Chapter 2 History of previous researches among the Silurian rocks of the South of Scotland.

Towards the close of last century, when Hutton was laying the foundations of physical geology, the Southern Uplands played an important part in establishing the truth of the Huttonian theory. Hutton observed that the tract of schistus mountains, extending from St. Abbs Head to Portpatrick, where the strata are highly inclined or vertical, is flanked on each side of the ridge by nearly horizontal beds, resting on the upturned edges of the older rocks. He contended that the vertical strata of the schistus mountains had been originally deposited as sediment on the sea floor, and that by the action of the earth's internal heat they had been consolidated and elevated so as to form a land-surface. He further held that the vertical schistus had been denuded by natural agencies before the deposition of the horizontal strata, and that the overlying conglomerates, sandstones, and shales are merely the consolidated gravel, sand, and mud derived from the waste of the underlying rocks. In support of these conclusions, he referred to the section of Siccar Point on the Berwickshire coast, which he had visited with his friends Sir James Hall and Professor Playfair in 1788; and also to that in the river. Jed south of Jedburgh — the latter being illustrated with a drawing by Mr. Clerk of Eldin — where conglomerates, sandstones, and marls (Upper Old Red Sandstone) rest unconformably on the vertical schistus (Silurian). These views regarding the origin and physical history of the Palaeozoic rocks were gradually worked out by Hutton before the publication of his great work in 1795, and are now adopted as fundamental principles of geology.<ref>Theory of the Earth. Vol. I., pp. 421, 431. 437. 454.</ref>

In 1792, his generalisations were confirmed in a remarkable manner by the discovery of organic remains in one of the bands of limestone in the Southern Uplands. While riding between Noblehouse and Crook on his way to Moffat, Sir James Hall visited the limestone quarry at Wrae in Peebles' shire, where, among the blocks lately broken off for use, he found shells quite distinct and in great abundance. Regarding the value of such evidence, Hutton remarked, "I have already observed that one single example of a shell, or of its print, in a schistus, or in a stone stratified among these vertical or erected masses, suffices to prove the origin of these bodies to have been, what I had maintained them to be, water-formed strata erected from the bottom of the sea".<ref>Theory of the Earth. Vol. I., pp. 334–6.</ref>

In his "Mineralogy of Dumfries", published in 1805, Jamieson grouped these older Palaeozoic sediments with the Transition Rocks or Grauwacke Series of Werner. He had traced them from the northern extremity of the Pentland Hills to Langrobie in Dumfriesshire about three miles from the Solway Firth. He further states that the same class of rocks reaches from Langholm to Moniaive, terminating near New Galloway, where they give place to primitive strata. The Moorfoots are occupied by Transition rocks, and he had every reason to believe that they extend as far as St. Abbs Head. He gives lithological descriptions of various rocks in the series.

In 1812, an important paper was communicated to the Royal Society of Edinburgh by Sir James Hall, in which he endeavours to account for the remarkable undulations of the greywacke series which had then been proved to extend from the sea-coast of Galloway to Berwickshire. While visiting the shore-sections in Berwickshire in 1788 with Hutton and Play-fair, it occurred to him that the folds might be accounted for by supposing that the strata, originally flat, had been subjected to compression by forces acting in opposite directions, under a superincumbent weight that might be upheaved by a powerful exertion. He inferred that when the forces were simple or regular, they would produce simple curvatures. When complicated, or where they acted at successive periods, they may have given rise to abnormal folds. The founder of experimental geology at once proceeded to test his conjectures by experimental methods. He devised a machine whereby pliable beds of clay were pressed together, and thus produced isoclinal and normal folds similar to those at Fast Castle in Berwickshire. His results, figured in the Transactions of the Society, have a special interest in view of recent researches on mountain-building on the Continent, in America, and in Britain.<ref>Sir James Hall. On the Vertical Position and Convolutions of Certain Strata and their Relation with Granite. Read 3rd Feb. 1812. Published 1815. Trans. Roy. Soc. Edin. Vol. VII.</ref>

Proceeding to consider how the horizontal thrust may have been produced, he suggested that it might be explained by Hutton's original hypothesis, according to which our continents have been raised from the bottom of the sea and elevated to their present position by the internal action of the same heat which shows itself externally in volcanoes.

In this paper also, the author endeavours to account for the convolutions of the schists and greywackes, partly by the intrusion of granite. Subsequent to 1790 he had visited on several occasions the mass of granite to the west of Loch Ken, and had made observations that confirmed his previous conclusions. He describes in considerable detail the nature of the junction between the granite and the schistus from the Hill of Lauren to New Galloway, indicating the best-marked veins of granite which occur at these localities. He infers that the granite is posterior to the schists, and has flowed into its present position from below upwards, in a liquid state.

After a lapse of more than a quarter of a century, the progress of research among these older Palaeozoic rocks was signalised in 1839 by the announcement of further discoveries of organic remains made by Mr. Charles MacLaren and Mr. J. Carrick Moore. The former author, in his volume on the "Geology of Fife and the Lothians", notes the occurrence of an *Orthoceras,* subsequently named *Orthoceras MacLareni,* and fragments which had some resemblance to parts of small trilobites in the greywacke slate near Deerhopefoot, by the side of a small stream that falls into the North Esk in the Pentland Hills. Early in the same year a brief notice was communicated to the Geological Society of London by Sir Charles Lyell on the occurrence of graptolites in the slates of Loch Ryan, Wigtown-shire, which had been found by Mr. J. Carrick Moore.<ref>Geology of Fife and the Lothians, 1839, p. 203. The Occurrence of Graptolites in the Slate of Galloway. C. Lyell. Proc. of the Geol. Soc. Vol. III, p. 28.</ref>

In 1840 Mr. J. Carrick Moore communicated a paper to the Geological Society of London "On the Rocks which form the west shore of the Bay of Loch Ryan in Wigtownshire", in which he recognises the strata as forming part of the great greywacke chain, which had been coloured in the geological maps of Dr. Macculloch and Mr. John Phillips as a belt stretching from the Irish Sea to St. Abbs Head. He refers to the prevailing strike, the coarse conglomerates with pebbles of igneous rock near Corsewall Lighthouse, and the graptolites occurring abundantly in certain seams.<ref>Proc. of the Geol. Soc. Vol. III., p. 277.</ref>

In 1841, Professor Nicol's essay "On the Geology of Peeblesshire" appeared in the Transactions of the Highland Society. In his early years he had roamed far and wide over the hills and glens in his native valley of the Tweed, and had discovered graptolites in the Grieston Slates in that county. Following the nomenclature then in vogue, he grouped the greywackes and associated slates with the Transition Series of Werner.<ref>Trans. of the High. Soc. Vol. VIII., p. 149.</ref>

In an essay on the Geology of the Stewartry of Kirkcudbright by Mr. R. H. Cunningham,<ref>Geognostical Description of the Stewartry of Kirkcudbrightshire. High. Soc. Trans. (New series.) Vol. VIII. p. 697.</ref> published in 1843, a description is given of the different groups of rock which enter into the geological structure of the county. The author notes generally the character of the Silurian rocks with reference to their contortions, but attempts no classification of their different beds. He indicates the representatives of the lower stratified rocks found on the shore, and describes in detail the various masses of granite and their relation to the Transition strata. He calls attention to the occurrence of syenite, porphyry, and trap in various parts of the Stewartry, and alludes to the connection between granite, syenite, and porphyry, regarding them as mineralogical varieties which had a contemporaneous mode of formation.

