Lower Helderberg of New York, and regarded it as possible that strata lower than the Clinton might be present (1868 : 573). He further stated that the fauna was intermediate in position between that of New York and England.

In 1859 Rev. D. Honeyman, then a minister in the town of Antigonish, published a short paper in the Transactions of the short-lived Literary and Scientific Society of Halifax giving a popular description of the section. Being favorably situated, he spent much time studying the rocks of this and neighboring regions and appears to have made a large collection of fossils from the Arisaig exposures. The results of these and later studies appeared in a number of papers extending from 1859 to 1887 (See list at end of this article). Basing his conclusions on Salter's identification of fossils, he at first considered the section as extending from the Mayhill sandstone to the Upper Ludlow, both of Silurian age ; but his later papers express the view that the section begins in the Ordovician, the Utica and Hudson River being represented (1886 a : 318), which view was supported by Hall. He made five subdivisions of the section, which he called, beginning at the base, A, B, B', C, and D. The most valuable of his papers are those of the years 1864 and 1875. Honeyman deserves a great deal of credit for his earlier work, his sole stimulus being the love that he had for the science of Geology.

The most complete detailed description of the Arisaig strata occurs in the Report of the Canadian Geological Survey for the year 1886. Messrs. Hugh Fletcher and E. R. Faribault of the Survey made the section, which from a structural and petrological standpoint leaves little to be desired, but in failing to cite the fossils collected their work does not give the stratigrapher the needed information to determine the historical record of the rocks described by them. The authors assign the strata to the Silurian, ranging from the Medina to the Lower Helderberg.

The latest work is by Dr. H. M. Ami, who gives a provisional list of fossils, but without locating them in the section. In his last published statements (1901 : 203 ; 1901 b : 354) with reference to the section, he applies, beginning at the base, the names Arisaig, McAdam, Moydart, and Stonehouse to form divisions of the series ; without, however, fixing precise limits to his divisions.

Location and Boundaries.—The Silurian rocks under discussion lie upon the Straits of Northumberland, at the little village of Arisaig, Nova Scotia. They underlie an area about six miles long by one and one-half miles wide (1886 : 41P),

washed on the north and northwest by the waters of the Straits of Northumberland and separated from the Pre-Silurian rocks to the southeast by a great fault. On the shore they are overlain unconformably at their western side by a series of conglomeratic sandstones of probable continental origin which are thought to be of Carboniferous age (1886:89P), the two series being separated by about fifty feet of fine-grained amygdaloidal trap. To the southwest occur a series of continental sandstones and volcanic tuffs (1901:309) which are considered to be of Devonian age. These form the Knoydart formation of Ami (1901 b:207; 1900 a:303) and from them he has obtained fish remains (1900 a:309) and a series of tracks (1901 a:330). The Silurian is underlain unconformably (?) at Arisaig pier and to the east by a series of banded hornstones, red conglomeratic shale, and syenites (1886:9P), which in many places have been broken through or covered by fine-grained amygdaloidal trap. A part of these rocks Honeyman and Dawson considered as altered Silurian (1864:339; 1891:565). Fletcher regards them as possibly of Pre-Cambrian age, but states that little can be said of them except that they are older than the "Medina." It is probable that Fletcher is correct, as there appears to be little evidence for the former view.

Structure.—The entire section is well exposed on the cliff and reef along the Strait and by several small brooks crossing it from south to north; two of them, Doctor's and Arisaig, which are cut in the lower shales, crossing the entire section.

The structure of the rocks is, according to Honeyman, that of a synclinal fold (1864:333); but it can hardly be considered as a typical syncline, a fact to which he also calls attention (1864:335). It may be better characterized as a downfaulted block which has broken south of its mid line, giving rise to a trough which plunges to the southwest.

This conclusion is derived from the fact that the lowest beds of the Silurian have not been seen on the southern side of the area, and by the evidence for faulting given by the topography. The Silurian hills are separated from Eigg mountain or Maple ridge, the Cambro-Silurian upland, by a low area called "The Marshes," which extends approximately parallel to the shore for ten or more miles and marks the fault zone, as Fletcher has pointed out. The beds are tilted away from this fault zone for a short distance, but this is what should be expected. The trough thus formed is much modified by secondary folds and faults which in the lower part of the section reach a maximum. Hence the rocks range from a horizontal attitude just west of the mouth of Arisaig brook to a vertical and overturned attitude at Beach Hill Cove. The general dip of the rocks of the shore is toward the southwest.

The entire section is much fractured and in many places the rocks have been crushed literally to fragments. In the harder rocks the fractures have been filled by quartz and calcite, being in many places so well cemented that when struck the rocks break elsewhere than along the original line of fracture. As many as twelve cemented fractures have been counted on a fragment three inches wide. This cementation is confined to the harder rocks, being practically absent in the shales.

The general direction of the fracture lines is, on the average of those taken, about twenty degrees east of north and thirty degrees west of north; but many variations occur. The section has probably been subjected to pressure more than once in its history.

The greatest fault found occurs at the top of zone 12, where the lower shales have been elevated and abut against higher limestones. In this case the direction is thirty-five degrees west of north.

Some of the joint blocks are very symmetrical. In three beds in which they were particularly regular the following measurements were taken: N. 20° E. by N. 80° W., N. 30° W. by N. 70° E., and N. 28° W. by N. 70° W.

Petrological Divisions.—The rocks can be divided petrologically into the upper shales and limestones having their base on the "Red Stratum," the middle limestones and shales, the middle dark shales, the lower green and dark shales, and the basal shales and arenaceous limestones. These petrological divisions foreshadow the paleontological ones, although from the latter standpoint it is difficult to fix boundaries, as no sharp break occurs in the section except at the fault at the top of zone 12. There is a total thickness of thirty-four hundred and sixty-five feet.

