PRE-CARBONIFEROUS ROCKS

OF

COBEQUID HILLS, N. S.

A Petrographic Study

of

THE PRE-CARBONIFEROUS ROCKS OF THE WENTWORTH SECTION OF THE COBEQUID HILLS, N. S.

by

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Illustrations

I. Introduction

The Cobequid Mountains are a continuous chain of hills stretching through Cumberland and Colchester counties just north of Minas Basin and Cobequid Bay. The hills start at Parrsboro, due north of Cape Blomidon, where the amygdaloidal traps of North Mountain terminate in a synclinal basin that plunges into Minas channel. From here they extend 75 miles slightly north of east towards New Glasgow until, when about twelve miles west of there, they end abruptly near Mt. Thom. Here a stretch of lowland separates them from the Pictou-Antigonish Highlands on the east.

This ridge of pre-Carboniferous rock occupies the southern part of the Oxford Sheet between Folleigh on the east and Collingwood Corner on the west; or, more exactly, between the 63° 30′ and the 64° 0′ meridians.

Statement of Problem

The Canadian National railway crosses the mountains in a north and south direction at Wentworth Valley, passing through Folleigh. Numerous cuttings have been made in igneous and metamorphic rocks and these afford an excellent cross-section of the ridge which at this point is about 8 miles in width--the average of the whole chain.

Towards the close of the 1932 field-season, a traverse was made along the railway, the purpose being to obtain information and specimens for study during the winter. Petrographically, this is virgin territory, and a microscopic study of thin-sections from the area, it was thought, would help to establish definitely the different facies of igneous and metamorphic rocks occurring there. Thus, when work is renewed in the district, a more intimate knowledge of the rocks than a megascopic examination could give will be conductive to a fuller understanding of the problem they present.

This study is not purely petrographical, however, but in its broader aspects is a determination of the character, structure, and relationship of the pre-Carboniferous igneous rocks, and the metamorphic and sedimentary rocks of this section.

II. Character of Country

Topography

The Cobequid Mountains, consisting of pre-Carboniferous rocks, both sedimentary and igneous, form one of the highland regions of the Acadian Physiographic Province. Stretching to the north and south of this highland are lowlands underlain by Carboniferous and Triassic sedimentary rocks--the Cumberland-Pictou lowland on the north and the Hants-Colchester lowland on the south. The former merges into the Central Lowlands of New Brunswick. The lowlands are nearly plain or gently rolling, drained by sluggish, meandering streams. Their average elevation is little over 200 feet above sea level. This rises gently to elevations of about 300 feet at the base of the Cobequids. Then there are abrupt ascents to elevations of 800 to 1000 feet, and here the streams spill turbulently down the steep slopes and the topography is distinctly youthful.[2]

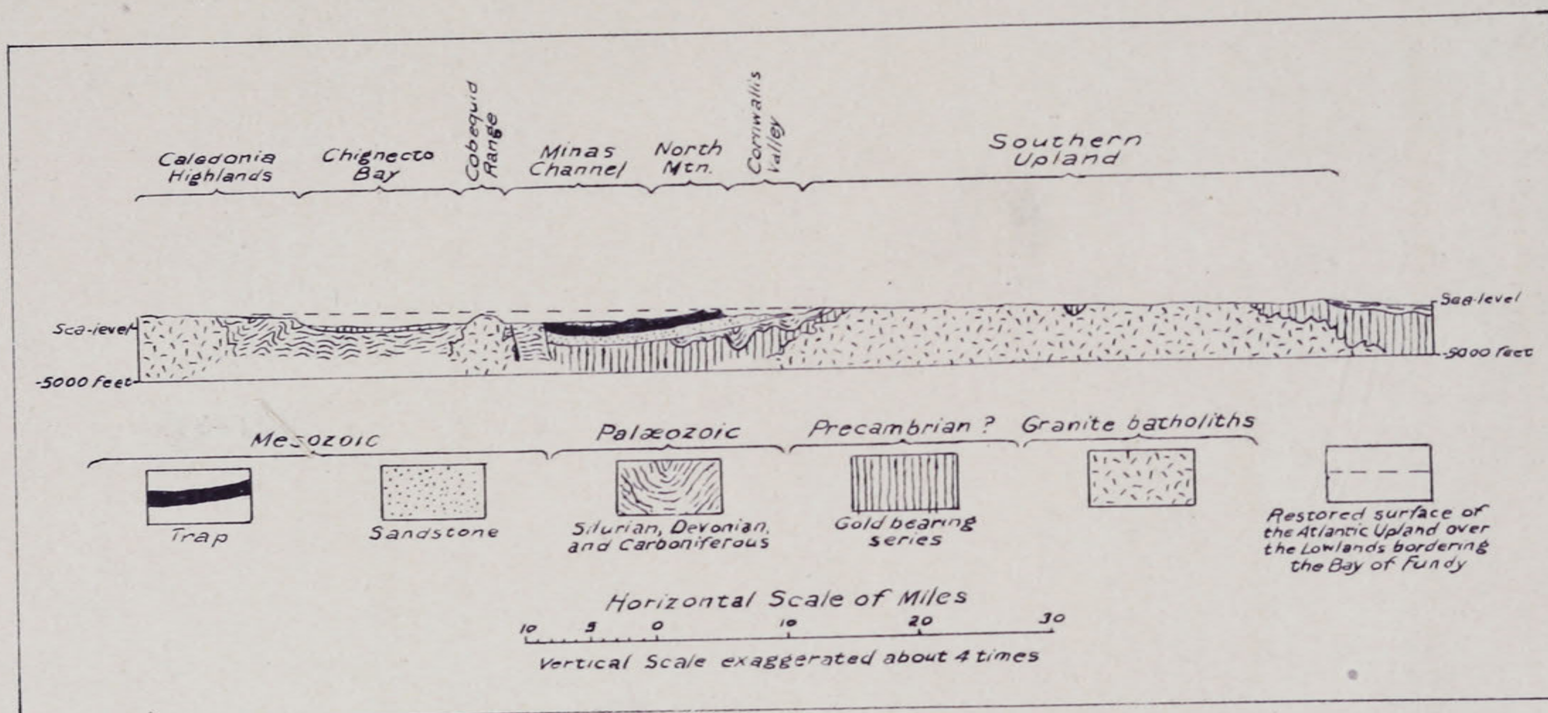
Viewed at close range this elevated region has a mountainous aspect. This belies its real character, for it rarely exceeds 1000 feet in elevation and the average is about 900 feet. From a distance, the even height of the subsidiary hills is apparent and their rounded summits merge to form a rolling surface--in reality a residual plateau.

Drainage

The Cobequid upland forms a divide, from which the drainage is south into Minas Basin and Cobequid Bay, and north into Northumberland Strait. Although this watershed is low in comparison with general Appalachian elevations, it comprises the highest chain of hills in Nova Scotia. The principal rivers flowing to the north are the Maccan, the Philip, and the Wallace rivers. The last named has its source to the east of Folly Lake and flows as a small stream through the Wentworth Valley. Flowing southward and originating in Folly Lake is Folly River which, with the Debert, Chigamois, and North rivers, flows into Cobequid Bay. Immediately to the west is Great Village River, and flowing into Minas Basin is Economy River. These southward-flowing streams are all relatively short.

Physiography

The Cobequid Mountains, together with the Southern Plateau, North Mountain, the Pictou-Antigonish Highlands, and the highlands and Northern tableland of Cape Breton Island, form the upland districts of Nova Scotia. These areas match-up in elevation with the highlands of New Brunswick, Gaspe, and Newfoundland to form a unit in what can be recognized as an uplifted and subsequently dissected peneplain, which Daly has correlated with the Cretaceous peneplain of New England. These remnants of a once very extensive flat-lying area are grouped together and conveniently termed the "Atlantic Upland." Besides their conspicuous elevation above the surrounding portions of the country, the different parts of this physiographic element have another relationship in common. Starting at sea-level along the southern coast of Nova Scotia, their elevations show a gradual increase both northwestward to the Highlands of New Brunswick and Gaspe, and northeastward to the table-



Generalized geological cross-section from the Caledonia highlands, N.B., to Chester, N.S.

lands of Cape Breton, Newfoundland, and Labrador. This relationship is well brought out in the accompanying generalized cross-section, which shows diagramatically the tilting which has resulted from a general upwarping of the area. The Cobequid Mountains, it will be seen, play an important part in maintaining the general level of the Atlantic Upland.

Like all the other upland areas of the Acadian Physiographic Province, the Cobequid Chain owes its topographic expression to the resistant character of the rocks of which it is composed. The uplift after the formation of the Cretaceous peneplain inaugurated a new cycle of erosion, which was instrumental in wearing down the weaker sandstones and shales of the surrounding lowlands. These lowlands constitute another truly peneplained surface which, according to Daly, dates from the Tertiary period.

One of the most conspicuous topographic features of the Cobequid Mountains is the Wentworth Valley Pass, through which the Canadian National Railway crosses this mountain barrier in its course to Nova Scotia proper. By using this gap in the ridge, the railway avoids a detour of many miles either to the west or east. The summit of the pass is at Folleigh, which has an altitude of slightly over 600 feet, and were it not for the gap the railway from Truro to Amherst would have to cross the Cobequids at the average summit level of about 900 feet.

Throughout the Cobequids, the great depth of the carved valleys seems, at first sight, difficult to account for in view of the relatively small size of the streams occupying the depressions, especially when we consider the narrowness of the divide from which these streams originate. But when we consider the vast amount of erosion that has taken place in reducing the surrounding lowlands from the 900-foot to the present level, the erosion represented by these deep V-shaped valleys appears small in comparison.