In 1843 Mr. Thomas Stevenson read a paper before the Wernerian Natural History Society "On the Geology of the Island of Little Ross, Kirkcudbrightshire"<ref>Edin. New Phil. Jour. Vol. XXXV. p. 83.</ref>, in which he describes the lithological characters of the strata and announces the discovery by Mr. I. T. Syme, C.E., of a shell resembling a *Terebratula.* He also records the discovery by Mr. Fleming, of Kirkcudbright, of an *Orthoceras* in the Silurian rocks on the mainland opposite to Little Ross Island.

In 1844, appeared Professor Nicol's "Guide to the Geology of Scotland", in which he makes the following statement with reference to the strata of the Silurian tableland: "Fossils are so extremely rare in all this series of rocks that they furnish almost no assistance in classiing them. Graptolites and a few shells have been found in Kirkcudbrightshire and Peeblesshire, and some obscure vegetable impressions in Roxburghshire: but these are the whole amount, and hardly serve to connect this formation with the Transition rocks of England, far less to enable us to arrange the various beds in their true order. It is usual to consider this whole series as synchronous with the older Silurian rocks of Murchison".<ref>Guide to the Geology of Scotland. Pages 28–29. 1844.</ref>

In 1848, a marked advance was made by Professor Nicol, in a paper "On the Geology of the Silurian Rocks in the Valley of the Tweed", in which he correlates the strata on palaeontological grounds with Murchison's Silurian formation of Wales, and gives the first general description of the succession of the rocks. He observes that, in tracing the formation from Peebles and the Lothians, through Selkirk and Roxburgh to the confines of England, the coarser beds predominate in the north, while the finer-grained rocks prevail in the south. He infers that the materials may have been derived from the north and deposited in a sea becoming deeper to the south. From the constituents of the sediments, he concludes that they may have been derived from the North of Scotland.

Of special interest is Nicol's description of the rocks associated with the Wrae Limestone. The quarry having been abandoned, he was unable to estimate the thickness of the limestone, but he states that it is covered by blue slate in which he found angular nodules of limestone from an inch to several feet in diameter. In the slate he found no organic remains; but the masses of limestone are full of them, appearing therein as a crystalline mass of encrinite stems. A list of fossils, with notes by Mr. Salter, is appended, who was then inclined to regard the strata as of Lower Silurian age.<ref>Quart. Jour. Geol. Soc. Vol. IV., p. 195.</ref>

In this paper also, a suite of fossils, collected by Mr. Fleming from the rocks on the shore south of Kirkcudbright and transmitted by Lord Selkirk to the Geological Society of London, is named by Salter. He concludes that "on the whole the fossils appear to be of the date of the Wenlock Shales".

While Nicol was thus exploring the central portion of the tableland, Mr. J. Carrick Moore was extending his observations along the western margin. In a paper "On some Fossiliferous Beds in the Silurian Rocks of Wigtownshire and Ayrshire", contributed to the Geological Society of London (read May 17th, 1848, and published in 1849),<ref>Quart. Jour. Geol. Soc. Vol. V., p. 7.</ref> the author describes the general characters of the Silurian strata from the Mull of Galloway to Corsewall Point, indicating various localities where giving a horizontal section. He further makes the important announcement of the discovery of a band of fossiliferous limestone which he had observed at five localities along the course of the valley of the Stinchar (the Stinchar Limestone).

A note by Salter, on the fossils from the limestone of the Stinchar and the slates of Loch Ryan, is appended, in which he states that the former are decidedly of Lower Silurian age, and that he would identify them at once as belonging to the same epoch, if not to the same bed, as those of the Wrae Limestone in Peeblesshire. A list of fossils from the limestone is given and specimens are figured, including the first notice of the genus *Maclurea* in Britain.

In 1849, Professor Nicol, having made traverses over a great part of the Southern Uplands, communicated a further paper to the Geological Society "On the Silurian Strata of the Southeast of Scotland."<ref>Quart. Jour. Geol. Soc. Vol. VI., p. 53.</ref> Graptolites from Grieston and Thornilee are recorded, and several examples are figured for the first time from that region. He states "that from the whole facts noticed in this and a former paper, there can be little doubt that the slates and greywackes of this part of Scotland belong to the Lower Silurian period, and are probably the equivalents of the Llandeilo flags of Wales".

From the stratigraphical relations of the strata, Nicol infers that "in this part of the chain there is an anticlinal axis over which the beds have been folded. Taken generally, this axis will pass from the group of felspar-porphyry hills east of Innerleithen to Loch Skene, north of Moffat".

In 1850, a further advance was made in the investigation of these Silurian rocks by Professor Harkness, who, in his native county of Dumfries and in the adjoining county of Kirkcudbright, had studied their development.<ref>On the Silurian Rocks of Dumfriesshire and Kirkcudbright. Quart. Jour. Geol. Soc. Vol. VII., p. 46. Pub. 1851.</ref> The results of his researches were embodied in a paper contributed to the Geological Society of London. The author describes generally the strata entering into this formation; indicating in particular three parallel bands of anthracitic or black shales which he had traced for miles; (1) Hartfell, Greskine, &c., (2) Dobb's Linn, Frenchland Burn, &c., (3) Selcoth Burn and Craigmichan Scaurs. He regards them as repetitions of the same band due to a series of parallel faults which might probably account for the prevalent N.N.W. dip of the strata.

After referring to the existence of Wenlock Shales at Kirkcudbright and their fossils, Harkness proceeds to describe the inclinations of the strata between Kirkcudbright and Lockerbie. He infers that an anticlinal axis traverses the range near its southern extremity, and suggests that it may have resulted from the granite eruption of Criffel.

Towards the close of 1850 Professor Harkness communicated to the Geological Society a description of the Upper Silurian strata on the east side of Kirkcudbright Bay, including the graptolitic flagstones and soft grey shivery shales with limestone nodules.<ref>Quart. Jour. Geol. Soc. Vol. VII., p. 54. Read Dec. 4, 1850.</ref> He refers to the graptolites occurring in profusion in certain bands and to the orthoceratites, and states that the general character of the fossils in the deposits about Balmae is such as to indicate an intimate relation between the Wenlock Shales and this portion of the Silurian series. A description of the graptolites from the black shales of Dumfriesshire, which had been submitted by Professor Harkness to M. Barrande and Mr. Salter, is appended to this paper.

From the statements made in the foregoing paragraphs it is clear that some progress had already been made in the exploration of the rocks of the Silurian tableland, chiefly through the researches of Nicol, Carrick Moore, and Harkness, aided by the Silurian palaeontologist Salter, when in 1850 Sedgwick and Murchison, with the knowledge gleaned from a prolonged study of the Silurian and Cambrian rocks of Wales, endeavoured to correlate the old Paleozoic rocks of the South of Scotland with their probable equivalents in the Welsh Principality.