Character and Color of the Rocks.—The rocks comprise shales, ranging from fine-grained carbonaceous paper shales to others decidedly coarse and arenaceous, tough argillaceous limestones, rarely pure limestones, flint-like flags, and fine-grained sandstones. In the lower shales are a few beds of low-grade iron ore, once worked but now abandoned.

The color of many of the rocks on a wave-beaten surface is a dirty green, on a weathered surface a rusty yellow or brown. The shales range through gray, red and black. In the upper part they are red followed by gray and green shades. The thick middle shale horizon is of a dark gray color. The upper half of the lower shales are green; in the lower half dark to black colors predominate. The sandstones and flinty flags have some shade of blue. The limestones range from gray to grayish-green, the latter predominating.

Manner and Place of Deposition.—The strata were formed at no great distance from the shore, as is indicated by their decidedly arenaceous character, the great amount of ripple marking which is particularly characteristic of the upper levels, and the lenticular character of the fine-grained sandstones that are present almost throughout. These last show on a polished or weathered surface wavy and cut-off lines of lamination indicating rapidly changing wave action.

Fossil Content.—The rocks, in general, are fossiliferous throughout; only one stratum, the "Red Stratum" of authors, being without organic remains. They are particularly abundant in the upper red shales and flags, and at many horizons in the middle and lower shales. The impure limestones as a whole contain few fossils, but a series of intercalated nearly pure limestone lenses have them in more than ordinary abundance. These lenses are of two classes: the one wide, but thin, contains merely fragments; the other, about three times as wide as thick, contains many well-preserved fossils, usually of but one species.

Raised Beaches.—Three well-defined raised beaches stand above the present one and slope gently to the northeast. Their heights at Stonehouse brook, the top of the section, are roughly estimated at twenty-five, seventy-five, and one hundred and twenty-five feet. East of McAdam brook the lowest merges into the present one. The lowest two still have very steep cliffs, so their uplift must have been comparatively recent. Whether these beaches rise in elevation westward is not known.

Topography.—The faulting and fracturing of the rocks have had little effect on the upland topography of the area underlain by the Silurian. The brooks crossing the section flow in deep and narrow gorges which do not owe their location to the presence of fractured or faulted zones. Exceptions are McDonald's and Arisaig brooks, which have chosen weakened zones as points for breaking over the shore cliff. The gradient of all the streams is high, falls are present in each, and all the evidence points to recent uplift of the region.

In the shore line topography the story is a different one. Weakened zones have made the smaller detail of the shore. In the soft shales this is not so marked, but in the hard shales and interbedded shales and limestones it is particularly evident. The fractured zones erode readily and the cliff presents a serrate appearance.

The varying hardness of the rocks determines a higher order of detail, shales zones being the location of coves, hard rocks forming points. The latter is well shown by the hornstones of Arisaig pier and by a double example in zone 35, where at the present time is a prominent point; and this appears to

have been true at another period of the shore's history, as the first raised cliff has here a point which is a replica of the lowest one.

Description of the Silurian Section.

In order to facilitate the study of the appearance and duration of the species in their true time relations the section is

Honeyman 1864	Dawson 1868, 1891	Fletcher 1886	Ami 1901	Twenhofel 1909	
Division D.	Upper Arisaig. (Lower Helderberg or Ludlow)	Lower Helderberg or E ₆ . 1038 feet.	Stonehouse Formation.	Division IVb or Stonehouse Formation. (Ludlow)	Red shales and limestones. 97 feet.
Red Stratum.			Moydart Formation.		Argillaceous limestones and shales. 978 feet.
Division C.	Lower Arisaig. (Clinton or Upper Llan-doverly)	Niagara or E ₂ . 1293 feet.	McAdam Formation.	Division IVa or Moydart Formation. (Approximates Louisville or Wenlock time)	Red Stratum. 32 feet.
					Argillaceous limestones and shales. 347 feet.
Division B'. Total thickness B', C, D, 500 feet.				Upper Clinton or E ₂ . 148+ feet.	Arisaig Formation.
Division B. 170 feet.	Lower Clinton or E ₂ . 345+ feet.	Division II or Arisaig Formation. (Clinton or Lower Llan-doverly)	Green shales with thin sandstones. Dark shales with thin sandstones. 833+ feet.		
Division A. 200 feet.		Medina or E ₁ . 182 feet.	Division I. (Clinton)	Sandstones, limestones, and shales. ?160 feet.	

given beginning at the base and extending upward. Forty zones have been established, the character of the sediments being the basis for division. These forty zones have been grouped in five subdivisions. The thickness for each zone has

been measured in all cases except where the beds are much disturbed or are covered. In the latter cases the thickness has been estimated or calculated. Figures of attitude are magnetic.

Collections were made at over two hundred different levels in order to delimit any sudden faunal change to definite horizons. The local faunules show that no break in sedimentation occurred and that the disturbances that the rocks have undergone were not extensive except in a single case at the top of the Clinton. The entire collection reveals a fauna of from 140 to 160 species, a total in harmony with Ami's list of 1892. The preliminary identifications of the fossils made by Professor Schuchert relate only to known forms or to comparisons with well-known species. They are chiefly of brachiopods; as the equally abundant pelecypods are nearly all undetermined, awaiting future detailed comparison and description.

Subdivisions of the Arisaig Silurian have been made by four previous writers, as indicated in the appended table, which attempts to show the equivalents of the present section in terms of the older ones.

BASE OF SILURIAN SECTION.

Silurian Division I.

Zone 1 is usually regarded as the equivalent of the New York Medina, but Professor Schuchert states that all the fossils collected belong rather to Clinton time than to the Medina, and that he has found nothing in the collection indicative of the Medina.

