Art. XXII.—*Geology of Arisaig-Antigonish District, Nova Scotia;** by Merton Y. Williams.

(Contributions from the Paleontological Laboratory, Peabody Museum, Yale University.—Abstract of a thesis presented to the Faculty of Yale University for the degree of Doctor of Philosophy, June, 1912.)

Purposes of the investigation and scope of the article.

During the summer of 1910 the writer and his assistant, Mr. M. H. McLeod of Northeast Margaree, Cape Breton Island, Nova Scotia, were engaged by the Geological Survey of Canada to make a detailed examination and survey of an area in northeastern Nova Scotia which it was hoped would furnish critical data for the unravelling of the Paleozoic stratigraphy of that part of the province. Pending the publication by the Geological Survey of the complete report with maps, the following summarized statement is offered as covering the most important conclusions.

Acknowledgments.

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Location and extent of the district.

The Arisaig-Antigonish district of northeastern Nova Scotia fronts on Northumberland Strait about one-third of the way from Cape George to Pictou Harbor. From a water-front 10 miles long with Arisaig Point at its center, the district extends inland 11 or 12 miles to the southeast, including the gypsum deposits south of the Intercolonial Railway. The approximate area studied is 115 square miles.

Previous work.

Geologically the region is classic as a result of the labors of Sir J. William Dawson† and the Rev. D. Honeyman‡ in

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

† Dawson, J. W., Acadian Geology, editions 1–4, 1855, 1868, 1878, 1891.

‡ Honeyman, D., Quart. Jour. Geol. Soc., London, xx, 1864; xxvi, 1870. Trans. Nova Scotian Inst. Nat. Sci., 1866, 1882, 1886, 1887.

unravelling the stratigraphic sequence of the Silurian section exposed along the coast at Arisaig—a section unique because of its completeness, fossil contents, and decided European affinities. Later workers on the Silurian rocks have been Dr. H. M. Ami* of the Geological Survey of Canada, and Professors Schuchert and Twenhofel.† In 1886 Hugh Fletcher‡ of the Geological Survey of Canada published his final report on Pictou and Antigonish Counties, which gives the best general account of the district so far printed. Dr. Ami carefully described the Devonian strata of the area and published an account of the lower vertebrates obtained from them. Numerous other geologists have directly or indirectly added to the information relating to the region about Arisaig, which according to Honeyman became during his later life a household word in the homes of Canadian geologists.

Physiography.

Not only to the geologist and physiographer but to the casual traveler as well, the Arisaig-Antigonish district is a region of interest and delight. Possessing for Nova Scotia a maximum difference of relief, the area presents to the visitor during the summer months a delightfully green expanse of lowlands and rolling uplands, which flank a steep-scarped and generally wooded plateau. Trout streams, often several miles in length, occupy picturesque gorges in the plateau and uplands and flow in gently graded valleys across the lowlands. The plateau in places attains a height of 1000 feet and has an average elevation of about 800 feet. The uplands vary from 200 to 400 feet or more in height and the lowlands occupy the lower elevations down to about 50 feet above sea-level,

The plateau quite definitely belongs to the land forms recognized in the Maritime Provinces by R. A. Daly§ as being the remnants of a Cretaceous erosion surface of low relief, and the uplands belong to the secondary erosion surface of Tertiary time recognized by Daly in Nova Scotia. However, because of the resistance offered by the Silurian and Devonian rocks to erosion, the land surface above them was never reduced very nearly to a plain. The lowlands, consisting of stream valleys and seaward slopes, are the product of the earlier erosion cycles plus the differential erosion of glacial and recent time. They are best developed on the soft Carboniferous strata.

* Ami, H. M., Trans. Nova Scotian Inst. Nat. Sci., i, new ser., pp. 185–192, 1892. Bull. Geol. Soc. America, xii, pp. 301–312, 1901.

† Twenhofel, W. H., and Schuchert, Charles, this Journal (4), xxviii, pp. 143–169, 1909.