The Wentworth Valley Pass is unique, however, in that it is decidedly too wide and too deep to have been eroded by the streams which now occupy it.

Folly Lake is situated at the highest point of the floor of the Pass, extending over an area of about 200 acres at an elevation of 605 feet. The relief here is about 200 feet and the pass is nearly as wide at its highest point as it is where it opens into the lowlands on the north and south sides of the range--that is excluding the large amounts of glacial drift which occupy the sides and floor of the valley. The uniformity in width of the valley, and its size in relation to the streams now occupying it, suggest immediately that this valley marks the course of a great transverse river. As a result of stream piracy, the water gap was converted into a wind gap. Then, as the lowlands on each flank of the ridge were reduced in elevation, smaller streams lowered the levels of the two ends of the gap. Folly Lake owes its existence to the blocking of the gap by large masses of glacial drift deposited when the retreating ice-sheet was at the northern flank of the ridge and a tongue of ice still lingered in the gap.

Another wind gap, at Parrsboro, is even more striking in that its flat floor has an elevation of only 85 feet above sea-level at its highest point, and the general relief between the summit of the range and the valley floor is everywhere about 500 feet.

The question that immediately suggests itself is, what of the old paths of the rivers that formed these gaps? We shall consider here the case of the Wentworth Valley Pass, as being the more closely related to our present study. The floor of the Pass probably stands at about 300 to 400 feet above the surrounding plains. The process of denudation that has lowered the lowlands by this amount since the abandonment of its channel by the presumed transverse river has evidently obliterated the valley this river had carved on the plains. Glacial drift, also, has doubtless played a part in concealing the former river valley. We can assume, however, that the river flowed southward, following the slope of the Atlantic Upland.

Goldthwait has suggested that the Musquodoboit River has a possible connection with the Wentworth gap. Below Wyse Corner, the course of this river is consequent on the Atlantic Upland. That part of the river above Wyse Corner is an adjusted tributary or "subsequent" river. At Wyse Corner the river makes a sharp right-angled bend before leaving the softer rocks and entering on its southeast course through the Southern Plateau country. This latter portion of the river is almost directly in line with the Wentworth Valley gap, from which it is distant about 50 miles.

Since, in the intervening stretch, there is no evidence of a former connection between the Wentworth and the Musquodoboit River valleys, Goldthwait's suggestion must be regarded as an interesting possibility only.

III. Previous Work

Before proceeding to a discussion of the general geology of the area, an outline of the history of exploration in the district is appropriate.

The results of the earliest work on the geology of Nova Scotia are contained in a paper by C. T. Jackson and F. Alger of Boston. This paper first appeared in 1828 in Silliman's American Journal of Science, and in 1832 it was published as a 'separate' under the title of "Mineralogy and Geology of Nova Scotia." It is devoted principally to a description of the trap and sandstone of the North Mountain region and a determination of the zeolites and other minerals associated with the trap rocks. Apart from its historical interest, the paper is of little value at the present time. It is illustrative, however, of the aptitude the pioneers of geology in this country had for correlating isolated facts over widespread areas under adverse conditions. Speaking of the granite of the Province, the authors (1) say, "On the authority of Messrs. Smith and Brown we also add, as another locality of this rock, Cobequid Mountain in Cumberland County......" This is the earliest mention of the Cobequids in a geological paper. In the geological map accompanying the paper, the Cobequids are shown as an oval area about six miles long just north of Cobequid Bay and coloured in as "granite with black mica."

The Messrs. Smith and Brown of whom the above authors made mention are cited (2) in Dawson's third edition of Acadian Geology as having made "an important addition.....to the geology of the Province in 1829, in a chapter contributed to Haliburton's History of Nova Scotia."

In 1836 a book entitled "Remarks on the Geology and Mineralogy of Nova Scotia" was published in Halifax. The author's name is Abraham Gesner, a Parrsboro surgeon. Living at the west end of the Cobequids, he was better able to judge of their extent than other writers. He states (3), "With much labour has the Cobequid Chain of mountains been traced from one side of the Province to the other; and notwithstanding we might claim the original discovery of its continuation, and boundaries, and were the first to mark its outline upon the map of the Province." We shall refer later to his work when discussing the earlier views on the geology of the area.

In 1855 the first edition of Sir William Dawson's Acadian Geology appeared, and in 1868 a second, revised and enlarged edition was published. In the map accompanying the latter the Cobequid Mountains are shown in their full extent as patches of "Granite, Syenite, etc." intruding the upper Silurian.

Prior to this, in 1863, Logan's "Report of Progress" appeared, but in it no specific mention is made of the Cobequids and the reader is referred to Dawson's book for information on the Acadian region.

In the Geological Survey Report for 1872-73 the results are published of observations by Alfred R. C. Selwyn on the Acadia Iron Ore Deposits which were for many years worked at what is now Londonderry, a few miles southwest of Folleigh.

Accompanying the report are some analyses of the ore by B. J. Harrington and C. Hoffmann. Analyses, by the latter, of iron slag from the Acadian Iron Company's blast furnace appear in the 1874-75 Report, and of specular ore from the Acadia Mines in the 1873 Report. The specular ore analyses are included in a report by Harrington on the Iron Ores of Canada, which contains some interesting notes on the Acadia Mines.

In 1878 the third edition of Dawson's Acadian Geology appeared. The revision took the form of a supplement, which contains some interesting facts regarding the geology of the Cobequids, summarizing the results of work that had been carried out since the publication of the 1868 edition.

A report by R. W. Ells in the 1885 Geological Survey Report contains the results of investigations in portions of Cumberland and Colchester counties. This is perhaps the first detailed report of a more theoretical nature made on the area, and contains an account of a traverse made along the Wentworth Valley section.

During the summers of 1887 to 1891, Hugh Fletcher was working in this area and the report on his investigations is contained in the Annual Report of the Geological Survey for 1890-91. This work also contains notes on a survey along the railway in the Wentworth Valley. His geological map of the district, based on chain surveys made by Scott Barlow during the years 1871 to 1878, and on odometer and pace surveys made by himself and his assistants, appeared in 1905. In 1892 Mr. Fletcher continued the work of the previous years, making a study of the more westerly parts of the Cobequids.

In the fall of 1893, R. Chalmers made an examination of the surface geology of the western end of the Cobequids and the results of his findings are embodied in a report contained in the Annual Report of the Geologic Survey for 1894.

Up to his death in the fall of 1909, Hugh Fletcher and his assistants were engaged in work in and around Cumberland County. Most of his detailed work in the Cobequids, however, had been completed prior to 1893.

In 1916 A. O. Hayes, while working in the Maritime Provinces, spent two weeks in a study of the Londonderry Iron Ore Deposits. His paper is contained in the Summary Report of the Geologic Survey for that year.

In 1924 J. W. Goldthwait's "Physiography of Nova Scotia" was published by the Geological Survey in Memoir form. The substance of his account of the physiography of the Cobequids is embodied in the first part of this thesis.

Others who have described various phases of the geology of the Cobequids, including the Wentworth Valley district and the iron ore deposits, are Prof. J. E. Woodman, Henry Louis, Rev. Dr. Honeyman, and Professor Hind.

GENERAL GEOLOGY

I. Introduction

The pre-Carboniferous of the Cobequid Upland is known as the Cobequid Series. Up to the present, sufficiently detailed geological work has not been done on the complex to determine definitely the relationships of the several rock types of which it is composed. The physiographic expression of the area is due mainly to this complexity of rock type. The Series includes both igneous rocks and metamorphosed sedimentary rocks. The former range in acidity from diabase to acidic granite. The metamorphic rocks are chiefly dark quartzites, black slates, red and green argillites, and green micaceous and chloritic schists, but there are in addition small areas underlain by crystalline limestone. In the central portions of the range these altered sedimentary rocks occur only as scattered remnants. On the southern flank, however, there is a considerable development of them, with associated iron ore deposits that occupy a zone of fissuring extending east and west of Folly River.

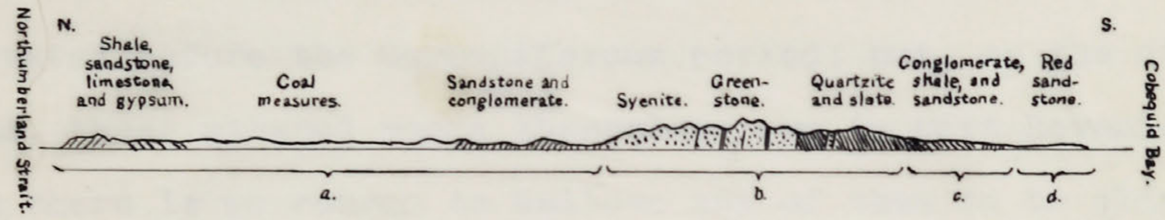
On the flanks of the Upland, the rocks of the Cobequid Series are overlain unconformably by Carboniferous beds (Mississippian and Pennsylvanian) which dip away from the complex and which also underlie the adjacent lowland.