1. Base of section at Beach Hill Cove. Here are exposed greenish calcareous sandstones and thick-bedded argillaceous limestone with some shale. Attitude vertical or even overturned. Not seen at Arisaig, where the first strata following the break in the shore cliff are banded hornstones. This zone coincides with Honeyman's Division A (1864: 336), with the Medina or Division E 1 of Fletcher (1886: 37P), and with the lower portion of the Arisaig formation of Ami (1901: 354).

Thickness estimated at 160 feet.

Fossils are scarce and difficult to collect and were found only in the upper seventy-five feet which is exposed at the east and west points of the cove. *Lingula* cf. *oblonga*, *Dalmanella* cf. *elegantula*, *Cornulites flexuosus*, and *Zaphrentis* cf. *bilateralis*.

CLINTON ZONES.

Silurian Division II, or Arisaig Formation.

Zones 2 to 12 are correlated with the New York Clinton on

the basis of the presence of *Monograptus clintonensis*, *Retiolites geinitzianus venosus*, and *Anoplotheca hemispherica*. Division II begins with dark carbonaceous paper shales, and has in its upper half green shales with fine-grained sandstones. It is believed to be coincident with Divisions B and B' of Honeyman (1864: 333), to include somewhat more than the Upper and Lower Clinton or Division E2 of Fletcher (1886: 37P), and to form the upper portion of the Arisaig formation of Ami (1901: 394).

In this division there is an estimated thickness of over eight hundred feet, which is probably less than the true thickness, as some of the strata have been lost by faulting.

2. From Arisaig Pier to the Lobster Factory there are no outcrops. At the middle of Beach Hill Cove are exposed about one hundred feet of black carbonaceous paper shales that partly or wholly lie below zone 3. Strike almost E.-W., but varying ten to twelve degrees either side. Fossils are scarce, due to the much weathered condition of the shales. Base of Honeyman's Division B and Lower Clinton of Fletcher's section.

3. Broken down cliff of dark to black rusty weathering papery shales. Beds much disturbed, and in part the strike is almost that of the shore.

Estimated thickness 100 feet.

Fossils abundant: *Anoplotheca hemispherica*, *Anabaia anticostiana*, *Lingula* cf. *oblonga*, *Acaste downingiae*.

4. Dark-gray to green and black fine-grained soft shales, weathering rusty. Much disturbed. Strike N. 50°-70° W.; dip 30°-50° W., with many variations.

Estimated thickness 215 feet.

Fossils fairly abundant: *Monograptus clintonensis*, *Anoplotheca hemispherica*, *Anabaia anticostiana*, *Cornulites flexuosus*, *Calymena* cf. *tuberculata*.

5. Dark-gray somewhat papery shales with a few hard bands; all weather rusty. Strike variable. N. 60°-70° W.; dip 30°-40° W.

Estimated thickness 50 feet.

Monograptus clintonensis, *M. priodon chapmanensis*, *Retiolites geinitzianus venosus*, *Orbiculoidea tenuilamellata*, *Dalmanella elegantula*, *Schuchertella* sp., *Chonetes tenuistriata*, *Anoplotheca hemispherica*, *Anabaia anticostiana*, *A. depressa*, *Cornulites flexuosus*, *C. distans*.

6. Dark-gray splintery shale without hard bands. The base of this zone is about fifteen yards west of the present

mouth of Arisaig brook, but by faulting it is brought to view in the mouth of the brook. Strike N. 86° W.; dip 16° W.

Thickness 23 feet.

This zone appears to coincide with the base of Honeyman's Division B' and the Upper Clinton of Fletcher's section. Fossils: *Monograptus priodon chapmanensis*, *Dalmanella elegantula*, *Anabaiia depressa*, *Cornulites distans*, and *Dalmanites sp.*

7. Green arenaceous micaceous shales and fine-grained sandstones in beds from one to six inches thick. Much fractured. Attitude almost horizontal. Strike N. 20–90° W.; dip 0–2° W.

Thickness 30 feet.

Fossils fairly abundant: *Monograptus clintonensis*, *Orbiculoidea tenuilamellata*, *Dalmanella elegantula*, *Chonetes tenuistriatus*, *Camarotoechia* near *equivariata*, *Anabaiia anticostiana*, *Anoplotheca hemispherica* (rare), *Schuchertella sp.*, *Avicula emacerata*, and fragments of *Eurypterus*.

8. Green shales and thin lenticular fine-grained sandstones. Strata in a small synclinal fold.

Estimated thickness 30 feet.

Fossils very common, especially graptolites: *Monograptus clintonensis*, *M. priodon chapmanensis*, *Retiolites geinitzianus venosus*, *Orbiculoidea tenuilamellata*, *Leptæna rhomboidalis* (first appearance), *Chonetes tenuistriatus*, *Camarotoechia* near *equivariata*, *Anoplotheca hemispherica* (small and rare), *Cornulites distans*, *Avicula cf. rhomboidea*, *Pterinea honeymani*, *Modiolopsis (?) cf. primigenia*, *Dalmanites sp.* and fragments of *Eurypterus*.

9. Light-green, more or less arenaceous shales with numerous lenticular fine-grained sandstones. A shale layer three feet thick full of *Leptæna rhomboidalis* occurs. The beds are much disturbed and thickness is uncertain.

Estimated thickness 66 feet.

Monograptus clintonensis, *Chonetes tenuistriatus*, *Camarotoechia cf. obtusiplicata*, *Rhynchonella cf. robusta*, *Anoplotheca hemispherica* (rare), *Serpulites cf. dissolutus*, *Cornulites distans*, *Avicula rhomboidea*, *Modiolopsis (?) cf. primigenia*, and *Eurypterus* fragments.