‡ Fletcher, Hugh, Geol. Surv. Canada, II, p. 128P, 1887.

§ Daly, R. A., Bull. Mus. Comp. Zoology, Harvard University, xxxviii, pp. 73–103, 1901.

Glaciation.—Throughout the region mounds of unsorted clay and gravel are common, and in places are capped by sorted sands. On the plateau the ice of glacial times moved, as inferred from the direction of striæ on the rock surfaces, in a direction 10° east of south, but on the lower lands its course was somewhat varied as a result of the diversity of the topography at that time.

Recent movements.—Post-glacial rejuvenation is thought to be indicated by the presence of elevated terraces along the Northumberland Strait between 10 and 145 feet above the present sea-level. These terraces appear to be old sea beaches which have been modified only by the agents of erosion at work at the present time.

The geological record.

The geological history of the district is written in sedimentary records representing, with interruptions, the time from Upper Cambrian to Pennsylvanian. The following table will help to make the sequence clear.

SEDIMENTARY FORMATIONS.

Cenozoic.

Quaternary.

1. *Recent.*—Stream gravels and residual soils, modified glacial gravels.
2. *Pleistocene* or Glacial.—Unstratified clay-gravel deposits, red clayey marl.

Paleozoic.

? Pennsylvanian or Upper Carboniferous.

1. *Listmore formation* (Millstone Grit of Fletcher).—Light gray and red-brown sandstones, thin argillaceous shale, thin green conglomerate, etc. Thickness (Fletcher), ... 982 feet.

Mississippian or Lower Carboniferous.

1. *Ardness formation* (Carboniferous Limestone of Fletcher).—Brown and green sandy shale, ripple-marked sandstone and shale, gypsum (along the I. C. R.), and a compact bed of gray limestone. Thickness (Fletcher and corrected), 2045 "
2. *McAra's Brook formation* (Carboniferous Conglomerate of Fletcher).—Limy gray shale, green shale, cross bedded conglomerate, breccia and basal conglomerate. Cut by intrusive diabase sheets and dikes. Thickness (Fletcher), 1145 "

Devonian (Lower).

1. *Knoydart formation* (Upper Devonian of Fletcher).—Hard, fine-grained, red, sandy slate, and hard, gray sandstone, cut by small diabase dikes. Thickness (outcrops measured by Fletcher; probably should be doubled),.... 683 feet.

Silurian.

Arisaig series (Silurian of Fletcher).

1. *Stonehouse formation* (= more or less of Ludlow of England).—Red shale and limestones, argillaceous limestone and gray shales. Thickness (Twenhofel),..... 1075 "
2. *Moydart formation* (approximates the Louisville of United States, or Wenlock of England).—The red stratum or red shale, argillaceous limestone and shale. Thickness (Twenhofel),..... 379 "
3. *McAdam formation* (Rochester of United States or upper Llandovery of England).—Black shales and argillaceous limestone. Thickness (Twenhofel) + iron-zone probably 100 ± feet,..... 1120 "
4. *Ross Brook formation* (=Clinton of the United States, or lower Llandovery of England).—Green shale with thin sandstones, dark papery slates, etc. Obscure basaltic? intrusive. Thickness (Twenhofel),..... 833 + "
5. *Beechhill Cove formation* (= lower Clinton).—Sandstones, limestones and shales, resting on aporhyolite flow and volcanic breccia. Thickness (estimated from width of outcrop),.... 200 "

? Ordovician.

1. *Malignant Cove formation.*—Coarse, cross bedded, silicified conglomerates and grits; irregular dikes of basalt. Thickness observed (original thickness probably much greater),.. 20 ± "

Upper Cambrian (Ozarkic).

Brown's Mountain group (included in Cambro-Silurian of Fletcher).