Earlier Views

Besides the historical interest attaching to his work, Gesner's observations in the Cobequids are significant in that he recognized, in part, the general structure of the upland and its relation to the surrounding plain. He (4) says, "The granite and other primary masses of these mountains appear to have been forced upwards through the strata of the secondary rocks. This opinion seems fully established, where the strata on each side of the chain are seen leaning towards and upon the more elevated granite and porphyry. On the Cumberland side of this chain the strata lean to the southward and dip north. On the south side the layers incline northward dipping in the contrary direction." This expresses in a few words what Dawson later pictured in a diagrammatic cross-section of the ridge in the supplement to the third edition of Acadian Geology.

The map accompanying the first edition of Acadian Geology shows the Cobequid Mountains in their true extent and as consisting of two series of rocks; those forming the northern half of the chain as "Syenite, Porphyry, Greenstone, etc."; those of the southern half as "Devonian and Upper Silurian, mostly metamorphosed." The latter are shown as occupying the whole southern half of the range, encircling the eastern end, and extending on the north side of the ridge westward as far as Wentworth, where the unconformably overlying beds of the Carboniferous System are in contact with the igneous rocks. The accompanying diagram, (page 16) reproduced from the first edition of Acadian Geology, shows what Dawson thought at the time to be the structure of the range and the surrounding country. The section passes through the Cobequids two miles west of Wentworth Valley.

Section across the Cobequid Hills from the mouth of Great Village River to Pugwash--Distance 20 miles



a.	Carboniferous district of Cumberland.	c.	Carboniferous district of Londonderry.
b.	Metamorphic band of the Cobequid Hills.	d.	New red sandstone of Londonderry.

In the table of rock formations appearing in the text, Dawson (5) has listed opposite Devonian, "Fossiliferous Slates of Bear River...... Perhaps also parts of the metamorphic rocks of the Cobequid and Pictou Hills." Opposite Upper Silurian appears, "Possibly some of the metamorphic, non-fossiliferous rocks of Nova Scotia and Cape Breton....." We see, then, that up to this time, owing to the alteration and disturbance that these rocks had undergone, and also to the paucity of fossils in the district, no definite age had been assigned to the Cobequid Series, except, of course, that it was older than the Carboniferous of the surrounding plain.

Referring, however, to M. Jules Marcou--who, in his application of De Beaumont's theory of the parallelism of mountain ranges of like age, would have assigned the Cobequid Mountains and the hills on the east side of Bras d'Or

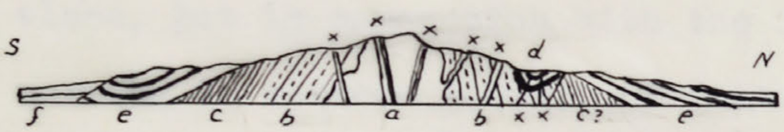
Lake to a system of elevations older than the Lower Silurian--Dawson states that he considers this "much too ancient." He (6) says, "I have already stated that the rocks of the Cobequid Mountains have been altered and elevated before the Carboniferous period; but, on the other hand, these altered rocks themselves are in part Devonian, and there is no reason to believe any of them to be older than upper Silurian. I would therefore refer the great line of dislocation of the Cobequids......to the close of the Devonian period."

In the supplementary chapter to the first edition, dated August 1860, some fossils from Earlton and New Annan at the eastern end of the chain are referred to the Upper Ariasig series, and Dawson expresses a belief that the greater part of the sedimentary rocks of the Cobequids could be correlated with this series, which was regarded as the upper part of the Silurian. In the map accompanying the second edition of the book, the igneous rocks have been reduced to several elongated areas and the rest of the Cobequids are mapped as Upper Silurian.

In 1878, a supplement to the second edition appeared. In the meantime fossils discovered at Wentworth in the supposed extension of the Silurian of Earltown had been examined, and Dawson correlated the Wentworth beds with the Lower Arisaig series, making them equivalent to about the Clinton of New York.

As already stated, the pre-Carboniferous rocks of the Cobequids are termed the Cobequid Series. This is according to the present classification, but Dawson evidently made a distinction between the "great series of slates, quartzites and volcanic rocks" underlying the Wentworth beds and the Wentworth series itself. Speaking of the arrangement of these "pre-Wentworth" rocks in the central part of the Cobequids, he (7) says, "There is a central mass of red intrusive syenite or syenitic granite...... This sends veins into the overlying beds, and is itself penetrated by dykes of diabase. On this central mass rests a great thickness of felsites, porphyries, felsitic agglomerates, and diorites evidently of volcanic origin. Upon these are gray, black, and reddish slates and quartzites, with a bed of limestone, and penetrated by metallic veins. The lower volcanic portions and the upper, more strictly aqueous, parts might perhaps be separated as a Lower and Upper Cobequid Series; but the difference appears to depend rather on the mode of deposition than on any great difference of age." In the accompanying diagram (page 19) showing the general structure of the Cobequid range in a cross-section through the Wentworth Valley, we see his interperetation of the relationship of the two series. By comparison with the cross-section on page 16 we see also the development of his ideas as regards the Cobequids since 1855. The following comparative table gives his correlation of the rocks of the Cobequids with those of similar age in England.

General Structure of the Cobequid Range.



(a) Massive Syenitic Granite.
(b) Lower Cobequid Series, Felsite, Porphyry, Agglomerate, etc.
(c) Upper Cobequid Series. Ferriferous Slates and Quartzite.
(d) Wentworth Fossiliferous Beds.--Upper Silurian.
(e) Carboniferous.
(f) Triassic.
(x) Veins of Syenite and Diabase.

COMPARATIVE TABLE (8)

England, etc.	Nova Scotia and New Brunswick
Upper Silurian	
Ludlow, Wenlock, and Llandovery or Mayhill.	Upper Arisaig Series, Lower Arisaig, New Canaan, Wentworth, and Restigouche Series.
Lower Silurian	
Caradoc and Bala, with Snowdon Felsites and Ash Beds, Coniston and Knock Series.	Upper Cobequid Series, Slates, Felsites, Quartzites, and Greenstones.
Great Felsite and Trap Ash Series of Borrowdale (Ward).	Lower Cobequid Series, Felsites, Porphyrites, Agglomerates, and massive syenite of Cobequids, Pictou and Cape Breton.

R. W. Ells is the next investigator whose work in the area would warrant his being considered an authority on the subject. The extent of his labours was not confined to Nova Scotia alone, but in connection with the Cobequid area he had been working in eastern Albert and Westmoreland counties in New Brunswick, where he had encountered considerable pre-Cambrian in the Caledonia Mountains. He immediately detected a similarity between the Cobequid series and the pre-Cambrian of New Brunswick. We shall quote in full a paragraph (9) from his report as illustrative of the view he takes of the age of the rocks.

"In general it may be stated that in lithological character, the Cobequid Series is almost identical with the pre-Cambrian of Southern New Brunswick, consisting of a great thickness of crystalline rocks. Among these are large areas of syenite and diorite, the former both red and green or the protogine of the New Brunswick series, often epidotic, red crystalline felsites sometimes porphyritic, schists of various kinds, chloritic, talcose, micaceous and hornblendic, quartzite, gneiss and hard green slates with crystalline limestone. The schistose portion apparently rests upon the syenites and diorites, which seem to constitute the bulk of the central and northern areas. On the north the series is overlaid, at Wentworth, by the fossiliferous Silurian just described and, elsewhere, by Lower Carboniferous sediments, while on the south the belt of rocks containing the iron ores extends along its whole length in unconformable contact."

Thus we have again to define our Cobequid Series. The statement at the end of the preceding paragraph, "while on the south the belt of rocks containing the iron ores extends along its whole length in unconformable contact", leads us to infer that Ells did not include these in the Cobequid Series, and that what he calls the Cobequid Series is really Dawson's Lower Cobequid Series plus the syenite and diorite. When Dawson described his Upper Cobequid Series as "...gray, black, and reddish slates and quartzites, with a bed of limestone and penetrated by metallic veins" he was evidently referring to the same series which Ells called the "rocks containing the iron ores." In his description of the Silurian, Ells named these the Iron Ore series and accepted tentatively the age assigned to them by Dawson and Honeyman. He (10) observes, however, "in lithological characters they very closely resemble Devonian rocks of other parts of the Province as well as of New Brunswick", thereby anticipating the results of later findings.

What Ells did, then, was to lower the age of Dawson's Lower Cobequid series from Lower Silurian to pre-Cambrian. He was perhaps more justified in assigning this age to them on a lithological correlation with rocks of the neighbouring Caledonia Mountains of New Brunswick than Dawson was in his lithological correlation with the rocks of England. As a consequence of his correlation, Ells would have to ascribe the dikes and other igneous masses which cut the Iron Ore Series to a later intrusive period or periods.

We now come to Hugh Fletcher's work in the area. Having spent more time in the Cobequids and neighbouring districts than any investigators before or since, we may consider his views as more developed and enlarged than those of other observers.

The rocks at Wentworth he accepts as Clinton, on the authority of his predecessors and on the basis of the determination of fossils from the series by Ami and others.

Ells, it will be remembered, suggested that the metamorphic rocks of the Iron Ore Series could be classed as Devonian on lithological grounds. The discovery and determination of abundant fossils in the series confirmed this opinion to some extent. These strata have in places yielded plants similar to those found in the Riversdale-Union Group, and Fletcher correlated them with this group. In his report on the area, they are classed as Middle Devonian.

That the Riversdale-Union Group is Devonian, however, is a matter of grave doubt, and there has been considerable controversy on the subject. Arguments based on palaeontological evidence place the strata at about Millstone Grit age. The entire Cobequid Series, then, Fletcher regarded as altered Silurian and Devonian beds cut by post-Devonian intrusives, for, he (11) says, "....red syenite, diorite, felsite and similar rocks cut no strata newer than the Devonian."