10: Light-green, soft, somewhat papery shales weathering a dirty greenish-yellow and many thin lenticular fine-grained sandstones. This zone begins at a small promontory forming the west end of a synclinal fold which is believed to be the disturbance of zone 18 of Fletcher's section and ends at a fault about forty yards east of the mouth of Smith's brook. This appears to be the fault described by Fletcher (1886: 39P) and

marks the base of his Niagara. Strike N. 55° W.; dip 10°–35° W.

Estimated thickness 66 feet.

Chonetes tenuistriatus, *Rhynchonella* cf. *robusta*, *Anoplothea hemispherica*, *Cornulites distans*.

11. Greenish-gray shales with some much shattered lenticular fine-grained sandstones. Zone ends at a small gulch in the cliff, that is here forty or more feet high and crowned by stratified glacial material. Strike N. 54° W. to N. 73° E.; dip 34° W. to 10° E.

Estimated thickness 63 feet.

Very fossiliferous: *Monograptus clintonensis*, *Retiolites gein-itzianus*, *Orbiculoidea tenuilamellata*, *Dalmanella elegantula*, *Leptæna rhomboidalis*, *Chonetes tenuistriatus*, *Camarotæchia* cf. *obtusiplicata*, *Wilsonia* cf. *saffordi*, *Anoplothea hemispherica*, *Cornulites distans*, *Dalmanites*, *Conularia*.

12. Dark-gray shales, weathering rusty, with very few hard bands. Beds much disturbed.

Thickness thought to be near . . . 80 feet.

Fossils abundant, particularly graptolites: *Monograptus clintonensis*, *Leptæna rhomboidalis*, *Chonetes tenuistriatus*, *Anoplothea hemispherica*, *Modiolopsis* (?) cf. *primigenius*, *Calymene*, and *Dalmanites*.

HIGHER NIAGARAN ZONES

Silurian Division III, or McAdam Formation.

Following zone 12, the highest member of the Clinton, there is a fault of considerable importance, the eastern limb of which has been elevated and a part of the strata lost. The fossils of zone 13 are markedly different from those below and yet a number of species, chiefly pelecypods, range on both sides of the fault. Apparently the throw has not been extensive. The species of zones 13 to 27 are not many in number; but indicate, rather distantly however, the Rochester shale. This time equivalence is best seen in the presence of *Monograptus* cf. *riccartoensis*, *Dalmanella* cf. *edgelliana*, *Camarotæchia neglecta*, *C.* cf. *obtusiplicata*, *Spirifer crispus*, and first appearance of large *Atrypa reticularis*. Other species that help to confirm this correlation could be mentioned, but most of these have a longer upward range. In fact, all the zones about the fault have an indigenous fauna that gradually changes into those of the higher beds. Division III is believed to coincide, in the main, with the McAdam formation of Ami (1901: 304), in part with the Niagara or Division E3 of

Fletcher (1886: 37P), and in part with Division C of Honeyman (1864: 333). It consists chiefly of dark splintery arenaceous shales with a total thickness of one thousand and twenty feet.

13. More or less thick-bedded greenish-gray to dark-gray rubbly argillaceous limestone and splintery micaceous-arenaceous shale. The zone is much disturbed and at its base is thrown into a small anticlinal fold of which the eastern limb has been broken off and elevated an unknown distance. Strike N. 56°-72° W.; dip 32°-37° W.

Estimated thickness 140 feet.

If one may judge from Honeyman's map (1864: 336), this zone forms the base of his Division C. Fossils abundant: *Mariacrinus* (?), *Dalmanella elegantula*, *Leptaena rhomboidalis*, *Stropheodonta* sp. 1, *Camarotoechia neglecta*, *C.* cf. *obtusiplicata*, *Atrypa reticularis* (first appearance).

14. Dark-blue to gray micaceous-arenaceous shales with a few flags and thin limestones to a large trap boulder at foot of cliff. Strike N. 76° W.; dip 32° W.

Thickness 33 feet.

Fossils abundant: *Dalmanella elegantula*, *Camarotoechia neglecta*, *Tentaculites*, *Homalonotus dawsoni* (?).

15. Greenish-gray interbedded arenaceous-argillaceous limestone and shale to McAdam's boat landing. Zone much disturbed. Strike N. 64° W. to N. 57° E.; dip 42° W. to 39° E. Much of the shore follows line of strike.

Thickness estimated at 63 feet.

Pholidops implicata, *Dalmanella elegantula*, *D.* n. sp. very large, like *D. edgelliana*, *Camarotoechia neglecta*, *Pterinea emacerata*, *Calymene*, *Homalonotus dawsoni* (?).

16. Dark-gray shales. Strike N. 64° W.; dip 33° W.

Thickness 24 feet.

Fossils common: *Dalmanella elegantula*, *Camarotoechia neglecta*, *Tentaculites*.

17. Greenish-gray and dark-gray, crumbling, more or less arenaceous shales. Strike N. 75° W.; dip 37° W.

Thickness 88 feet.

Fossils scarce: *Dalmanella elegantula*, *Camarotoechia neglecta*.

18. Hard shales, breaking into dagger-like fragments, and knotty calcareous flags with nearly pure limestone lenses. Strike N. 80° W.; dip 40° W.

Thickness 49 feet.

Fossils scarce: same as in 16 with *Chonetes tenuistriatus*.

19. Dark soft mud-shale with many fossils. Strike N. 72° W.; dip 40° W.

Thickness 24 feet.

Dalmanella elegantula, *Camarotæchia neglecta*, *Tentaculites*, *Bucanella trilobata*.