1. *Baxter's Brook formation.*—Red and gray sandstones and schists, red and green slates; intruded by rhyolite necks and dikes, quartz porphyry neck, diabase and basalt intrusives. Thickness represented estimated at..... 500 "
2. *James River formation.*—Flinty graywacke and grits, silicified banded slates; intruded by granite, rhyolite, diabase, basalt, and monzonite. Thickness represented probably ..... 1 mile ±

Upper Cambrian deposits.—The oldest rocks known in the district are metamorphosed graywacke and slate of the Brown's Mountain group, which underlie the plateau areas and form the base for the younger formations. All of the younger sediments at one place or another rest directly upon the metamorphic rocks. The Brown's Mountain group may be divided lithologically into two divisions,—a thick lower formation of silicified graywacke, impure quartzite and gray banded slate known as the James River formation; and an upper division of crumpled red slate with some sandstone and schist, known as the Baxter's Brook formation. Oölitic hematite beds are found in the James River rocks near the base of the Baxter's Brook division and again at a lower horizon. The sedimentary origin of the iron ore is most probable from the consideration of the oölitic and sparingly fossiliferous character of the ore, its longitudinal extent, and its close association with definite rock horizons.* Some secondary concentration or transference of material may, however, have taken place.

So far as could be observed, the two formations have entirely conformable relations to each other, and on the evidence of *Obolus* (*Lingulobolus*) *spissus* and *Lingulella* (?) obtained from the upper iron-ore horizon (both from the ore itself and the associated schist), these rocks are proven to be of Upper Cambrian or Ozarkic age. The iron ore is likewise correlated with the Wabana ore of Belle Isle, Conception Bay, Newfoundland; but because of low grade and faulted condition it has not yet been commercially developed, although portions of it will probably be profitably mined sooner or later.

The characters of the Brown's Mountain sediments are thought to indicate that they were deposited in a shallow transgressing sea; the upper red slates were formed, perhaps, by the inwash of fine oxidized sediments from a land already reduced to moderate relief.

The present structure of the Upper Cambrian rocks consists of broad folds extending in a northeast direction, crossed by a few closed northwest secondary folds. The upper red slates are also intimately crumpled and folded as a result of the many intrusive bodies which have penetrated them.

? *Ordovician deposits.*—Erosion agencies appear to have worn wide channels out of the Brown's Mountain rocks before the later sedimentary formations were laid down. The coarse cross-bedded conglomerates and grits of the Malignant Cove formation, occurring at Malignant Cove and to the south, were deposited upon the cleavage surfaces of the James River slates. Their deposition was evidently influenced by strong current

* For particulars see Woodman, J. E., Canada, Dept. Mines, Mines Branch, Report on Iron Ore Deposits of Nova Scotia, Pt. I, 1909.

action and their sedimentation characters, together with their general red color, suggest for these poorly sorted but well-worn deposits a continental origin.

Because of the orogenic disturbances suggested and because of the silicified character of its rocks, which are similar to those of the Brown's Mountain group, the Malignant Cove formation is thought to be a remnant of early Ordovician sedimentation.

Silurian deposits.—On the shore about one mile west of Malignant Cove, rocks of Silurian age rest unconformably upon an old rhyolite flow. As the Malignant Cove conglomerate contains fragments similar to, if not identical with, this rhyolite, it seems probable that the rhyolite flow was earlier than the conglomerate deposition and may have been at one time covered by the Malignant Cove formation. Be this as it may, but small isolated deposits of conglomerate now remain between the rhyolite flow-breccia and the sandy shales at the base of the Arisaig series.

The Silurian formations occupy an area about 1½ miles wide, extending from Malignant Cove about 6 miles to the southwest along the shore. The 3,500 feet of sediments here represented consist in a generalized ascending order of argillaceous sandstone, black carbonaceous shales, arenaceous and argillaceous shales, a 2½ foot bed of fossiliferous hematite, argillaceous limestones, and red shales. As previously shown by Schuchert and Twenhofel, the Arisaig series represent a period of time in Europe between the lower Llandovery and the Ludlow, and so far as they can be correlated with other American occurrences they represent the time interval between the Clinton of eastern New York and the Guelph of interior America. The sediments are thought to be the deposits of a shallow sea during varying conditions of clear and muddy waters. For the detailed description of the formations and list of their fossils the reader is referred to the work of Twenhofel and Schuchert cited above.