II. Brief Description of the Carboniferous Rocks

We come now to a consideration of the Carboniferous rocks which lap up against the flanks of the Cobequids everywhere except at the extreme western end at, and near, Cape Chignecto.

According to Fletcher, the lowest division of the Carboniferous represented here is the Carboniferous conglomerate which comes in contact with the Devonian Iron Ore Series on the southern slope of the mountains. We must note first that Fletcher (12) says, "....there is nothing to fix the precise age of these rocks except their strong resemblance to the lower Carboniferous of other localities." This admittance has some bearing on the controversy regarding the age of the Riversdale-Union Series, which will be referred to later.

Proceeding southward along the railway, after passing the Devonian, the Carboniferous conglomerate is encountered, holding pebbles of all the earlier rocks, those of the igneous rocks being especially conspicuous and attaining as much as a foot in diameter in places. Interbedded are bands and patches of brownish and greenish-grey sandstone. Here the railway swings sharply to the west, but along Folly River, where there is a continuous section, the arenaceous beds, with very thin interstratified beds of coaly matter become predominant. Following and overlying this are greenish and dark grey argillaceous shales, succeeded in turn by grey and brownish sandstones. Further to the south, conglomerate again appears and is practically continuous to the faulted contact with the Triassic about two miles northwest of East Mines.

On the north side of the Cobequids, at Wentworth, brownish and grey sandstones and shales rest unconformably on the limited patch of Silurian, and elsewhere on this side of the mountains they come in contact with the altered volcanics (?) and igneous rocks of the Cobequid Series. Near Wentworth, the beds dip north at about 45°. These rocks are mapped as Carboniferous Limestones by Fletcher, and are believed stratigraphically immediately above the Carboniferous Conglomerate of the south side of the ridge.

Overlying these strata further to the north is the Millstone Grit formation of early Pennsylvanian age. The basal member consists of conglomerate interbedded with sandstone and shale. The upper part is more varied in character, consisting of greyish-green sandstone interbedded with brown and green shale and sandstone, with coarser grit and conglomerate beds occurring towards the top.

Above this are Permo-Carboniferous strata, an erosional unconformity separating them from the Millstone Grit. These rocks are known as the New Glasgow series and comprise brown and greenish-grey conglomerate, arkose sandstone, and shale, all alternating recurrently. They lie in a broad open syncline plunging gently eastward. To the north, the faulted Clairmont Anticline brings the Carboniferous Limestone to the surface again, and beyond this, on the northern limb of the anticline, the Millstone Grit, followed by Permo-Carboniferous strata, is again repeated.

The Windsor Series, in which occurs the Malagash salt deposit, is probably related in age to the Carboniferous Limestone series and is brought to the surface along the axis of an anticlinal fold stretching almost continuously from Malagash Point westward to Cumberland Basin.

The Productive Coal Measures, ranking in age between the Millstone Grit and the New Glasgow Series, is missing in many places, probably having been removed by erosion along anticlinal folds during the period represented by the erosional unconformity.

The following is a provisional classification of the Carboniferous formations of the district:

Permo-Carboniferous	New Glasgow Series
Middle Pennsylvanian	Productive Coal Measures
Unconformity	
Early Pennsylvanian	Millstone Grit
Mississippian	Carboniferous Limestone Carboniferous Conglomerate
Uncomformity	
Pre-Mississippian	Cobequid Series

As regards the controversy concerning the age of the rocks flanking the south side of the Cobequids, we can say that the Iron Ore Series is in part at least the equivalent of the Riversdale-Union Group. The question then centers about the age of this latter group. Fletcher contended that it belonged to the Devonian while Kidston and White place the horizon of the strata at or about that of the Millstone

Grit. If the latter view is correct, Fletcher's Carboniferous Conglomerate, which overlies the Iron Ore Series, must belong to a much higher horizon than that he attributed to it, and the age of the intrusives rises also. We must note again, however, that Fletcher left the question open when, referring to the Carboniferous Conglomerate, he said, "....there is nothing to fix the precise age of these rocks." In the following, the Iron Ore Series will be tentatively considered as Devonian, following Fletcher's view.

III. Detailed Description of the Wentworth Valley Section

The area traversed in the survey with which this thesis deals includes mainly the strip along the Canadian National Railway starting at the point where the old road to Wentworth swings north across the railway track. This is about $2\frac{1}{4}$ miles west of Wentworth Station. From Wentworth Station the traverse continues in a direction somewhat east of south for about $8\frac{3}{4}$ miles to where the track swings sharply west and crosses the main road from Amherst to Truro.

In addition to this, Smith Brook, which is a mile south of Wentworth Station, was paced upstream for about $1\frac{1}{4}$ miles, and on the northern flank of the Cobequid chain parts of the east branch of Roaring River, and also parts of Giles Brook and Whetstone Brook, were surveyed.

On the east branch of Roaring River, which flows just east of the road to Higgins Mountain, no outcrops are encountered until about one mile south of the railway, where dense green argillites are intruded by diabasic rock and both are cut by a granite dike striking northeast.

Proceeding up-stream, argillites are again exposed, and then, towards the source of the river and near the summit of the mountain, is a mass of diabase which is succeeded within 100 feet by coarse grained granite. East of here and towards the head of Giles Brook a large cliff-like exposure reveals an altered chloritic quartz porphyry shot through with small quartz stringers and aggregates of pink syenitic material. At the head of Giles Brook the green argillites are again seen.

Along the railway, the first outcrop appears about one mile east of the point where the old road to Wentworth crosses the track. Here occurs a small outcrop of dark grey finely laminated shale and 50 feet to the west is red soft sandstone containing pea-sized quartz pebbles. Lithologically, these beds appear to belong to the Carboniferous Limestone series. The outcrops are small and a reliable determination of the attitude of the beds could not be made. The steep dip to the north characteristic of the Carboniferous near its contact with the Cobequid Complex is not developed however since it would be quite apparent even in a small outcrop.

About 500 feet farther to the east, Caldwell Brook has been diverted to flow through a tunnel under the railway embankment. At the north end of the tunnel massive grey sandstone with interbeds of mixed chocolate-brown and grey shales are exposed with strike N 83° E and dip 45° N. These belong to the Carboniferous Limestone series. At the south end of the tunnel(which has a length of about 300 feet) dense dark grey and greenish argillites appear. These are much jointed and slickensided and are cut by small stringers of granitic material. These rocks are lithologically similar to the green argillites appearing in the vicinity of Giles Brook and they probably belong to the same series. Ells, it must be noted, considers them a part of the Wentworth series, but they have more the general aspect of the argillites of the vicinity of the east branch of Roaring River and are considered here as unconformably underlying the Wentworth series and are grouped in with the quartz porphyries occurring near the head of Giles Brook. This group of rocks, believed by the writer to be older than the Wentworth series, will be tentatively designated the "pre-Wentworth Series."

About 500 feet eastward from the tunnel the Silurian rocks of the Wentworth Series first make their appearance. On the south side of the railway track is a small outcrop of red rubbly altered shale. This is overlain to the east by greenish-grey fine-grained argillaceous sandstone and a considerably altered and somewhat rubbly variety of the latter. These beds strike N 50° E and dip steeply to the southeast. About 3500 feet beyond this, at a point 900 feet west of the main branch of Whetstone Brook, fine-grained sandstones again make their appearance and are in places considerably altered by the intrusion of fine-grained gabbro masses and diabase dikes which, in places, hold inclusions of the altered sedimentary rocks.

Where the stream crosses the railway, a patch of gabbro intrudes the Silurian beds on the north side of the track and has considerably altered them. Farther downstream the rocks exposed are soft greyish and dark bluish-grey shales and rubbly shales, all dipping steeply to the south. The last outcrops of these Silurian beds occur at the forks of the main and east branches of the brook. Below the forks the Carboniferous Limestone sediments occupy the stream striking east and west and dipping to the north at about 36°.

On the south side of the track where the east branch of Whetstone Brook crosses it there is a fine development of these altered Silurian sediments striking east and west and dipping steeply south at about 77°. The rocks are greyish indurated shales. At the north end of the tunnel through which this stream flows across, from one side of the track to the other, a green quartzitic sandstone is cut by a diabase dike striking N 60° W and dipping southwest 54°.

As regards the structure of the Wentworth series, Ells (13) states: "The Silurian rocks of this locality lie in the form of a narrow basin, the reverse dip to north being seen in the first cutting near (500 feet northwest of) the station. The fossiliferous beds, therefore, of that locality, occupy the center of the synclinal while the rocks of Caldwell Brook, to the west, probably represent the lower members."

It will be remembered that Dawson, in his diagrammatic cross-section of the Cobequids, also showed the structure as synclinal. It is difficult to picture such a relationship as existing, however, when only about 800 feet west of the cutting that Ells mentions the Silurian sediments dip steeply to the south at about 77°. Failure by the writer to observe the "reverse dip to the north" could be well attributed to inexperience but if it does exist the relations are more in the nature of a hinge fault, the fault plane running normal to the strike of the bedding. Fletcher, in his map published in 1905, does not indicate a synclinal structure.