20. Greenish-gray to dark arenaceous shale with more or less thick beds of argillaceous limestones that are much veined by quartz and calcite. Zone ends at mouth of McAdam brook. Strike N. 75°–80° W.; dip 40°–48° W.

Thickness 123 feet.

Fossils scarce except in a few lenticular limestones: *Pholidops implicata*, *Dalmanella elegantula*, *Camarotæchia neglecta*, *C. cf. obtusiplicata*, *Tentaculites*, *Bucanella trilobata*.

21. Black, somewhat papery, soft carbonaceous shales with no hard bands. Strike N. 64° W.; dip 36° W.

Thickness 30 feet.

22. Dark-gray to black carbonaceous splintery shale with a few hard bands and many oblate spheroidal concretions. Strike N. 65–80° W.; dip 35–40° W.

Thickness 144 feet.

Dalmanella elegantula, *Chonetes tenuistriatus*, *Camarotæchia neglecta*, *C. obtusiplicata*, *Leptaena rhomboidalis*, *Spirifer crispus* (first appearance), *Grammysia* (small form), *Calymene tuberculata*.

23. Dark-gray to black soft carbonaceous shale. Strike N. 70° W.; dip 39° W.

Thickness 17 feet.

Fossils as in 22.

24. Dark-gray to black splintery arenaceous and finely laminated carbonaceous shales. At various levels occur thin beds of lenticular fine-grained sandstones and very large oblate spheroidal concretions. Near the top is a bed thickly crowded with pelecypods. Strike variable but in general N. 70° W.; with dip 45° W.

Thickness 170 feet.

Dalmanella elegantula, *Chonetes tenuistriatus*, *Camarotæchia neglecta*, *C. obtusiplicata*, *Atrypa reticularis*, *Spirifer crispus*, *Grammysia* (small forms), *Bucanella trilobata*. About thirty-five feet from the top occur *Monograptus cf. riccartoensis* in great abundance.

25. Dark-gray to black carbonaceous slaty shales in thick beds with some lenticular fine-grained sandstones showing wavy lines of lamination. Strike N. 43°–54° W.; dip 62° W.

Thickness 44 feet.

Fossils abundant, but poor: *Dalmanella elegantula*, *Chonetes tenuistriatus*, and an abundance of *Cleidophorus*.

26. Gray and greenish-gray argillaceous limestones and slaty flags. Steeply upturned. Strike N. 46° W.; dip 62° W.

Thickness 15 feet.

Fossils as in 24.

27. Greenish-gray argillaceous-arenaceous limestones in thick beds, many of which are beautifully ripple marked. Strata much disturbed and thrown into a synclinal fold.

Thickness estimated at 56 feet.

Division IVa, or Moydart Formation.

This division is not marked basally by a sudden introduction of new faunal elements and no marked petrologic change occurs, there being a gradual increase in the amount of limestone with progress upward. The top of Division IVa is drawn at the upper limit of the "Red Stratum" or zone 32. The total thickness is three hundred and seventy-nine feet.

The strikingly new and characteristic species is *Chonetes novascotica* that gradually becomes the dominant fossil of Division IV, attaining to larger and larger size until in Division IVb specimens are more than one inch long on the hinge line. *Spirifer crispus* of Division III is succeeded in IVa by *S. subsulcatus* and the latter gives rise to *S. rugacosta* that attains to typical development and large size in Division IVb.

Division IVa forms the upper portion of Honeyman's Division C (1864: 336), the upper portion of Fletcher's Niagara or Division E3 (1886: 38P), and is believed to form the lower portion of the Moydart formation of Ami (1901: 354).

28. Greenish-gray more or less arenaceous-argillaceous limestone of a prismatic and nodular character, alternating with thick beds of bluish-gray shale that break into irregular fragments. Strike N. 80° W.; dip 30° W.

Thickness estimated at 117 feet.

Fossils are scarce but some of the limestone lenses are rich in them. Large crinoid columns, thick branches of a ramose monticuliporoid bryozoan, *Dalmanella elegantula*, *Chonetes novascotica*, *Camarotoechia* cf. *formosa* or *borealis*, *Spirifer subsulcatus*, *Pterinea emacerata*, *Grammysia acadica*, *Serpulites* cf. *dissolutus*, *Orthoceras* sp. 1, *Diaphorostoma* cf. *niagarensis*, *Homalonotus dawsoni*.

30. Bluish to greenish-gray shales and thin limestones. Beds little disturbed. Strike N. 75° W.; dip 37° W.

Thickness 32 feet.

Fossils abundant: *Chonetes novascotica*, *Camarotoechia* cf. *formosa*, *Homæospira* cf. *acadiæ*, *H.* cf. *evax*, *Spirifer subsulcatus*, *Orthoceras* sp. 1, *O.* sp. 2, *Homalonotus dawsoni*.

31. Greenish-gray more or less heavy-bedded argillaceous limestones, some beds of nearly pure limestone, bluish-gray mudstones cleaving into thin beds, soft shales, and splintery arenaceous flags. The zone begins just east of the mouth of McDonald's brook. Strike N. 72° W.; dip 36° W.

Thickness 101 feet.

Ramose bryozoa as in 28; *Camarotoechia* cf. *formosa*; an *Eatonia medialis*-like rhynchonelloid, but not at all this species; *Spirifer subsulcatus*; *Homæospira* cf. *acadiæ*; *Orthoceras* sp. 2; *Calymene tuberculata*; *Homalonotus dawsoni*; *Cornulites proprius*.