The Silurian formations are separated from the older rocks by a great fault having a probable throw of 3000–4000 feet. During the down-faulting, readjustment within the younger strata took place, resulting in crumpling, overturning, and many small faults which have divided the area into a number of blocks. Because of the soft, yielding nature of the strata the structure is but poorly expressed in the surface exposures.

Devonian deposits.—Red sandy slates containing some gray impure sandstone rest unconformably upon the Silurian strata to the southwest. They, too, have been downfaulted to the northwestward by the major dislocation of the region, and have suffered readjustment in the form of a synclinal flexure and minor faulting. Ami, who gave these the name of Knoydart

formation, has shown from Ostracoderm fishes obtained from the lower strata that the deposits may be correlated directly with the lower Old Red Sandstone of Europe. In origin the Knoydart formation is evidently continental and probably originated in large measure along the estuary of a Lower Devonian river.

Mississippian deposits.—Mississippian sedimentation is represented in the Arisaig-Antigonish district by the McAra's Brook and Ardness formations. The former consists of red conglomerates, sandstones, and sandy shales, and on the east of the area includes considerable thickness of micaceous gray sandstone and oil-shale. Remains of *Calamites* and fern-like impressions have been found in the oil-shale. Near the top the sandstone is limy and is apparently conformably overlain by the basal limestone of the Ardness formation.

The limestone which forms the lowest stratum of the Ardness formation is about 20 feet in thickness, and is succeeded by red sandstone and sandy shales, with some similar interbedded deposits of gray or greenish gray color. Along the south of the district, particularly in the valley occupied by the Intercolonial Railway, gypsum deposits probably 200 feet thick succeed about 200 feet of red sandstone and shale which rest upon the basal limestone. In the gray beds, particularly in those exposed along Northumberland Strait, fossil plants and carbonized wood occur in small amounts. The horizon-marking fossils are brachiopods obtained from the basal limestone exposed west of McAra's Brook. These are: *Productus doubleti* Beede, very common; *P. dawsoni* Beede; *Pugnax* sp. undet.; *Martinia glabra* (Martin); and *Beecheria davidsoni* Hall and Clarke, rare. The limestone is thus shown on faunal evidence to be the same as that occurring at Windsor in the Windsor series. On the basis of the age determination thus made and the apparent conformability of the McAra's Brook and Ardness formations, they are both considered to be of Mississippian age.

? *Pennsylvanian deposits.*—Westward along the Northumberland Strait the Ardness formation is overlain by strata consisting of red and gray sandstone and sandy shale. Fletcher has termed these rocks the Millstone Grit formation; to avoid possible confusion with other areas in Nova Scotia, also thought to be equivalent to the so-called Millstone Grit, the present writer has distinguished the deposits in the Arisaig region as the *Listmore formation.*

So far as evidence goes in the Arisaig-Antigonish district, the Listmore formation overlies the Ardness conformably. In deference, however, to the determination of Fletcher, based on observations made over a wide area, the age of these strata is provisionally considered as Pennsylvanian, and a disconformity

is thus presupposed between the Listmore and the Ardness formations.