In 1850, Professor Sedgwick communicated a paper to the meeting of the British Association *in* Edinburgh "On the Geological Structure and Relations of the Frontier Chain of Scotland".<ref>Brit. Assoc. Rep. for 1850. Trans. Sects., p. 103. and Edin. New Phil. Jour. Vol. LI., p. 250.</ref> Having crossed the chain in 1841 with Mr. J. Carrick Moore, and having made further traverses in 1848 with the hope of determining (on the principles laid down by Professor Rogers) the line from which the undulations had originated. Sedgwick arranged the strata in five successive groups in ascending order:

1. A group of hard arenaceous beds always in a highly inclined position, in which a pyritous alum schist abounds, extending from Lockerbie to the neighbourhood of Moffat. The alum slates are crowded with graptolites.
2. A great arenaceous group with bands of earthy flagstone and coarse slate, part of which is well exposed in the railway cuttings north of Moffat. This series extends into Peeblesshire and the upper parts of the valley of the Tweed, and thence to St. Abbs Head. Some calcareous bands, associated with very coarse conglomerates, appear in this group north of Peebles, and a well-defined bed of limestone is seen at Wrae and Drummelzier.
3. South Girvan group, comprising the Stinchar Limestone and associated conglomerates, together with the strata forming the plateau between the valleys of Girvan and Stinchar and visible on the shore south of Girvan.
4. North Girvan group, the members of which constitute the Craighead "inlier" north of the Girvan valley. It includes the Craighead Limestone, which is associated with a great mass of trap, shelly sandstones, with shales and flagstones containing numerous trilobites.
5. Balmae group. The members of this sub-division bound the south-east extremity of Kirkcudbright Bay, and are composed of thick-bedded greywacke alternating with flagstone in thin beds together with thick masses of indurated slate. Some of the beds contain numerous graptolites, while the calcareous concretions are associated with corals, orthoceratites, and shells.

In the concluding remarks to his paper, Sedgwick states that the lowest fossils in the chain appear to be graptolites. The South Girvan group is compared with the Bala and Coniston Limestone, while the North Girvan group is correlated with the grits and shelly sandstones that overlie the Llandeilo Limestone. Finally, he expresses his belief that, while the Grampians had probably their greatest elevation after the period of the Old Red Sandstone, the principal elevations of the frontier chain (Southern Uplands) were produced before the deposition of the Old Red Sandstone.

A list of organic remains, collected by Sedgwick in the course of his traverses and determined by Professor M'Coy, is appended to this paper.

In 1850 also, Sir Roderick Murchison made a series of traverses across the Silurian tableland, accompanied by Professor Nicol, and during part of the time by Professor Harkness. Having visited, at various periods, portions of the Southern Uplands, he had a strong desire to examine the rocks more closely, as they had been referred by others to the Silurian

system. He was further stimulated to pursue his investigations by Sedgwick's verbal communication to the Geological Section of the British Association at Edinburgh on the highly fossiliferous rocks near Girvan. A large collection of organic remains was obtained in the course of these traverses, which was subsequently determined by Mr. Salter. The results of these observations were embodied in an elaborate memoir, published in the Quarterly Journal of the Geological Society in 1851. A list of Silurian fossils from Ayrshire, with descriptions of some of the special types, was appended, together with a geological sketch map of the coast of Carrick, Ayrshire.

The rocks constituting the Silurian series of Ayrshire are arranged by Murchison in the following descending order:

3. Schists and flagstones (orthoceratites).

2. Shelly greywackes, sandstones with conglomerates (Caradoc and Llandeilo).

1. Limestone and schist (Lower Llandeilo).

The orthoceratite flags and graptolite schists of Piedmont, Ardwell, and Penwhapple Burn, forming the highest subdivision, are represented as occupying a syncline on the south side of the Girvan valley; the beds being traceable from the shore at Ardwell eastwards to Penwhapple Glen. They are mapped as resting on the grits of Saugh Hill and the coarse conglomerates of Kennedy's Pass. Again, on the north side of the Girvan valley, he refers the shelly sandstones of Mulloch Hill to his middle group, and the trilobite shales of Drummuck to the upper division. The lower group includes the limestones of Stinchar, Tormitchell (Tramitchell), and Craighead, being brought to the surface by a series of axial folds. He, however, calls attention to a suggestion of Professor Nicol's that the shelly sandstones of Saugh Hill (Group 2) may overlie the orthoceratite flags (Group 3). Reference is made to the great series of igneous rocks so prominently developed in certain areas.

Regarding the structure of the Southern Uplands generally, Murchison accepts the view that a powerful anticlinal arch passes somewhere near Dumfries, and north-east by Lockerbie; but owing to the extraordinary folding of the strata, he found it difficult to arrive at a reliable order of succession. He, however, made an important suggestion, that the three bands of anthracite shales traced by Professor Harkness may be repeated by folds rather than by faults; the upper parts having been removed by denudation. Murchison clearly saw that, whatever be the exact place of the graptolite shales in the Silurian series, the recognition of their being repetitions of one band, by means of folds, formed an important step in limiting the thickness of the strata.

Regarding the age of the beds of the central chain, Murchison states that it is difficult to decide the question, since there are scarcely any other fossils than graptolites and certain obscure orthoceratites with annelida in the schists of Dumfriesshire. He considers that Harkness, in viewing them as an upper portion of the Lower Silurian rocks, places them rather high in the series. He suggests that "they probably represent that great mass of Welsh schist which underlies the Llandeilo or Bala Limestone, but is still superior to the lowest zone of Silurian life".

With reference to the strata at Balmae Head, Kirkcudbright, Murchison accepts the conclusion arrived at by Salter from a determination of the fossils, that these beds could not be older than the Wenlock Shales.

In 1852, Professor Nicol announced the results of his detailed researches among these Silurian rocks, giving a horizontal section drawn across the chain from the Pentlands to the Cheviots.

Continuing his traverses in the South of Scotland, Professor Harkness stated in 1852 that he had traced the anthracite bands of Dumfriesshire through the greater part of Selkirkshire to the neighbourhood of Galashiels<ref>On the Silurian Rocks of the South of Scotland and on the Gold Districts of Wanlockhead and the Leadhills. By R. Harkness. Quart. Jour. Geol. Soc. Vol. VIII., p. 393.</ref>. He no longer referred the Silurian rocks of Dumfriesshire to Caradoc time as in his former memoir, but regarded them as lying below the representatives of the Llandeilo flags, as suggested by Murchison. A note by Salter, descriptive of some graptolites collected by Harkness from the South of Scotland, precedes this paper.

The first detailed description of the Upper Silurian rocks of the Kirkcudbright shore was given by Professor Harkness in 1853. The strata from Netherlaw Point to Balmae Head are classified by him in three groups: 1, Shale and sandstone at

the top; 2, Greywacke sandstone; 3, Indurated black shales with graptolites. A prominent sub-division of the highest group consists of grey shales with fossiliferous calcareous nodules, alternating with light grey ripple-marked sandstones. From Group 3 he obtained *Graptolithus priodon, O. Flemingii,* and orthoceratites. He mentions the occurrence at Coal Heugh, near Barcaple, of anthracite bands (black shales) which connect the rocks in the Dee with the lowest beds in the Silurian system. The results of his observations are embodied in the following general conclusion: that we have in this portion of the Stewartry (1) certain deposits representing the Llandeilo flags, (2) conglomerates and sandstones which may be regarded as the representatives of the Caradoc Sandstone, and (3) a higher series of beds (Balmae beds) which are the equivalents of the lower portion of the Upper Silurian rocks.