32. The "Red Stratum." A brick-red shale of which the upper thirty feet is prismatic and locally nodular. Shows little evidence of stratification except near its base. It is rather sharply differentiated from the overlying green shales, but grades into the subjacent zone. Twenty feet below the top is a nodular band ten inches thick. The nodules are bright green to greenish-white in color and have their longer axes transverse to the bedding. The same color shows along the fracture lines. At the base are included twenty-seven inches of thin beds of ferruginous limestone and shale which form the transition to zone 31. Strike N. 68° W.; dip 40° W.

Thickness 32 feet.

Division IVb, or Stonehouse Formation.

This subdivision has its base on the top of the "Red Stratum" and extends to the amygdaloidal trap at the top of the Silurian section. It is faunally characterized by the large size of the species and especially by the abundance of *Pholidops implicata*, *Chonetes novascotica*, *Spirifer rugæcosta*, *Homæospira*, n. sp. 1, *Grammysia acadica*, *G. rustica*, *Pteronitella venusta*, *P. curta*, *Calymene tuberculata*, *Acaste logani*, *Homalonotus dawsoni*, and an abundance of *Beyrichia pustulosa* and *B. æquilatera*. The subdivision has a total thickness of one thousand and seventy-five feet. It corresponds to the upper portion of the Moydart formation of Ami and the whole of his Stonehouse formation (1901:354). It coincides with Division D of Honeyman, as described in the Quarterly Journal of the Geological Society of London (1864:336), and to the Lower Helderberg or Division E6 of Fletcher (1886:37P).

33. Very deep-green shales with a few thin lenticular bands of limestone. Strike N. 58°-66° W.; dip 40° W.

Thickness 33 feet.

34. Gray to bluish-green, rubbly more or less arenaceous-argillaceous limestone in thick beds; many of which are of a lenticular character. In many places ripple marked and much fractured and veined by quartz and calcite. In the lower beds occur small black nodules. Strike N. 48° W., changing to N. 58° W. near the base; dip 40° W.

Thickness 342 feet.

Fossils not common: *Stropheodonta* n. sp. 1, *Leptena rhomboidalis*, *Chonetes novascotica*, *Atrypa reticularis*, *Spirifer subsulcatus* (large), *S. rugocosta*, *Homæospira* cf. *evax*.

35. Fauna and beds of same character as in zone 34 except that the ripple marking is more prominent and characterizes the zone. Strike N. 38° W.; dip 38° W.

Thickness 179 feet.

36. Greenish-gray quartz-veined rubbly arenaceous-argillaceous limestone in thick beds, and grayish-blue splintery flags with some green and rusty-purple shale to the mouth of McPherson's brook. Often ripple marked. Strike N. 50° W.; dip 40° W.

Thickness 111 feet.

Chonetes novascotica, *Stropheodonta* sp. 1, *Atrypa reticularis*, *Spirifer rugocosta*, *Grammysia acadica*, *Pteronitella venusta*.

37. Grayish-green arenaceous shales, argillaceous limestone, and splintery grayish-blue flags. Much veined and ripple marked. Strike N. 50° W.; dip 30° W.

Thickness 67 feet.

Pholidops implicata, *Chonetes novascotica*, *Camarotoechia* cf. *borealis* (Davidson's fig. 224-26), *Spirifer rugocosta*, *Pteronitella venusta*, *Grammysia*, *Calymene tuberculata*, *Homonotus dawsoni*.

38. Greenish-gray argillaceous limestone and shale with grayish-blue flinty flags. All in thick beds and much veined by quartz and calcite. Strike N. 57° W.; dip 37° W.

Thickness 110 feet.

Many fossils. *Chonetes novascotica*, *Camarotoechia* cf. *borealis*, *Spirifer rugocosta*, *S. subsulcatus*, *Homæospira* n. sp. 1, *Cornulites proprius* (?), *Calymene tuberculata*, *Orthonota angulifera* (?), many bivalves.

39. Red and grayish-green shales, gray and red argillaceous limestones, and bluish-gray splintery flags to the mouth of

Stonehouse brook. Very extensively veined by quartz and calcite. Strike N. 52° W.; dip 43° W.

Thickness 136 feet.

Many fossils: *Pholidops implicata*, *Chonetes novascotica*, *Camarotoechia* cf. *nucula*, *C.* cf. *borealis*, *Spirifer rugocosta*, *Homæospira* n. sp. 1, *Cornulites proprius* (?), many bivalves, *Beyrichia æquilatera*, *B. pustulosa*, *Acaste logani*, *Calymene tuberculata*, *Homalonotus dawsoni*, *Eurypterus* or *Pterygotus* fragment.

40. Red shales and limestones with grayish-blue splintery flags dotted with very bright green patches. In the flags the fossils occur in thin calcareous layers attached to their under sides. Strike N. 63° W.; dip 30° W.

Thickness 97 feet.

Has in addition to the fossils of 39 the following: *Schwuchertella subplana*, *Pteronitella venusta*, *Bucanella trilobata* (large), *Grammysia acadica*, *Goniophora transiens*.

41. Amygdaloidal trap overlain unconformably by Carboniferous (?) sandstone. Apparently has altered neither the Silurian strata nor the sandstone, but Silurian contact obscure. Strike of upper contact, N. 32° E.; dip 23° E.

Estimated thickness... 40 to 50 feet.

VOLCANIC ROCKS AT THE BASE OF THE SILURIAN.

On a previous page mention has been made of the rocks underlying the Silurian strata and it was stated that these rocks have been for the most part considered as altered sedimentaries. For complete details regarding them the reader is referred to the Report of the Canadian Geological Survey for the year 1886, page 9P. Studies made of these rocks in the field led the writer to the conclusion that practically all are of volcanic origin, which seems also to have been the view of Fletcher (1886:9P). Since, however, they have so often been referred to as altered sedimentaries, it seemed desirable to investigate them by chemical and petrological means, and with this purpose in view specimens were collected from Arisaig Pier to Frenchman's Barn. These specimens have been studied by the writer in the Petrological Laboratory of the Sheffield Scientific School under the supervision of Professor L. V. Pirsson and in the Kent Chemical Laboratory under the direction of Professor F. A. Gooch; to each of these gentlemen the writer acknowledges his indebtedness.