Summary of the Carboniferous deposits.—The three formations of Carboniferous age are much alike in their general characters. Although exhibiting minor flexing and faulting, the strata have not suffered great disturbances and overlap the great fault zone which affected the older formations. They generally dip with gentle gradients away from the rocks representing the older land. The many highly inclined contacts and the unsorted, breccia nature of the basal conglomerate, particularly along the scarps of the plateau consisting of Upper Cambrian rocks, suggest deposition of material near its source in previous troughs of erosion. The McAra's Brook conglomerates probably represent a phase of continental sedimentation which was later characterized by swampy conditions or, at any rate, non-oxidizing conditions, which favored the deposition of gray sandstone and beds of oil-shale and impure coal. Shallow marine or littoral conditions followed, culminating in the laying down of the basal Ardness limestone. Shallower waters again prevailed, and in isolated pans gypsum deposits collected as a result of excessive evaporation. As the Appalachian revolution began to affect the area, continental conditions finally superseded the littoral and continued not only during the deposition of the upper beds of the Ardness formation and the whole thickness of the Listmore formation, but according to the work of Fletcher lasted through the formation of the coal measures and the deposition of the Permian in the vicinity of Pictou and westward. The Windsor submergence was evidently the last of marine conditions for northern Nova Scotia.

Igneous Geology.

A number of eruptive and irruptive rocks are associated with the Upper Cambrian formations of the Arisaig-Antigonish district. The largest individual intrusion is that of fine-grained pink granite north of James River station. This is in the form of a stock, and as seen in surface exposures is dense and evidently represents conditions not far removed from the contact with the former cover. East of Malignant Cove, what appears to be an irregular monzonite stock is exposed along the shore. A neck of rhyolite forms the center of the Sugar Loaf Hill south of Malignant Cove, and rhyolite exposures in the vicinity indicate that erosion has laid bare considerable masses of an eruptive rock which had never quite reached the surface. The rhyolite grades into quartz porphyry containing large phenocrysts of orthoclase feldspar. The irregular porphyry bodies evidently represent intrusions similar to those of the rhyolite but more deeply eroded.

Through the surrounding rocks there are many small rhyolite dikes which appear to be connected with the general rhyolite intrusion. An *aporhyolite* or devitrified rhyolite flow probably 200 feet thick rests at the base of the Silurian section and is of historical interest because it was long mistaken for metamorphosed sediments on account of its banded structure. "Eozoon" forms were at one time reported from it.

None of the above intrusives is known to cut any rocks younger than those of Upper Cambrian age, and excepting the monzonite all are perhaps of related origin. Fragments of rhyolite are common in the Malignant Cove conglomerate, which is supposed to be of early Ordovician age, and fragments representing the James River granite and the monzonite are also thought to have been recognized in the conglomerate deposits. The available evidence thus favors the supposition that the intrusion of rhyolite, granite, quartz porphyry, and monzonite, and the extrusion of the aporhyolite flow took place during late Cambrian or early Ordovician time. Obscure tuff beds associated with the Upper Cambrian iron-ore zone indicate volcanic activity at a still earlier date, but the deposits are too much altered to shed much light upon the characters of such remote eruptions.

At a number of localities in the district diabase occurs either as irregular necks, which is the case at the Sugar Loaf Hill north of Antigonish town, or else as dikes, generally but a few feet across. In a number of cases the basic intrusives are of a basaltic rather than of a diabase nature. Unlike the igneous rocks already described, the diabase cuts rocks of all ages from Upper Cambrian to early Mississippian. Apparently the intrusion took place during one general activity, and so the diabase dikes and necks are probably of early Mississippian age.

Intimately associated with the diabase intrusives along the shore east of Arisaig Point is a long red dike of soft fissile character. It cuts the diabase dikes and the aporhyolite flow. This dike has been traced for nearly 3 miles, although numerous breaks occur in it, and part of the way two dikes are present instead of one. Studied microscopically, the red dike is seen to contain much iron oxide, but it evidently was originally composed of clastic material. It is thought to have been of a fine breccia nature, which may have originated during pulsations of material which reached nearly to the surface. In places the red dike is associated with basalt which it cuts. It is possible that the basalt and the red dike represent late phases of the diabase intrusion and are essentially of the same age.

Thus igneous activity represented in the Arisaig-Antigonish district is thought to have been confined for the most part to late Cambrian or early Ordovician time, and to the early part of the Mississippian period.