The discovery by Dr. Slimon of beautifully preserved crustaceans in the Silurian rocks of the Lesmahagow district resulted in important additions to our knowledge of the "inliers" of these strata in the midst of the Old Red Sandstone of Lanarkshire. Accompanied by Sir Andrew Ramsay and Dr. Slimon, Murchison visited that district and examined the sections in the Logan Water where the fossils had been found. The results of these traverses were embodied in a paper contributed to the Geological Society in 1855,<ref>On the Discovery by Mr. Robert Slimon of Fossils in the Uppermost Silurian Rocks near Lesmahagow, *in* Scotland, with Observations on the Relations of the Palaeozoic Strata in that part of Lanarkshire. Read Nov. 1855. Quart. Jour. Geol. Soc.</ref> in which Murchison states that the dark fossiliferous shales exposed in the Logan Water pass conformably upwards into the Lower Old Red Sandstone of that district. A horizontal section is given showing the relations of the Upper Silurian strata to the Old Red Sandstone. He further points out that Salter had detected in Mr. Slimon's collection sculptured plates of crustaceans similar to those which had been hitherto referred to *Pterygotus,* together with the small *Lingula cornea* and *Trochus helicites* of the uppermost Ludlow Rock of Wales. These are associated with five or six new forms which Salter termed *Himantopterus,* and fragments of *Ceratiocaris.*

Appended to this paper is a description by Salter of some new crustacea from the uppermost Silurian rocks of the Lesma-hagow district, and a note by Professor Huxley on the structure and affinities of *Himantopterus.*

In 1855, a description of the section in Glenkiln Burn, Dumfriesshire, was published by Professor Harkness, special reference being made to the anthracite shales which occur at this locality, and to the Barlae flags north of Dalry, Kircudbrightshire.<ref>On the Anthracite Schists and the Fucoidal Remains in the Lower Silurian Rocks of the South of Scotland. Quart. Jour. Geol. Soc. Vol. XI., p. 468.</ref> The author places the Barlae flags on the same horizon with the Grieston Slates. A list of fossils, with notes, is appended to this paper.

In 1856, Professor Harkness communicated to the Geological Society a paper "On the Lowest Sedimentary Rocks of the South of Scotland". He therein indicates the position of the great anticline, the nature of the axial beds, and the fossils obtained from them. He abandons the theory that the parallel bands of black shales are repeated by faults, and adopts Murchison's view that they are due to folds. He announces the discovery of a species of *Olenus* at Corfarding, near Penpont, Dumfriesshire.<ref>Quart. Jour. Geol. Soc. Vol. XII., p. 238.</ref> (See p. 347.)

In the same year, a suggestive communication was contributed by Mr. Carrick Moore to the Geological Society, in which special reference is made to the system of folding in the Silurian rocks of Wigtownshire. He calls attention (1) to the peculiar arrangement of the strata from Corsewall Point to within six or eight miles of the Mull of Galloway. Along this line the rocks are bent into a series of anticlinal and synclinal folds which are thrown over to the north, the axes of the curves dipping to the south. He points out that the structure here described is similar to those inversions of rock in the north of Germany, in the Ardennes, the Eifel, and to those of the Appalachian chain in the United States. He further suggests that there are many reasons for believing that all the principal movements which these Silurian rocks have undergone had been impressed on them previously to the intrusion of the granites. (2) From the evidence supplied on the shore section between Corsewall Point and Dally Bay and also along the east shore of Loch Ryan, he infers that the coarse conglomerates of South Ayrshire are superior to the schists with graptolites.

In a paper contributed to the Geological Society of London in 1857, Professor Wyville Thomson described and figured some species of *Acidaspis* from the Lower Silurian beds in the Girvan district. He advanced a different order of succession from that of Murchison, holding that the whole of the fossiliferous beds of Girvan belong to, the very top of the Lower Silurian system; the Penwhapple: flagstones being the lowest of the series, and graduating upwards through the

Mulloch Hill Sandstones and the Craighead Limestone into the Saugh Hill grits.<ref>Quart. Jour. Geol. Soc. Vol. XIII. p. 206.</ref>

From the autumn of 1854, when the late Sir Andrew Ramsay, as Director for Great Britain, first began the detailed Geological Survey of Scotland in Haddingtonshire, down to 1867, when the Scottish stall was reorganised and enlarged, with Sir A. Geikie as Director for Scotland, the officers of the Survey (A. Geikie, J. Young, J. Geikie, B. N. Peach) had completed the examination of considerable portions of the Silurian table-laud in the counties of Haddington, Berwick, Edinburgh, Peebles, Lanark, and Ayrshire. The results of these detailed researches appeared in the geological maps and in the memoirs descriptive of the respective sheets. In Sheet 32 the various "inliers" of Upper Silurian strata in the Pentland Hills were delineated by A. Geikie, and their relations to the sub-divisions of the Lower Old Red Sandstone were defined. The existence of Ludlow Rocks was then clearly established, which pass, as at Lesmahagow, conformably upwards into the Lower Old Red Sandstone. In the memoir accompanying Sheet 32 (published in 1861), sketch sections are introduced by Sir A. Geikie showing the relations of the strata in the North Esk river and at the south end of the Pentland chain. It is stated that the section in the North Esk is on the whole an ascending one, though showing minor folds. In the Appendix to the memoir the fossils, numbering about forty species, are named and described by Salter, who likewise gives valuable comparative notes on the Upper Silurian strata of the Pentland Hills and Lesmahagow areas.

In 1863, the memoir descriptive of the Geology of Eastern Berwickshire, by Sir A. Geikie, and in 1866 that descriptive of the Geology of East Lothian, by the same author, appeared. The Silurian rocks of these areas are referred to the lower division of the system, the marked convolutions of the strata, especially on the Berwickshire coast line, are portrayed, and various new localities for graptolites are recorded. Special reference may be made to the discovery of *Graptolithus priodon* at Siccar Point, near Cockburnspath, and at Ellemford on the Whiteadder, below Longformacus. The following statement, made by such an eminent palaeontologist as Salter, is significant as showing how the zonal value of graptolites was not then clearly recognised. "At present all that can be certainly affirmed is that the rocks are of Lower Silurian age. Though the *Graptolithus priodon is* a Middle and Upper Silurian species in England and Wales, it is plentiful at Grieston, near Innerleithen, on the Tweed, in company with *G. Sedgwicki* and other Lower Silurian fossils".<ref>The Geology of East Lothian, p. 71.</ref>

At a later date, Sheets 7 and 14 of the one-inch maps, with their accompanying explanations (A. Geikie, J. Young, J. Geikie, B. N. Peach), were published. In Sheet 7, embracing the region bordering the coast between Glen App and Girvan, Ayrshire, the order of succession advocated by Murchison was generally adopted. The strata of the Ballantrae region were supposed by Professor James Geikie to exhibit certain arrested stages of metamorphic action, so that we can in many instances begin with unaltered beds and trace the gradual changes which they undergo during their passage into crystalline and pseudo-igneous rocks. The strata cited in illustration of these phenomena embrace (a) felspathic rocks, (b) dioritic rocks, (c) serpentine and altered limestone. The geological history of this intricate region will be given in subsequent chapters (19 and 20)

In Sheet 14 and its accompanying explanation, the anticlinal arrangement of the strata forming the Craighead inlier on the north side of the Girvan valley is clearly portrayed by Sir A. Geikie. The beds forming the core of the arch, comprising the Craighead Limestone and associated strata, which graduate upwards into the Drummuck mudstones, are regarded as of Caradoc age; while the overlying strata, composed of the Mulloch Hill conglomerate, with sandstones, grits, shales, and conglomerate bands, are grouped with the Lower Llandovery formation. Lists of fossils from the Craighead Limestone, then supposed to be of Caradoc age, and the Lower Llandovery Rocks of Kirk Hill, are given. The strip of Silurian strata extending from Straiton to the hills overlooking Kilkerran is revealed for the first time, and though no definite age is assigned to the latter, the beds are described as having a much less ancient aspect than others in the neighbourhood.