In the cutting, which Ells mentions, 500 feet northwest of Wentworth station, gabbro and diabase, the latter slickensided along small joints, again make an appearance and these are followed by greyish-green argillites cut by numerous quartz-pyrite stringers. These argillites resemble those of the pre-Wentworth series. They are followed farther south by isolated outcrops of quartz porphyries and a small mass of gabbro. The porphyries range from grey to dark grey in color and in one outcrop near Smith Brook the rock assumes a pinkish tinge due to the predominance of pink orthoclase phenocrysts. The areas in between the porphyries are drift covered, indicating that the sediments they intruded were very much less resistant in character than the argillites occurring elsewhere.

Along Smith Brook the porphyries appear considerably altered and chloritic in appearance and resemble the quartz porphyry outcropping near the head of Giles Brook. Here also they are impregnated with pink feldspathic material due to the proximity of a granite mass to the south. About 1000 feet upstream from the track, granite occurs and up a small branch from the south is intruded by a vertical dike of diabase striking almost due south. Then, on the main stream, gabbro is succeeded by a dike like mass of granite porphyry. The two walls of the dike cannot be seen. It is in contact, however, on the west with gabbro which extends for four or five hundred feet upstream where granite again occurs and continues to the end of the traverse about one mile west of the track.

South of Smith Brook granites and syenites prevail, along the track, for a distance of about $2\frac{1}{2}$ miles. About 2000 feet south of the brook one passes from a normal granite to a small mass of gabbro within 500 feet. There is no contact. This gabbro is impregnated with pink feldspathic material and cut by granite ~~again~~ stringers. About 1000 feet south of the gabbro, granite again occurs and is immediately followed by a dark amphibolitic rock also impregnated with pink feldspathic material.. About 1200 feet south of this a contact between the amphibolite and granite occurs. The contact is not sharp nor distinct but within a certain zone granitic material is shot through the amphiolite and the adjacent granite is seen to contain inclusions of the latter. South of this contact about 1500 feet, an isolated outcrop of gabbro appears. Here there is not such an evident impregnation with granitic material but there is nevertheless a considerable development of pink feldspar.

Beyond here for about 2000 feet granite and syenite prevail, immediately followed by a small mass of gabbro which shows an impregnation with pink feldspars near a syenitic mass. South of the gabbro an isolated outcrop of syenite is cut by a dike of diabase striking N 20° E and almost vertical.

For about three-quarters of a mile beyond this the exposures are of granite, and then, 500 feet beyond the last granite outcrop, gabbro again occupies the railway cuttings. There is here, however, no impregnation with granitic material. For about $1\frac{1}{2}$ miles there are no outcrops until near the foot of Folly Lake where an isolated patch of gabbro appears.

About 3500 feet south of the foot of Folly Lake the Devonian Iron Ore series occurs in the cuttings. The first exposures are of grey metamorphic quartzites. Then, in the next cutting, about 300 feet farther south, occurs a small mass of gabbro intruding a brownish-grey quartzite, somewhat flinty in appearance. Schistose grits are then exposed showing bands of slaty material and these are followed by b banded quartzites succeeded again by schistose grits. The strike throughout is about N 60° E and the dip is southeast at about 50°. An outcrop of greenish-grey indurated sandstone follows and to the end of the cut dikes of diabase and small gabbro masses intrude the sediments.

About 200 feet south of the end of the cut a grey flinty schistose grit strikes N 60° E and dips southeast 52°. About 150 feet south of here a small mass of amphibolite outcrops on the west side of the track. In the next cutting deformed quartz porphyry comes in contact with a small mass of diabase. The age relations are obscure.

From here to within about 3000 feet of the point where the railway crosses the main road from Truro to Amherst, amphibolites, diabases and gabbros prevail. In one cutting there is an abrupt change from amphobolite to a bluish-black basalt with phenocrysts of plagioclase. The basalt is quite massive.

Following the igneous rocks there is again a development of sedimentaries which continue practically uninterrupted to the railway crossing. In this group a greenish-grey altered sandstone is succeeded by a fine-grained purple argillite striking N 20° E and dipping southeast at about 40°. Greyish-brown and grey sandstones then follow, the latter being jointed and cut by small veins of ankerite. Following these outcrops a small patch of diabase intervenes before the beginning of the Carboniferous Conglomerate at about 700 feet northeast of the point where the railway crosses the main road from Truro to Amherst. These sediments strike nearly east and west and dip south at 57°.

IV. Description of Rock Types

1. Introduction

In the preceding description of the Wentworth Valley section, the general appearance and character of the rocks have been indicated as the courses of the several traverses were outlined. The age relations of the different groups are shown in the following table. They have been suggested by the writer's observations in the field, the palaeontological and stratigraphical conclusions reached by previous workers, and the petrographical determination of the various rock types. In connection with the latter it may be said that in many cases the true character of the rocks could not be definitely established macroscopically. For instance, many of the dense green argillites and diabases are very similar in appearance and where the structural relations could not be ascertained it was difficult to classify a specimen of this type as a metamorphosed sedimentary or igneous rock. The various reasons for assigning the several rock types and groups to their respective horizons will be discussed later under "Age Relations."

2. Table of Rock Groups

Period	Series	Character
Carboniferous (Mississippian)	Carboniferous Limestone	Ss. and shs. on northern flank of Cobequids
		Unconformity
	Carboniferous Conglomerate	Congls. and ss. on southern side of Cobequids
	Unconformity	
Pre-Carboniferous	Intrusive Series	3. Diabase dikes intruding granite and syenite 2. Granite and syenite and associated dikes 1. Gabbro and amphibolite and associated dikes
	Unconformity	
Devonian (Middle)	Iron Ore Series	Metamorphic quartzites, banded quartzites, slates, schistose grits, argillites and sandstones with veins of ankerite
	Unconformity	
Silurian (Medina and Clinton)	Wentworth Series	Red and grey rubbly shs. Green quartzitic and greenish grey sandstones etc.
	Unconformity	
Pre-Silurian	Pre-Wentworth Series	Argillites and quartz porphyries of the northern flank of the Cobequids

3. The Sedimentary and Metamorphic Rocks and pre-Silurian Intrusives

1. Pre-Silurian

In this group are classed the argillites of the east branch of Roaring River, Giles Brook, and Caldwell Brook, and the quartz porphyries of the vicinity of the two first named brooks, Smith Brook, and the area between Smith Brook and Wentworth Station.

a) The Argillites:

These rocks are dense green and greyish-green, having a considerably altered appearance. There is a slight tendency towards a fine banding in some outcrops, but in general hand specimens appear massive and structureless except where there has been a development of jointing.

Microscopically, these rocks are usually extremely fine grained and clastic in appearance. Banding is never conspicuous, although it was noted in some of the thin sections examined, being due to the parallel orientation of the flaky minerals.

The principal clastic material consists of subangular grains of quartz enclosed usually in a chloritic and sericitic aggregate. In a specimen from the head of Giles Brook the quartz is more sharply angular and is accompanied by fragments of plagioclase and orthoclase, so that the rock assumes the aspect of an argillaceous grit.

These rocks are termed argillites on account of their metamorphic appearance, with the development of the flaky minerals, and their lack of conspicuous banding.

The following description of slide #83, made from a specimen collected at the south end of the tunnel on Caldwell Brook, is typical of the group.

Slide #83 Argillite.

This rock is extremely fine-grained with here and there irregular patches that are more easily resolvable and present a quartz mosaic appearance. This is probably re-crystallized material. In ordinary light the slide presents a clastic appearance with detrital grains of quartz surrounded by a dark colored chloritic cement. Mixed in with the chlorite and quite conspicuous under crossed nicols are flakes of sericite.

The finer portions of the rock are chloritic, with sericite occurring somewhat subordinately and obscured quartz aggregates distributed throughout.

A few minute grains of epidote, rutile, and zircon are present. Specks of brown iron-oxide and small grains of magnetite are abundantly distributed.

Texture.

Holocrystalline
Very fine grained, microcrystalline,
Clastic. Maculose

b) The Quartz Porphyries:

These range from grey to dark grey in color and when highly altered, as they usually are, they present a chloritic appearance with little or no evidence of prophyritic structure. The less altered varieties show conspicuous phenocrysts of quartz and feldspar in a dense groundmass.

Quartz is usually the dominant phenocrystic mineral, with feldspar, which includes orthoclase, albite and microperthite, quite subordinate. Occasionally, however, the feldspathic crystals gain the ascendency, and in one occurence the rock is an albite porphyry. Often the quartz phenocrysts show the effects of resorption, having a rounded or embayed outline, and some of them contain inclusions of the matrix. Sometimes the feldspar phenocrysts are partially replaced by a sericitic or saussuritic aggregate.

The groundmass is always a very fine grained quartz-feldspar mosaic with disseminated chloritic material and aggregates of brown and black oxide.

In the more deformed varieties, a cataclastic structure makes its appearance, with a considerable fracturing and shattering of the phenocrysts and a more pronounced development of chlorite.

These rocks are classified as quartz porphyries in conformity more or less with Holmes' definition, as "a rock containing phenocrysts of quartz and alkali feldspar, typically orthoclase, with or without mica, in a cryptocrystalline or microcrystalline groundmass.

Slide #13, representing a sample taken from a cutting about 600 feet north of Smith Brook, is characteristic of the group.

Slide #13 Quartz Porphyry

This rock consists of phenocrysts in a microcrystalline groundmass which consists of a mosaic of quartz and feldspar, together with chlorite and sericite.

The quartz phenocrysts show bubble inclusions and trains with occasionally inclusions and veinlets of the groundmass. They are partly corroded. Some retain a few crystal faces and one or two are idiomorphic.

Some of the phenocrysts are completely replaced by felted masses of sericite shreds and were possibly feldspar originally.