The rocks, as first seen at Arisaig Pier, consist of relatively light-colored hornstones which show banding to a high degree. Eastward they become coarser and darker and at the western

base of the prominent rock mass known as Frenchman's Barn appears a bed of red shale containing rounded boulders overlain by a thick-bedded series of dark-green stratified rocks. Both the shale and the dark-green rocks have an almost vertical attitude. Along lines of fracture all the rocks have a light-green color and there is a conspicuous irregular band of like color, varying from fifty to seventy-five feet wide, which is said to have been traced for more than a mile (1886:9P). Throughout the whole, at different points, are younger masses of amygdaloidal trap.

A chemical examination of the light-colored hornstone of Arisaig Pier gave the following analysis, which was done in triplicate to minimize possibilities of error:

SiO ₂ -----	76.70	per cent.
Al ₂ O ₃ -----	12.98	"
Fe ₂ O ₃ }-----	0.25	"
FeO }-----		
CaO-----	0.54	"
MgO-----	0.06	"
K ₂ O-----	4.14	"
Na ₂ O-----	4.92	"
H ₂ O-----	0.59	"
TiO ₂ -----	trace	"
CO ₂ -----	"	"
P ₂ O ₅ -----	0.31	"
Total-----	100.53	"

This analysis corresponds very closely to that of a rhyolite, as is evident from the high per cent of alkalis present, which would hardly be the case were the rock an altered sedimentary. An analysis of the red shale shows that it is, in all probability, of sedimentary origin. Examination of the rock in thin sections gave abundant evidence that the hornstones are none other than rhyolites. The thin sections show that the hornstones are made up of alternating bands of a very dense and less dense material, in the latter of which the minerals can be readily determined. These consist of quartz and alkalic feldspar, the quartz acting as a sort of sponge for the feldspar and giving what is known as micropoikilitic structure. Numerous micro-lites, of which the character has not yet been determined, are present. Many small flakes of chlorite, along minute lines of fracture and in places of alteration, explain the green color common in many places, and a section made from the green band shows that the color in this particular section is also due to chlorite. Pieces of angular fragments, characteristic of extrusive volcanic rocks, are present in the dense bands. The thin sections

show that the dark green rock overlying the red shale is a volcanic breccia, containing, in addition to the angular fragments of glass and fine material, pieces of quartz and feldspar. Small flakes of clay are also present, which appear to be due to alteration subsequent to deposition.

Correlations by Charles Schuchert.

Mr. Twenhofel gathered a large collection of the Arisaig fossils in over 200 lots from as many horizons in the section of 3465 feet. In looking over this mass of material one is impressed with the strangeness of this Silurian fauna, which is more European in derivation than American. None of the characteristic Silurian fossils of the United States is present excepting a few forms like *Anoplothea hemispherica*, *Camartechia neglecta*, *C. obtusiplicata*, and a few other brachiopods occurring in all Silurian districts. On the other hand, the pelecypods remind decidedly of Westmoreland, England, and yet the widely distributed European *Cardiola interrupta* is not present, but is said to occur in northern Maine. Another peculiarity of this Silurian fauna is the almost complete absence of corals, but this fact may be ascribed to the muddy and sandy shore condition of this sea. The only American Silurian region having a fauna suggesting direct marine connections is that of the Appalachian trough, best known about Cumberland, Maryland.* A comparison with this region shows, however, that the Arisaig fauna has its own decided characteristics; but that it still has by far more in common with the Cumberland trough extending to Clinton in eastern New York, than with the faunas of western New York or the Mississippi Valley. Another striking fact is that even though the Arisaig section is a very thick one and though it has been stated more than once that the Helderbergian faunas or their equivalents are present, there are no fossils in these strata suggesting anything more recent than the Ludlow (of the Christiania area of Norway).

Division I.—This horizon is usually regarded as equivalent to the Medina of New York; but on grounds other than its position, there is not the slightest evidence for this correlation. As yet no *Anoplothea hemispherica* have been gathered here, but the other fossils are those of Division II. None of the typical Medina fossils is present and until such are found these strata are best regarded as of Clinton or Lower Landoverly time.

Division II or Arisaig formation.—The lowest faunas of the Arisaig series are distinctly Silurian and there is nothing present representing the thick transition series between the

* See Prouty, this Journal, Dec., 1908, pp. 553-574.

Richmond and Clinton equivalents, so well developed at Anticosti in the St. Lawrence embayment. The section practically begins with the *Anoplothecca hemispherica* faunas, clearly of Clinton time in America and the Lower Llandovery of northern Europe. This biota maintains itself through 800 feet of shales and sandstones when the continuing deposits are cut out by a fault of unknown magnitude. To this division may well be applied Ami's formational name Arisaig. The guide fossils of Division II are: *Monograptus clintonensis*, *M. priodon chapmanensis*, *Retiolites geinitzianus venosus* (The equivalents of these graptolites do not appear in the Norwegian section earlier than the upper division of the Upper Llandovery), *Chonetes tenuistriatus*, *Anabaia anticostiana*, *A. depressa* (= *Atrypa depressa* Sowerby, which appears in the Norwegian section at the top of the Lower Llandovery and continues throughout the Upper Llandovery), *Anoplothecca hemispherica* (restricted in the Norwegian section to the Lower Llandovery), *Cornulites distans*, and *Acaste downingia*.