In the course of the Geological Survey of Ayrshire a large collection of organic remains was obtained, which were determined by the palaeontologists of the Survey and Professor Young. This list *was* subsequently published as an appendix to the explanation of Sheet 3, one-inch.

As the officers of the Survey carried their geological lines north-eastwards along the northern margin of the Silurian tableland into Lanarkshire prior to 1867, the Upper Silurian inliers of the Hagshaw Hills and Logan Water were mapped in

detail by Mr. B. N. Peach. Various sub-divisions were established and a rich suite of organic remains was collected which confirmed the conclusion previously arrived at by Sir Roderick Murchison and Mr. Slimon regarding the age of the beds.

In 1865, Mr. George C. Haswell published a small volume "On the Silurian Formation in the Pentland Hills", in which he describes the geographical position of the Silurian rocks and their relation to other representatives of the same system in Scotland. He records, describes, and figures about fifty-five species of fossils from various localities in that, chain, giving a Table showing their vertical range in the Silurian system. He finds that fifteen species in his list occur in the Ludlow Rocks, fifteen in the Wenlock group, and nineteen in rocks older than the Wenlock. There are ten species which are never found higher up than the Wenlock group, and there are five species whieli range from the Ludlow group upwards.

In 1867, a paper "On the Silurian Rocks of the Pentland Hills", by Messrs. John Henderson and D. J. Brown, was communicated to the Geological Society of Edinburgh, embodying the results of their observations in the field, and their views regarding the age of the fossiliferous zones which they had carefully searched. A geological map with horizontal sections was published with Part II of this paper, read to that Society in 1869. Their conclusions may thus be briefly summarised: (1) That, to take the North Esk section as a basis of classification, the strata exposed in the lower part of the river course are of Wenlock age, their northern limit being marked by Bed E in their map, crossing the Esk about half a mile to the north of the reservoir. (2) That the beds to the north of this boundary line are of Ludlow age. (3) That the red beds, marked as the conformable portion of the Lower Old Red Sandstone in the Lyne Water by the Geological Survey, are likewise of Ludlow age, and can be traced across the intervening heights to the North Esk section. (4) That the Silurian rocks in the Lyne Water to the north of the red beds are of Ludlow age. This paper is accompanied by an elaborate Table of fossils, giving the vertical range of upwards of one hundred species of different classes. Of the Brachiopoda, numbering twenty-five species, which were determined by Mr. Davidson, twenty species are found in Wenlock strata, and ten pass up into the Ludlow Rocks.

In connection with the literature bearing on the Upper Silurian rocks of the Pentland Hills and Lanarkshire, reference must be made to the description by Mr. Thomas Davidson of the Brachiopoda from these beds, published by the Geological Society of Glasgow.<ref>On the Upper Silurian Brachiopods of the Pentland Hills and of Lesmahagow, in Lanarkshire. Trans. Geol. Roc. Glasgow. Part I.</ref> This description, accompanied by figures of many of the typical forms, was based on the examination of several thousand specimens from the Pentland Hills which had been collected by Messrs. Haswell, Henderson, and Brown, as well as of those in the possession of the Geological Survey. The author states that he revisited the latter locality in 1866 with Messrs. Haswell and Brown, and that he agreed with the views announced by Messrs. Brown and Henderson as to the age of the beds under description<ref>Further references to palaeontological researches relating to the Upper Silurian rocks of the Pentland Hills, including those by Professor Lapworth on Graptolites from Habbie's Howe and by Mr. Laurie Oil the Eurypterids of Gutterford Burn, will he subsequently given in the section dealing with the structural relations of the beds.</ref>

In 1867, the fourth edition of "Siluria" appeared, in which Murchison summarised his views regarding the Silurian rocks of the Southern Uplands, and availed himself of the detailed observations by the Geological Survey in Ayrshire and the Pentland Hills prior to that year. The highest sub-division of the Girvan sequence is now grouped with the Llandovery Rocks; in other points he follows generally the order of succession propounded by himself in 1850. Regarding the Upper Silurian rocks of the Pentland Hills, it is stated, on the authority of Sir A. Geikie, that while the upper part of the Pentland section may be considered as of Ludlow age, it is evident that there is room for a representation of the Wenlock series, which is rendered probable by the number of Wenlock species which have been obtained from these rocks.

In 1867, a clear summary was given by Sir Archibald Geikie of the results of all previous investigations regarding these ancient Silurian rocks.<ref>Trans. of the Geol. Soc. of Glasgow. Vol. III., p, 74.</ref> To the student of historical geology this contribution serves a useful purpose, because it enables him to focus the knowledge then ascertained. The author points out that, owing to the contorted and broken nature of the rocks, it is by no means an easy task to reduce them to a satisfactory order of succession. The labours of Murchison, Sedgwick, Harkness, and Nicol had shown that, viewed on the great scale, the Silurian belt may be regarded as a long arch, of which the centre, running parallel with the length of the chain, is composed of the lowest and oldest strata, while the outer portions consist of higher members of the series dipping away from the central axis towards the margin of the belt. This axis, running in a north-east and south-west direction crosses the valley of the Annan south of Beattock.

The order of succession then ascertained is given, and the results are thus summarised: With the exception of a comparatively small area in Ayrshire, where Llandovery Rocks appear, and other districts in Kirkcudbright, Lanarkshire, Ayrshire, Peeblesshire, and Midlothian, where Ludlow and Wenlock Rocks have been identified, the whole of the Silurian Uplands of the South of Scotland consist of grits, greywackes, conglomerates, shales, dark schists, and inconstant bands of limestone representing the Caradoc and Llandeilo Rocks of Wales.

In 1868, while the Geological Survey was in progress within the Silurian belt, in the counties of Lanark and Dumfries, Mr. R. L. Jack, in mapping the Leadhills district, discovered certain fossiliferous conglomerates (Duntercleuch and Glendowran) which, from their organic remains, were regarded as of Caradoc age. They seemed to rest on black shales, yielding graptolites of a Llandeilo facies. Though minor folds were recognised in that area, the strata were viewed as forming in the main a great synclinal trough, the Caradoc Rocks occupying the centre, and the Llandeilo Rocks coming to the surface on either side.

The subsequent extension of the field work towards Moffat, Eskdalemuir, and Melrose, and south-westwards towards the shores of the Solway and the Irish Sea, by B. N. Peach, R. L. Jack, J. Horne, H. M. Skae, C. R. Campbell, and D. R. Irvine, led the Survey to adopt the following order of succession.