The feldspar phenocrysts include both albite and orthoclase. Some of them show a milk white alteration, probably to kaolin, and are quite turbid.

Irregular rectangular areas occupied by minute grains of iron oxide, are associated with sericite, chlorite, and a very finely crystalline aggregate, white by reflected light, but with high birefringence (epidote). These areas doubtless represent former phenocrysts, possibly of some ferromagnesian mineral.

With the quartz and feldspar in the groundmass are aggregates of sericite with no definite arrangement. Chlorite is often associated. One or two minute veinlets of calcite traverse the section.

Texture:

Microcrystalline

Uneven grained

Porphyritic

2. Silurian

The character of the rocks comprising the Wentworth Series has been alluded to in the foregoing description of the Wentworth Valley section. It will be recalled that these rocks are in general red, greyish, and dark bluish-grey shales, often rubbly, especially where they are in close proximity to the igneous rocks that in places intrude them. These shales are accompanied by greenish-grey fine grained argillaceous sandstones and green quartzitic sandstones.

It will be noted that these rocks differ greatly lithologically from the metamorphosed sedimentaries of the pre-Wentworth Series. The alteration of the Silurian has been more of a physical than of a mineralogical nature, resulting in the formation of rubbly and indurated facies. The metamorphism of the pre-Wentworth sediments, on the other hand, has been accompanied by widespread mineralogical changes and the rocks have a considerably different macroscopic and structural aspect.

The rocks of the Wentworth series were not examined microscopically, except for one specimen from the east branch of Whetstone Brook at the north end of the tunnel through which this stream crosses from one side of the railway track to the other. Here a quartzitic sandstone has been intruded by a prophyritic basic dike. The intrusion has resulted in the recrystallization of the sedimentary rock to a cryptocrystalline quartz mosaic with an abundant development of chlorite, pyrite, and iron oxide.

3. Devonian

These rocks are quite diverse in their characteristics, ranging from unaltered sandstones to metamorphic quartzites and slates. The macroscopic appearance of these rocks has been adequately described on an earlier page, in the account of the section from about three-quarters of a mile south of Folly Lake to the contact of the Devonian with the Carboniferous Conglomerate Series of the south side of the Cobequids.

The general petrographic characters of the metamorphosed types are indicated in Slides #41, #49 and #50. Slide #41 represents the rock in the first cutting, 3500 feet south of the foot of Folly Lake. Slides #49 and #50 are of specimens taken from an exposure about 800 feet farther south along the railway.

Slide #41 Metamorphic Quartzite

This rock is a metamorphosed quartzite, the whole presenting a quartz mosaic with some flakes of biotite and muscovite which have probably developed from chloritic and sericitic material. Between crossed nicols there is no distinction of original grains and cementing material but each element of the mosaic is clear and homogeneous, presenting an irregular boundary which fits into the inequalities of the adjoining elements. Strain shadows are prevalent throughout. In places the cement is obscured by a brown dust and a few rounded grains of zircon are present. The opaque mineral is pyrite. The micas, zircon and rounded grains of apatite make up about 15% of the rock.

Texture:

Holocrystalline

Uneven, medium grained

Mosaic, Clastic

Slide #49 Slate

This rock has a very definite parallel orientation of the platy minerals which are sericite and chlorite. The latter is predominant.

Abundant granules of feldspar occur. They are quite fresh in appearance as if recrystallized and look like quartz. As far as could be determined they are orthoclase.

A few grains of zircon are present and localized in places is epidote. What appears to be leucoxene occurs here and there although there is no occurrence of an opaque mineral.

Veins filled with feldspar, probably albite, run in random directions.

The hand specimen has a black and white banded appearance. The slide is made up of a darker band apparently and is called a slate. The hand specimen is classed as a banded quartzite.

Slide #50 Schistose Quartzite

This rock is a metamorphosed sandstone. Quartz in large and small masses makes up the greater part of the rock. All the large quartz grains have an irregular elongated oval shape resembling an augen structure, in parallel orientation--a rather rude schistose structure. Strain shadows are prevalent. A few crystals of zircon are scattered throughout.

The matrix is composed of a microcrystalline quartz mosaic. Bands of opaque minute dust-like inclusions and yellow iron stain are arranged about the augen and run through the matrix. Discontinuous bands and scattered masses of chlorite occur.

Texture:

Holocrystalline

Uneven, medium grained

Schistose, mosaic

The less metamorphosed types of the Iron Ore Series, consisting of somewhat altered greenish-grey sandstones, fine grained purplish argillites, and greyish-brown and greyish sandstones, appear mainly in a cutting, 600 feet long, situated about 2000 feet north of the point where the main road from Truro to Amherst crosses the railway.

The argillites of this group differ widely from those of the pre-Wentworth Series, being considerably softer and more in the nature of hardened shales. The name argillite was given to them, however, by Fletcher and earlier writers and is descriptive as indicating the low grade of metamorphism of these shales.

Microscopically, the sandstones present a very uniform appearance being finegrained and consisting mostly of rounded and subangular quartz grains. Other allothigenous constituents are orthoclase and plagioclase fragments and small amounts of zircon, rutile and augite in minute grains.

Typical of these beds is Slide #72, described below.

Slide #72 Sandstone

This is a fine grained sandstone somewhat similar to #70. There are not however any feldspar constituents as in #70 and the cementing material is more pronounced. The feldspar is probably represented by the large amount of sericitic and chloritic material. The granularity is about the same and the clastic grains are only fairly well rounded fragments of quartz, many of them showing a considerable degree of angularity.

Zircon, rutile and augite in very small amounts are other allothigenous constituents. A few flakes of muscovite also occur.

The cement is chloritic and sericitic with some calcareous material. The latter is concentrated at one point. It is probably ankerite as in other parts of the slide this mineral can be seen to be undergoing extensive alteration to iron oxide. The other opaque mineral is original magnetite.

Texture:

Holocrystalline

Even, fine grained

Clastic

4. Pre-Carboniferous, post-Devonian Intrusives

1. Gabbros, Amphibolites, and Associated Dikes.

These rocks are not confined to any particular part of the district but are distributed, mostly in small patches and as dikes, throughout the area. The locations of the several occurrences have already been outlined.

a) The Gabbros:

These occur mainly as fine-grained dark colored rocks, often with a greenish tinge. In the slightly coarser grained varieties laths of plagioclase and stubby crystals of augite are quite easily recognized with the naked eye, but in the finer varieties the constituent minerals can be distinguished only with the aid of the hand lens. Sometimes an ophitic structure is suggested, but it is never distinct.
Seen under the microscope, the ophitic structure is usually quite well developed. Often the plagioclase laths "pierce" the augite crystals to such an extent that the component parts of an individual appear quite widely separated. Several of the specimens examined showed the effects of considerable deformation. Granulitization of the feldspars into very irregular banded areas with a brown semi-opaque iron-oxide cement occurs in Slide #40, of a sample taken about 500 feet north of the foot of Folly Lake. In these shattered areas epidote is quite abundant and the whole presents rather a streaked and drawn-out appearance with embedded cataclastic grains. Strain shadows are prevalent. In several slides some of the feldspar crystals appear bent and in others the yielding has resulted in fracturing. The calcicity of the feldspars is never extremely high, the average range being from about An 40 to An 60.

The pyroxene is a colorless augite usually showing considerable alteration, the dominant process being uralitization around the perpiheries of the crystals with the secondary amphibole appearing as irregular fringes. A more complete alteration results in the formation of scaly or leafy aggregates of amphibole and biotite. In slide #40, mentioned above, large areas are completely occupied by these alteration products, suggesting the former presence of augite. Obscure traces of an ophitic structure are exhibited. In this slide and #38 (from a point about 2000 feet north of the head of Folly Lake), schiller structure is common and well marked. In #38 there is a partial alteration of the augite to brown hornblende, resembling a staining in irregular areas scattered throughout the pyroxene.

Biotite is in all cases subordinate to chlorite, which is usually equal in amount to the amphibole. In some cases the biotite is in part altered to chlorite which is then often sprinkled with magnetite dust.

In slide #27, representing a patch of gabbro about 200 feet south of a syenite mass, a small amount of quartz is present and in some parts of the section this is in micrographic intergrowth with feldspar. In this slide a little calcite occurs as minute vein fillings, and one larger mass of the mineral is associated with the micrographic intergrowths.

Apatite occurs in some slides. In Slide #38, previously mentioned, a small vein traversing the rock is filled with albite and some associated epidote.

The opaque minerals of the gabbros are ilmenite (with associated leucoxene), magnetite, and pyrite.

The gabbros described above are classed as such following those that define gabbro as a rock of plutonic origin characterized by abundant plagioclase feldspar more calcic than andesine, and containing over 10% mafic minerals.

Typical of the group is Slide #44, from the second cutting south of Folly Lake.

Slide #44 Gabbro (Medium)

The feldspars occur mostly in lath-shaped form with a well developed ophitic structure. They are quite fresh usually, but in a few places aggregates of paragonite occupy portions of the crystals. Some of the crystals are quite bent. The calcicity ranges from about An 20 to An 53. [illegible]

In contrast to the feldspar the augite is quite altered, the principal development being uralite. It is incipient around the peripheries as fringes. In the center a cloudiness indicates its presence in small aggregates. Chlorite seems to be very subordinate. Biotite occurs in association with the opaque minerals and makes up less than 5% of the rock. Chlorite is not much more abundant.