The time equivalent of these fossils is clearly Clinton, but the recent unpublished work of Ulrich and Ruedemann shows that this formation at Clinton, New York, not only embraces the *Anoplothecca hemispherica* fauna, but also continues upward well into the equivalent of the Rochester of western New York. The Arisaig Division II is therefore thought to be equivalent to the lower beds of the eastern New York Clinton, i. e., beds having *Anoplothecca hemispherica*, and all of the Lower and possibly a part of the Upper Llandovery of Norway as recently described by Kiaer.*

Division III or the McAdam formation.—Above the only pronounced fault of the Arisaig section the strata continue without interruption to the amygdaloidal trap. Throughout a thickness of 2575 feet the faunas are continuously of one progressive development, and one can trace the evolutionary changes of the various elements from small individuals of the lower beds to the often much larger ones at the top of the Arisaig section. As this series is a very thick one, it has been deemed advisable to subdivide it into three divisions, and particularly so because this has been done by our predecessors in the same field.

Division III, consisting essentially of shales, has a thickness of 1020 feet. The fauna is poorly preserved and is not a large one, but when the many pelecypods are studied, a longer list will be at hand than can be given at this time. Many of the species extend throughout these beds to the top of Division IV. As guide fossils of Division III may be mentioned *Monograptus riccartensis*, *Camaratæchia neglecta*, *C. cf. obtusiplicata*,

* Das Obersilur im Kristianiagebiete, 1908.

Dalmanella cf. *edgelliana* (sometimes compared with *D. subcarinata*), *Chonetes tenuistriatus*, *Spirifer crispus*, and *Atrypa reticularis*. These fossils, and the absence of the guide Clinton or Lower Llandovery fossils, seem to indicate that Division III is to be correlated with the Rochester (probably within the lower Rochester) and the Upper Llandovery including probably also the Lower Wenlock.*

Division IVa or Moydart formation.—Basally this division is on physical characters inseparable from Division III, and on faunal grounds an arbitrary line of separation is drawn where the first *Chonetes novascotica* appear. The top of Division IVa is placed at the "Red Stratum," an horizon noted by all geologists studying the Arisaig series. The rocks of this division consist of argillaceous limestones and shales having a united thickness of 379 feet. The guide fossils are, earliest appearance of *Chonetes novascotica*, suggesting the European *C. striatella*; *Wilsonia wilsoni* in typical specimens like those figured by Davidson from the Wenlock; a rhynchonellid suggesting *Eatonia medialis*, but has a lamellose instead of a striate surface; *Camarotoechia* cf. *borealis* or *formosa*; *Spirifer subsulcatus*; a later and larger development of *S. crispus*; *Homæospira acadia*; *Orthoceras* suggesting the Ludlow *O. striatum*; *Homalonotus dawsoni*; *Calymene tuberculata*; and locally an abundance of ramose bryozoa, but of only one or two species. Faunally, this horizon is intimately connected with that of Division III, and as the species compare in development best with those of the middle Niagaran, as the Waldron and Louisville faunas, the time equivalence of Division IVa is thought to be of about this time. In North Europe the Wenlock has the nearest faunal approach, and according to Kiaer's work the Moydart fossils agree best with the Upper Wenlock of Norway.

Division IVb or Stonehouse formation.—This division begins basally at the "Red Stratum," and is terminated by the amygdaloidal trap. The lower 978 feet consist of argillaceous limestone and shales, of which about 840 feet have light green to gray colors. A red tinge begins to appear in zone 39 and the final 97 feet of zone 40 are of a decidedly brick red color with some green blotches, and shale predominates here over the limestone.

The fauna is essentially that of Division IVa, but the species have all attained to larger growth and the individuals are present in greater numbers and better preservation. *Chonetes novascotica* is dominant in fine large specimens throughout this division and in this reminds of the similar development of *C. striatella* of the Ludlow horizons of Norway (see Kiaer).

*See Kiaer, Das Obersilur im Kristianiagebiete, 1908.

Other common fossils are *Pholidops implicata* (= *Crania acadensis* Hall), *Spirifer subsulcatus*, *S. rugacosta* (a development out of the previous species and closely related to *S. bijugosa* McCoy of Ireland, said to be of Wenlock time), *Schuchertella subplana* (rare), *Rhynchonella nucula* (a Ludlow guide fossil), *Cornulites flexuosus* (reappearance of the lower form), *Bucanella trilobata* (much larger than those of lower horizons), *Grammysia acadica* (rather indicative of Ludlow), *G. rustica*, *Goniophora transiens*, *Pteronitella venusta*, *P. curta*, *Beyrichia pustulosa*, *B. æquilatera*, *Acaste logani*, *Calymene tuberculata* (large), and *Homalonotus dawsoni* (a flat-headed form unlike any other American species, attaining to a length of about three and one-half inches. One imperfect specimen of apparently the same form indicates a size of 5 inches or more. This species appears in Division II).

From this evidence Division IVb correlates clearly with the Ludlow. Kiaer cites *Megalomus gothlandicus* from the Middle Ludlow, and as this fossil occurs in Gotland with *Trimerella*, it would appear that Division IVb has its nearest time equivalent in the Guelph of Interior America.

Along the shore in the upper part of Stonehouse formation Mr. Twenhofel picked up the cast of a ventral valve of a large *Spirifer* related to *S. macropleura* and *S. niagarensis*. The specimen is out of a brick-red shale and is as large as the former species but has more plications and is a flatter form, in both of which characters it approaches *S. niagarensis*. This fossil seems to indicate proximity to Helderbergian (New Scotland) deposits, but as it is not *S. macropleura*, a form also unknown in the Helderbergian deposits of Dalhousie, New Brunswick, and Gaspé, Quebec, it does not seem wise to lay much correlation value upon it for the present.

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