Accepting the view that the lowest beds are exposed along the axial line between Dumfries and Eskdalemuir, the strata were arranged in ascending groups as the observer passes northwards to the Leadhills area: 1, The Ardwell group ("Hawick Rocks"); 2, The Moffat black shales; 3, Queensberry grits; 4, Dalveen group; 5, Lowther shales; 6, Upper or Leadhills black shales; 7, Carsphairn group. These sub-divisions of the Llandeilo Rocks were believed to he succeeded by fossiliferous grits and conglomerates (Duntercleuch, &c.) of Caradoc age, apparently, in certain sections, transgressing the underlying sediments. The Wenlock beds, occurring along the southern margin of the great tableland, were supposed to rest unconformably on the Llandeilo Rocks. While it was recognised that the higher bands of the Moffat black shales, and indeed that certain shales in the overlying Queensberry grit series yielded graptolites which elsewhere are characteristic of Llandovery Rocks, the apparent sequence of beds from the Moffat black shales to the Leadhills black shale series was assigned to the Llandeilo formation.

The palaeontological anomalies involved in this reading of the order of succession seemed to be satisfactorily explained by Barrande's doctrine of Colonies. That distinguished palaeontologist contended that in the Bohemian area, while there existed in the Silurian strata a normal sequence of organic remains similar to that of other regions, there were certain bands charged with the fossils of a higher zone which occurred on different horizons in a lower portion of the system. These hands were termed colonies; the occurrence of which he explained on the supposition that the younger fauna had already appeared beyond the limits of the Bohemian area, and for a time gained access to that region before the final disappearance of the older fauna.

Applying this generalisation to the rocks in the South of. Scotland, it was held that those graptolites which are found in the higher bands of the Moffat black shales and rarely in the series of Queensberry grits, though elsewhere characteristic of Llandovery Rocks, might be precursory forms, which gained access to the region during the deposition of the Lower Silurian sediments. Just as Barrande maintained that, in the Bohemian area, graptolites characteristic of the third fauna (Upper Silurian) appear in bands, intercalated at intervals in strata replete with the second fauna (Lower Silurian)so it was believed that, in the South of Scotland, the Llandovery graptolites of the Moffat region might be precursory forms which lived for a time and then disappeared, while the Lower Silurian graptolites reappeared and flourished during the deposition of the upper or Leadhills black shales.<ref>Barrande. *Defense des Colonies v. Apparition et reapparition en* An*gterre et en Ecosse des espèces Coloniales Siluriennes de la Bohême*. 1881. Sir A. Geikie. Text-hook of Geology. First ed.. 1882, p. 629. B. N. Peach. Proc. Roy. Phys. Soc. Vol. IX., p. 8.</ref>

The sequence adopted by the Survey seemed to find some support in the remarkable change in the character of the sediments when passing northwards from Eskdalemuir by Moffat to the Leadhills area. The Ardwell beds ("Hawick Rocks") differ from the normal type of the Queensberry grit series, while the Lowther shales can be readily distinguished from both the preceding groups.

On the other hand, it must be frankly admitted that the Geological Survey encountered great difficulties in their reading of the sequence. For example, in the continuous coast sections at the mouth of the Dee in Kirkcudbrightshire, no trace of an unconformity or a fault could be found between the Wenlock strata and the Ardwell beds, though, according to the views then held, such a discordance ought to occur.

The researches of Professor Lapworth, extending over many years, among the Silurian rocks of the South of Scotland, eventually furnished a complete solution of these stratigraphical and palaeontological difficulties. After a prolonged study of the vertical range and distribution of the graptolites, he discovered the clue to unravel the complicated stratigraphy of the whole region. In the following pages we endeavour to give a historical sketch of the development of his researches from his earliest observations in the neighbourhood of Galashiels to the publication of his final contribution relating to the stratigraphy and palaeontology of the Southern Uplands.

In 1870, Professor Lapworth published a paper "On the Silurian Rocks of the neighbourhood of Galashiels", in which he arranges the strata in two groups (a) the black shales of the Moffat series, (b) the Gala group.<ref>Trans. Edin. Geol. Soc. Vol. II., p. 46. Geol. Mag. 1870, pp. 204–209 and 279–284.</ref> He infers (1) that there are two distinct and characteristic faunas in the district, one peculiar to the black shales and the other to the Gala group. (2) That the upper fauna is pre-eminently of the Coniston or Bala type. Hence the Gala group may collectively be considered as a thick and almost inseparable series of greywackes and shales superior to the Moffat series, and of Caradoc age.

In 1871, a conjoint paper by Professor Lapworth and Mr. J. Wilson "On the Silurian Rocks of the Counties of Roxburgh and Selkirk"<ref>Brit. Assoc. Rep. for 1871. Geol. Mag., 1871 p. 456.</ref> was read before the Geological Section of the British Association at Edinburgh and published in the Geological Magazine. The strata are arranged in five groups, named from the districts where they are best developed, given here in ascending order:-1, The Hawick Rocks; 2, The Selkirk beds; 3, The Moffat Series; 4, The Gala Group; 5, The Riccarton beds.

Following previous investigations, the oldest rocks are supposed to come to the surface along the axial line extending from Berwick to Dumfries, being succeeded towards the north by higher groups in natural sequence. The important statement is made that there is but one band of black shales in the whole region lying at the top of the Moffat Series, which plunges underneath the Gala Group and reappears along the northern edge of the Silurian tableland.

To the south-east of the great anticline the Selkirk beds follow the Hawick Rocks; while the former are succeeded by the Riccarton beds, which are of Upper Silurian age. Five separate areas are indicated where these Upper Silurian strata occur: (1) To the south of Kirkcudbright, (2) to the south of the granite area of Criffel and Dumfries, (3) in the region stretching from a point near Lockerbie to the Old Red Sandstone near Stobs Castle, (4) in a large "inlier" surrounded by Old Red Sandstone and Carboniferous strata reaching from the village of Oxnam, near Jedburgh, to Arnton Fell on the Liddel, (5) in a small patch at the head of the Kale Water high up among the porphyries and limestone of the Cheviot Hills.

The northern boundary of the Upper Silurian rocks seems to form nearly a straight line parallel with the average strike of the Lower Silurian strata. Though unable to prove it, the authors suggest that this boundary may be a fault.

A careful comparison of the Moffat graptolites with those of other countries convinced the authors that these beds should be classed with the Utica Slate and Hudson River Group of North America and the graptolite-bearing schists of Wexford and Waterford; in other words, that they are of Bala age or bridge over the gap between the Bala and Llandeilo formations.

The fossils of the Gala Group led the authors to place it high among the Lower Silurian rocks, and indeed to believe that some of the high beds might be of Upper Silurian age. Its fauna approximates most closely to that of the Coniston mudstones of Cumberland and Westmoreland.

At the same meeting of the British Association Mr. D. J. Brown read a paper "On the Silurian Rocks of the South of Scotland"<ref>Brit. Assoc. Rep. Trans. of Sections, p. 93.</ref>. In a section drawn from Moffat Water in Dumfriesshire to Kilbucho in Peeblesshire, the author considers that the rocks form two series: a lower Moffat or Llandeilo and an upper or Caradoc series resting unconformably on the lower. This view of the unconformable relation of these groups is advocated

in a series of papers by Mr. Brown published in 1873 and 1874 in the Transactions of the Geological Society of Edinburgh.<ref>Trans. Geol. Soc., Edin. Vol. 11., pp. 227, 316, 377.</ref>

In 1872, Professor Lapworth advanced a comprehensive classification of the Silurian rocks of the Southern Uplands.<ref>On the Silurian Rocks of the South of Scotland. Trans. of the Geol. Soc. of Glasgow. Vol. IV., p. 164. Geol. Mag., May 1872.</ref>

Still accepting the great anticline between Berwick and Dumfries exposing the lowest strata, the author arranges the strata in the following order:

A. Lower Silurian

1. Hawick and Selkirk beds — Cambrian, Skiddaw

2. Moffat Shale or Anthracite

(a) Lower Anthracite — Lower Llandeilo

(b) Middle Anthracite — Upper Llandeilo

(c) Upper Anthracite — Lower Caradoc

B. Middle Silurian

1. The Gala Group, Girvan Series, Duntercleuch beds, Wrae beds, &c. — Upper Caradoc, Lower Llandovery and Upper Llandovery.