The opaque minerals constitute about 10% of the rock. Ilmenite is predominant and there is subordinate pyrite.

Texture:

Holocrystalline hypidiomorphic

Even, medium grained

Ophitic

Percentages.

Plagioclase An 20 to An 53	45%
Augite and chlorite	40%
Ilmenite and pyrite	10%
Biotite	5%

Rocks similar to the gabbros just described occur in various parts of the district. They are separated petrographically from the gabbros, however, because the plagioclase they contain is <u>less calcic</u> than andesine. For this reason they are here termed "augite diorites". Macroscopically, they are inseparable from the gabbros and diabases of the area.

They all occur in close proximity to the granitic rocks and are also characterized by an absence of epidote. The fabric varies from ophitic to granitic, and where there has been metamorphism, cataclastic and maculose fabrics occur.

The "diabase" previously described as being intruded by a granite dike on the east branch of Roaring River is of this type. Slide #44b represents the rock within a foot of the contact. As far as could be determined, the plagioclase is partly oligoclase and partly albite. The whole slide presents a rather cloudy appearance due to the abundance of brownish mossy aggregates with a tinge of green--a mixture of a ferruginous decomposition product and chlorite. The augite has been completely altered to the latter. In the other rocks of this group, that were examined, augite is still present. Slide #94 (about ½mile upstream on Smith Brook) is unique in that a vein traversing the section has a zeolitic filling. This is a colorless leafy mineral with negative elongation and birefringence about .021. The optic axial plane is parallel to the cleavage and 2V is about 70 . The index of refraction is greater than that of Canada Balsam and less than that of augite. The mineral was identified as prehnite.

b) The Amphibolites:

These rocks occur in association with the Iron Ore Series except for two outcrops within a mile south of Smith Brook, where a contact between granite on the south and amphibolite on the north is exposed. The following is a description of Slide #19a, made from a specimen taken at this contact.

Slide # 19a Amphibolite (Contact)

In slide #19 which is a granite, a gradation into a more basic rock was marked by a leafy aggregate of biotitized chlorite, chlorite, and feldspar more or less lathshaped in habit. The contact was neither sharp nor gradational but rather irregularly zonal. Slide #19a shows the basic rock with a fringe of the acidic. As before there is no sharp contact but in this slide the change from acidic to basic is marked by an amphibolisation. In the granite the anphibole (hornblende) is quite idiomorphic but when it becomes more abundant in the basic rock all crystal outlines are lost and it consists of irregular masses abundantly scattered throughout. In some places it is associated with chlorite in leafy aggregates. Here and there can still be traced a rude ophitic structure inherited from the augite of which it is an alteration product. Elsewhere long fibres have the appearance of tremolite. Irregular specks of an opaque mineral (probably magnetite) are abundant and biotite is present associated with both the hornblende and the chlorite.

The plagioclase is very badly altered to paragonitic masses which completely occupy many of the crystals which were too turbid to satisfactorily determine their index of refraction relative to Canada Balsam. However it is not likely high and the optic sign being positive the plagioclase is probably near albite in composition. Some of the feldspar fresher in appearance is recrystallized albite.

It will be noted from the above description that the amphibole comprises about 40% of the rock. In the amphibolites associated with the Iron Ore Series, this constituent reached as high as 60%. The calcicity of the feldspars is usually low and only in one slide does it ascend above that of andesine.

Besides the minerals mentioned in the description of Slide #19a, ilmenite with associated leucoxene, pyrite, and epidote also occur in the amphibolites. The fabric is typically maculose.

Macroscopically, the amphibolites are hard to distinguish from the finegrained gabbros. Generally, however, they are more melanocratic and they are always denser.

c) The Diabases, etc.

These rocks occur in association with the gabbros, and where they occur in small patches of uncertain structural relations the two are difficult to distinguish from one another, differing only in degree of granularity. Only in a few places were dike relationships seen in the field. At two places diabase dikes cut the granite and are therefore later. With the diabases is also classed a basaltic dike which probably cuts an amphibolite occurring in the Iron

Ore Series area.

In the description of the Silurian, Slide #86 (east branch of Whetstone Brook, at the north end of the tunnel), was mentioned as showing contact relations between a basic dike and a Silurian quartzitic sandstone. The age of the dike is uncertain, and whether it is post-granite, like the other basic dikes of the area, or not, is a matter of doubt. It differs considerably from the post-granite dikes in that it is microscopically porphyritic. The phenocrysts are lath shaped crystals with a sub-parallel alignment near the contact with the sandstone. These crystals have been completely altered to saussuritic aggregates of zoisite, epidote, and chlorite. The matrix is largely composed of a brownish glassy substance. Near the contact with the sandstone, pyrite occurs in irregular masses. The lath shaped form and the mode of alteration of the phenocrysts suggest that they were originally plagioclase and probably quite calcic. Microscopically, then, the rock is an altered porphyrite.

A specimen taken from a patch of diabase at the head of the east branch of Roaring River and about 300 feet from an outcrop of granite shows, in Slide #47, the development of a reddish or purplish color in the augite, indicating that it is titaniferous. Very narrow veins traversing the rock have a quartz filling.

In Slide #30, also, from a diabase dike cutting granite, this reddish tinge to the augite is present.

The fabric of these two rocks is ophitic and the calcicity, in both cases, as far as could be determined from the small feldspar crystals, ranges from about An 40 to An 65.

The basalt previously mentioned is unique among the specimens examined in containing an abundance of ilmenite in the form of a regular network (Slide #62). The augite has been completely altered, and interstitial to the feldspars is a finegrained mixture of practically irresolvable material. It includes, however, calcite, chlorite, epidote, and leucoxene.

2. Granites, Syenites, and Associated Dikes

The granite and syenite outcrops are confined mainly to Smith Brook and the area stretching southward along the railway from Smith Brook for about 3¾ miles. Along the railway, granite predominates, with intermittent outcrops of gabbro and amphibolite. At the head of the East branch of Roaring River, granite is exposed again, and about 3000 feet downstream a granite dike intrudes augite diorite.

The granites are all pinkish in color, with feldspar and quartz usually in equal amount. The granularity is from coarse to medium. As the percentage of quartz decreases, the rocks grade into syenites. The mafic constituents are in all cases very subordinate and consist of hornblende and biotite.

No true syenites were examined microscopically, but in some slides the percentage of quartz is relatively small and much of it is in graphic intergrowth with feldspar.

In only one slide was orthoclase definitely identified. Usually, the feldspar occurs as a graphic intergrowth with the quartz, or as microperthite, or as microcline or albite individuals, and in most specimens several of these types occur together. In no case has the alteration been very extensive.

The ferromagnesian minerals are hornblende and biotite. The latter is often largely altered to chlorite, which is sometimes streaked with the unaltered biotite. On the other hand, some of the chlorite appears to be going back to biotite, with liberated magnetite occupying the cleavage cracks. Small crystals of zircon surrounded by pleochroic haloes are common in both the chlorite and biotite.

The accessories are magnetite, ilmenite with associated leucoxene, zircon, apatite, and epidote. In one slide a group of tourmaline crystals was noted, and in another fluorite is present as an irregular cavity filling.

The granitic dike occurring on the East branch of Roaring River is a quartz porphyry resembling those previously described in resorption phenomena but differing largely in extent of alteration. The quartz-feldspar mosaic of the matrix is considerably clearer, with no extensive dissemination of chloritic material, although this mineral does occur in a few felty aggregates.

Intruding the Iron Ore Series is a cataclastic deformed quartz porphyry of striking appearance. It contains only about 5% of dark minerals. These are magnetite and biotite. Thus the slide is exceedingly clear when viewed in ordinary light, as the feldspars are not altered. The only contrast between the light-colored constituents is brought out by the slight difference in relief between the quartz and feldspar. Under crossed nicols the cataclastic structure is well exhibited, the slide showing larger shattered crystals of quartz, microperthite, and albite with an interstitial quartz-feldspar mosaic. Strain shadows in both quartz and feldspar are prevalent throughout the slide.

V. Sequence and Origin of Intrusives

The ages of the sedimentary and metamorphic rocks of the district have been established by previous workers in this field, on palaeontological and stratigraphical grounds. There is an exception, however, in the case of the metamorphic sediments of the pre-Wentworth Series of the northern flank of the Cobequids. Their stratigraphical relation to the Wentworth Series is obscure, and the writer admits that he is not fully justified in assigning them to a horizon lower than that of the Wentworth Series on the grounds of their more general metamorphosed appearance and different lithological aspect. Dawson's view that these beds form part of a series of volcanics as indicated in the figure on page 19, reproduced from his report, must be discounted. There is no such regular series of beds dipping northward under the Wentworth Series as he shows. These rocks, which comprise his Lower Cobequid Series, are in themselves a small complex and it is doubtful whether there are any volcanics at all in this area. From the writer's observations in the field, supplemented by the microscopic examinations of thin sections of the rocks, it seems certain that the quartz porphyries are intrusive rocks. The writer believes that the metamorphic rocks and porphyries of the pre-Silurian represent a series of sedimentary rocks that were first intruded and then possibly elevated during the Taconic Revolution, with subsequent deposition of the Silurian.

1. Age Relations

The quartz porphyries of the pre-Wentworth Series are believed to be the oldest intrusive rocks in the area. The evidence that can be brought forward to support this assumption is mostly negative. The main difficulty is that these porphyries are not found actually intruding any rocks, but the writer assumes that they intrude the argillites of the pre-Wentworth Series. The fact that they do not intrude the Silurian rocks to which they are in close proximity suggests that they are pre-Silurian.