C. Upper Silurian

1. The Balmae and Riccarton beds — Wenlock and Lower Ludlow

2. Lower Pentland beds, — Wenlock

(b) Upper Pentland beds — Ludlow

(c) Pentland Sandstone — Passage beds and Downton Sandstone.

The Appendix contains lists of fossils from the various zones.

In 1872, Mr. Hopkinson, whose researches among the Silurian graptolites are well known, described in the Geological Magazine<ref>Geol. Mag., 1872. Vol. IX., p. 501.</ref> some new forms of graptolites from the South of Scotland. In accordance with the previous researches of Professor Lapworth the author states that from the evidence afforded by the fossils it seems more probable that only one band of graptolite shale runs through the Llandeilo Rocks of the South of Scotland, there being in this band several distinct zones, each marked by a different assemblage of fossils, but with many species in common.

During the same year Professor Lapworth, in a paper contributed to the Geological Magazine "On the Results of some recent Researches among the Graptolite Black Shales of the South of Scotland",<ref>Geol. Mag. Vol. IX., p. 533.</ref> states that subsequent researches had clearly proved the correctness of his main conclusions as published in 1871, which are thus summarised:

There is but a single group of black shale, from 500 to 600 feet in thickness, named the Moffat Shale. This group is lithologically and palaeontologically separable into three great divisions: the Lower, Middle, and Upper Moffat. The Lower division contains the graptolites of the Hudson River Group of America and of the Llandeilo beds of Portmadoc, and is probably of Lower Llandeilo age. The Middle Moffat appears to be the equivalent of the Upper Llandeilo of Builth, while the Upper Moffat is decidedly Caradoc. The Moffat Shale, which in almost every case comes to the surface along

anticlines of the strata, passes up conformably into the overlying Gala Group (belonging to the Upper Caradoc and Llandovery period) in several localities in the southern districts, but to the north the basement bed of the latter rests usually on the Lower Moffat beds, so that there appears to be in many cases an entire absence of Upper Llandeilo and Lower Caradoc Rocks in that direction; the Lower Llandeilo being succeeded immediately by the Upper Caradoc beds.

In 1876 appeared a series of papers of the highest value by Professor Lapworth "On Scottish Monograptidae", published in the Geological Magazine.<ref>Geol. Mag. Vol. III. (New Series), pp. 308, 350, 499, 544.</ref> These publications revealed an important advance in the author's views regarding the geological structure of the southern portion of the Silurian tableland. Discarding the great anticline between Berwick and Dumfries, he maintains that the Hawick Rocks (the axial beds) pass conformably upwards into the Upper Silurian strata (Riccarton and Kirkcudbright) and form the highest members of the Middle Silurian series overlying the Moffat Shales. Regarding the three divisions of the Moffat Shales, he states that the Lower is of Llandeilo age, the Middle represents a portion of the Bala formations of North Wales, and the Birkhill Group belongs, in part at least, to the epoch of the Lower Llandovery.

The author describes in detail the vertical range and distribution of the *Monograptidae* in the Silurian rocks of the South of Scotland. From a review of all the facts he infers that we have sufficient evidence to justify us in accepting the following generalisations:;

1. Of the numerous forms of graptolites belonging to the family of the *Monograptidae* in the South of Scotland, each has a certain definite restriction in the vertical series of deposits.
2. The three successive rock groups of Birkhill, Gala, and Riccarton each possess a well-marked assemblage of *Monograptidae* which is easily separated as a whole from that of the other formations.
3. The general vertical succession of species and varieties of the *Monograptidae* in these rocks is in complete accordance with that in Ireland, Westmoreland, Central Europe, and Scandinavia.

In the same year Professor Lapworth contributed the chapter on "The Silurian System of the South of Scotland" to the "Catalogue of the Western Scottish Fossils", prepared for the meeting of the British Association at Glasgow, in which he gives a Table showing the succession of the strata with their English equivalents. The Birkhill Shales, Gala Group, and Hawick Rocks are viewed as one formation — the Valentian — from the ancient Roman name of the South of Scotland — their English equivalents being the Llandovery, Mayhill, and Tarannon beds respectively.

Regarding the Leadhills district, the author states that there are no Birkhill Shales in this area (unless indeed they are represented by the lowest Valentian zones), the highest black shales visible being the top zones of the Middle Moffat or Hartfell Shales. The Lower Moffat Shales occur in most localities, and the peculiar indurated bands of siliceous flag are often remarkably conspicuous. Every fossil of the Lower Moffat Shales has already been collected from this area, and there seems to be a perfect similarity in their vertical range in the Leadhills and Moffat districts.

The Valentian Rocks of the Leadhills are almost identical in lithological character with those of the Moffat area. Sometimes they contain fossiliferous zones, as at Duntercleuch, Snar, Wallace's Cast, &c. On the same horizon, however, similar fossiliferous bands occur in Peeblesshire at Wrae Hill, Stobo, Kilbucho, and Winkstone, and to the south-west near Moniaive and Dalry. The fossils show that the beds are in all probability of Llandovery age and the continuation of the fossiliferous deposits of the Girvan area.

A provisional classification of the rocks in the Girvan district is likewise given, comprising (a) the crystalline and metamorphic rocks of Ballantrae, and (b) the fossiliferous limestones, the majority of the fossils being considered as of Bala age. These are followed by the representatives of the Lower Girvan Series and Upper Girvan Series. Lists of fossils are given, and many of the graptolites characteristic of the different groups are figured.

In 1878 appeared Professor Lapworth's memoir on "The Moffat Series" in the Quarterly Journal of the Geological Society.<ref>Quart. Jour. Geol. Soc. Vol. XXXIV., p. 240 et seq.</ref> The publication of this paper marks an epoch in the history of the Silurian Geology of the South of Scotland. It remains the greatest and most original contribution to the study of the life-sequence and structural relations of these highly convoluted rocks. For nearly ten years the author had devoted himself to the mapping of the various outcrops of the black shale series throughout the Southern Uplands.