Where they come in contact with, or in proximity to, the granite, they are impregnated with pink feldspathic aggregates. This is conclusive evidence that they are pre-granite.

The gabbros and their related rocks are post-Devonian because they intrude the Devonian of the Iron Ore Series. Their impregnation near granite contacts with pink feldspathic material indicates that they are pre-granite. They have not been found definitely intruding the porphyries of the pre-Wentworth Series, but their relatively less altered appearance, both in hand-specimen and in slide, and the considerations mentioned above, suggest that they are younger than the porphyries.

Inclusions of the gabbro in granite at one contact, granitic injections and impregnations, and intrusions of granite dikes into gabbroic rocks, prove conclusively that the granites are later than the gabbros.

The granites and gabbros then represent the "plutonic phase" of the post-Devonian intrusive period, following the normal sequence of decreasing basicity which, according to Harker, is of such widespread occurrence.

Whether or not the "phase of minor intrusion", in which the normal order in the plutonic phase is commonly reversed, is represented in the district is uncertain. Both acid and basic dike rocks occur, but there is no evidence on which to base a determination of their mutual age relations.

The appearance of granophyric material in several of the gabbros is of interest in its relation to the application of the theory that granites can originate by fractionation and removal of the last crystallization material.

2. Origin of Gabbro Variations:

The variations in the normal gabbros of the area present a problem which merits discussion. The variations consist of the amphibolites and the augite diorites.

A. As mentioned previously, the augite diorites are always in close association, or in contact, with the acidic rocks. They are characterized by a deficient calcicity of their feldspar and an absence of epidote. If silica were introduced into them from the granite, there would be a tendency, on reaction with the aluminous material and the augite of the diorite, towards an increase in the content of the anorthite molecule. The following equation indicates the course of the reaction that might take place:

$$SiO_2 + Al_2O_3 + CaMg(SiO_3)_2 = CaAl_2Si_2O_8 + MgSiO_3$$

It should be noted, however, that the granites are quite sodic in mineralogical composition. In some of the granites microperthite is the sole feldspathic constituent and albite is present in many.

It is conceivable, then, that dominant soda could have been introduced into the gabbro in the neighbourhood of the intruding granite. Tyrrell discusses the albitisation of basic igneous rocks as a widespread phenomenon of autometamorphism. The reaction is expressed, according to Eskola, as follows:

$$CaAl_2Si_2O_8 + Na_2SiO_3 + 3SiO = 2NaAlSi_3O_8 + CaO$$

Autometamorphism is defined as the alteration of an igneous rock by its own residual liquors, but albitisation is not entirely restricted to this process. Soda may be introduced in considerable amount from the magma into adjacent rocks, as in the formation of spilosite. The impregnation of the gabbro with feldspathic material suggests that these constituents were considerably mobile at the time of emplacement of the granite mass.

It is conceivable, then, that the soda could have been introduced from the granite and lime released. Calcite is present in some of the augite diorites and the occurrence of prehnite in one of them is suggestive. In this connection, it may be noted that soda and soda-lime zeolites occur in the Scottish Carboniferous basalts as a result of the passing out of the released lime in residual solutions into the vesicles and fissures of the lava.

The amphibolites are also characterized by a deficiency of calcium. Amphibolitization of basic igneous rocks is dominantly the result of regional metamorphism. It is to be noted that the amphibolites of the Cobequids occur mainly in the Devonian area where the development of banded quartzites, slates, schistose grits, etc., point to the effects of regional metamorphism. The writer, however, does not believe that the amphibolites of the Cobequids are a result of regional metamorphism.

Although the Devonian metamorphic rocks are in some places at a stage of metamorphism comparable to Barrow's biotite zone in the regional metamorphism of non-calcareous sedimentary rocks, they are, for the most part, still in the chlorite zone. In the regional metamorphism of basic rocks, hornblende occurs in the chlorite zone, but a grade lower even than this, in fact the lowest grade, is a calc-albite-chlorite-schist and none of the amphibolites of the Cobequids have a schistose structure.

In the contact metamorphism of basic igneous rocks a common change is the alteration of pyroxenes to chlorite, biotite, or amphibole, and the amphibolites of this district are probably the result of this type of metamorphism, with the abundant development of amphibole. In the intermediate grades, plagioclase is broken down to zoisite and epidote with the release of fresh untwinned albite. Slide #19a, described on page 50, illustrates the contact metamorphic effects of a granite on a gabbro, with the development of an amphibolite. In this case the release of albite is probably due in large measure to an introduction of soda. As zoisite and epidote are not present in this specimen and are characteristically absent from all the amphibolites, the question of the mode of absorption of the released lime arises. Tremolite, however, is quite common in all the amphibolites and the calcium may be taken up by this mineral.

There is still one difficulty. If the amphibolites of the Devonian are to be attributed to the effects of contact metamorphism, by what were they intruded? No intrusive relations were definitely noted, except in one cutting along the railway where amphibolite is cut by a basaltic dike. Here the latter probably supplied the heat. Diabases probably younger than the amphibolite occur within 200 feet of amphibolite outcrops in two places, so it is probable that the contact metamorphic effects were due to the nearby intrusion of these rocks.

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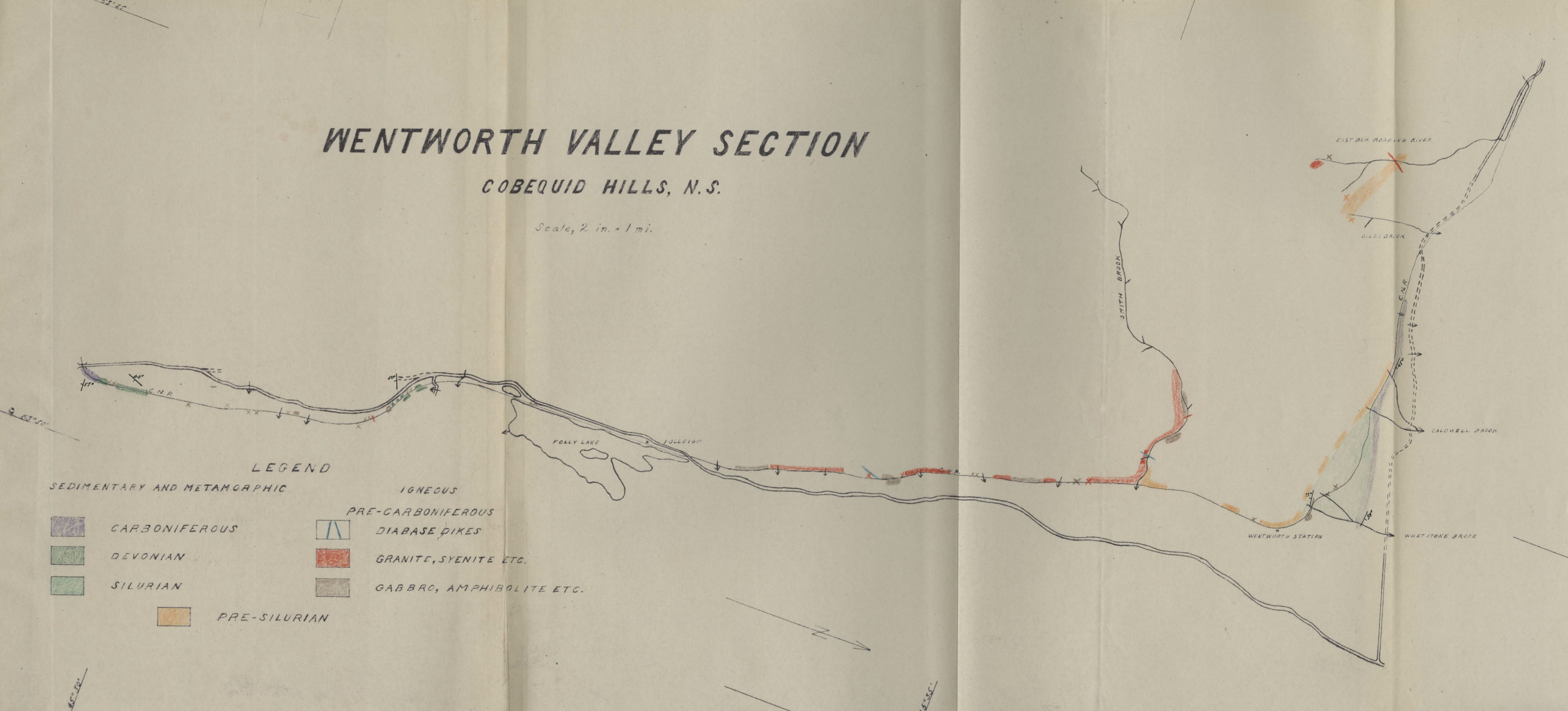

WENTWORTH VALLEY SECTION
COBEQUID HILLS, N.S.
Scale, 2 in. = 1 mi.
LEGEND
SEDIMENTARY AND METAMORPHIC
CARBONIFEROUS
DEVONIAN
SILURIAN
PRE-SILURIAN
IGNEOUS
PRE-CARBONIFEROUS
DIABASE DIKES
GRANITE, SYENITE ETC.
GABBRO, AMPHIBOLITE ETC.
C.N.R.
FOLLY LAKE
FOLLEIGH
SMITH BROOK
EAST BCH. ROARING RIVER
GILES BROOK
CALDWELL BROOK
WENTWORTH STATION
WHETSTONE BROOK