Selecting the Moffat district as a typical area where the sub-divisions of the series are admirably exposed, he unfolded in detail the structure of that interesting region. The paper is illustrated with maps and sections of the district extending from Annandale to St. Mary's Loch and from the Vale of Ettrick to Hartfell. Taking Dobb's Linn and Craigmichan Scaurs as typical sections showing the sequence and palteontological features of the Moffat series, he demonstrates the true order of succession of the strata based on the vertical range of the graptolites. He describes the prominent parallel bands to the north and south of the Moffat valley, and by means of confirmatory sections places his conclusions beyond all doubt. The various sub-divisions, lithological characters, and fossil zones are treated in great detail; a Table showing the vertical distribution of the fossils is given, and the respective faunas of the three divisions of the Moffat Series are compared with their foreign equivalents. The main conclusions are here briefly summarised:

1. The black shales of the Moffat region are portions of one band, repeated by parallel folds, the axial planes of which are usually inverted; the thickness in this district is 300 feet, but the base is not seen.
2. They fall into three groups: the Glenkiln, Hartfell, and Birkhill, corresponding to the Upper Llitndeilo, Caradoc, and Lower Llandovery formations respectively. Each group is divisible into zones, characterised by special mineralogical and palieontological features.
3. Compared with the development of these formations in Wales, there is a marked north-westerly attenuation of the Lower Silurian rocks in Britain — a feature which is common to the Silurian rocks of Europe.
4. Passing from Moffatdale northwards to the north-west margin of the Southern Uplands, the black shale zones gradually disappear, till near the edge of the chain there is only a greatly degenerated representative of the Hartfell–Glenkiln division. To the south of the Moffat district the greywackes and shales rest on the Birkhill (Lower Llandovery) Shales in the Ettrick valley, and after innumerable foldings in Eskdalemuir they pass conformably upwards into the Riccarton beds (Wenlock).

Perhaps one of the most striking palaeontological features of this paper is the great distinction between the graptolite faunas of the two lower divisions and that of the Birkhill Shales; indeed the boundary line marks a distinct palaeontological break (see p. 57).

In 1879 appeared Professor Lapworth's monograph on "The Geological Distribution of the Rhabdophora", in which he gave a comprehensive view of the evidence bearing on the vertical distribution of the graptolites in the Lower Palaeozoic rocks of Europe and America. This paper was accompanied by a valuable series of Tables showing the range of the graptolites in the different divisions of the Lower Palaeozoic systems.<ref>Annals and Mag. of Nat. Hist.. Ser. 5. Vol. III., pp. 245, 449.</ref>

In connection with this review of the geological literature bearing on the black shales and their organic remains, reference ought to be made to the researches of Professor H. A. Nicholson, of Messrs. Carruthers, Hopkinson, W. Dairon, and others who have described and figured fossils from these bands.

Before proceeding to indicate the results of Professor Lapworth's detailed investigations in the Girvan district we must call attention to certain palaeontological researches relating to the extensive series of fossils from the Silurian rocks of that region. It is noteworthy that considerable difference of opinion has arisen among geologists and palaeontologists as to the age of the prolific fossil-bearing zones and associated strata of the older Palaeozoic rocks of the Girvan area. In many instances this is doubtless due, as Professor Lapworth truly states, to the fact that the larger proportion of fossils has been obtained from a few limited areas, and mainly from half a dozen different horizons, while the less fossiliferous strata have been left practically untouched. In some cases, however, as will be shown in the sequel, it may be accounted for by the conflicting nature of the evidence supplied by different groups of organisms from one and the same band. In the Appendix to this volume dealing with the Bibliography, upwards of twenty palaeontological memoirs referring to the Silurian rocks of Girvan are enumerated; at present we shall refer only to those bearing on the order of succession.

In the volume on "British Palaeozoic Rocks and Fossils", published in 1855, by Sedgwick and M'Coy, many of the types from the Girvan region are figured and described, and horizons are assigned to some of the fossil-bearing zones. The Craighead Limestone is referred to Upper Bala time, the Aldons Limestone to the Lower Bala, and the Mulloch Hill Sandstones and Drummuck beds to the Upper Bala formation.

In the "Catalogue of Cambrian and Silurian Fossils" in the Cambridge Museum, prepared by Mr. Salter, with a preface by Sedgwick, which appeared in 1873, the Stinchar Limestone (including the limestone visible at Aldons, Bougang, and Knockdolian) is assigned to the Lower Bala horizon (Llandeilo); the Craighead Limestone, with the Glenwhapple and Ardwell beds, to the Middle Bala position; while the Drummuck and Mulloch Hill beds are relegated to the Upper Bala formation.<ref>In the classification of the Lower Palieozoic rocks given in this volume, the terminology here used is clearly defined; the Lower Bala group (Sedgwick) represents the Upper and Lower Llandeilo rocks (Murchison); the Middle Bala group (Sedgwick). the Caradoc and Bala rocks (Murchison); and the Upper Bala group (Sedgwick) is the equivalent of the Lower Llandovery formation of Murchison.</ref>

In Mr. Salter's unfinished Monograph of the British Trilobites (1864–83), only a few of the types of this group from the Silurian rocks of Girvan are figured and described; but viewing these species in the light of the known vertical range of the trilobites in the Lower Palaeozoic rocks of Wales, he groups the Craighead Limestone and Penwhapple beds with the Caradoc formation (Murchison), and the Drummuck Mudstones and Mulloch Hill Sandstones with the Llandovery Rocks. From the Bougang Limestone (the representative of the Stinchar Limestone) Salter records the tail of a trilobite which he doubtfully refers to *Asaphus (Isotelus),* assigning it to the horizon of the Llandeilo flags.

In the Monograph of the Silurian Brachiopoda (1864–1871) by Mr. Davidson, various forms from the Girvan region appear, and are referred to certain definite horizons. An analysis of these references shows that the Craighead Limestone, Bal-clatchie and Ardwell beds are assigned to the Caradoc formation, while the Saugh Hill grits, the Penkill beds, and Mulloch Hill Sandstones are grouped with the Llandovery Rocks. The Supplement to the foregoing Monograph (1882–4) contains a special section devoted to Scottish Silurian Brachiopoda, in which the author has followed the stratigraphical sub-divisions for Ayrshire propounded by ProfessorlLapworth and the list of localities furnished by Mrs. Gray. In his general list, the Craighead Limestone is now referred to the Llandeilo instead of the Caradoc formation, the beds at Balclatchie, Dow Hill, and Ardmillan Brae are classed as Llandeilo; the strata at Whitehouse Bay and Shalloch Mill are regarded as Middle Caradoc, and the Trilobite Mudstones of Drummuck as Upper Caradoc.

In the three Fasciculi of the valuable Monograph of the Silurian Fossils of the Girvan District by Professor H. A. Nicholson and Mr. R. Etheridge, jun. (1878–80), a systematic descriptive account is given of a large series of organic remains from that region, numerous types are figured, and suggestions are made regarding the probable age of some of the fossil-bearing zones. From an examination of the corals, Professor Nicholson arrived at the following conclusions:

1. The Craighead Limestone is of Lower Silurian age, corresponding perhaps with the upper part of the Trenton Limestone, or the beds of the Cincinnati and Hudson River formations of North America.
2. The Mulloch Hill beds represent the Upper Llandovery or May Hill Sandstone of "Siluria".
3. The Penkill beds near Girvan (greenish-grey mudstones in Penwhapple Glen) must find their place towards the lower portion of the Upper Silurian series.
4. The Shalloch Mill beds with a thin band of coralline limestone are referred to Upper Silurian time.
5. The Balclatchie beds, described as dark green coarse-grained volcanic ashes (Balclatchie grits), are probably low down in the Silurian series.

On the other hand, from the evidence supplied mainly by the trilobites, Mr. Etheridge, jun., thus summarised the results of his investigations:

1. The Craighead Limestone and Shale may be of Caradoc age.
2. The Mulloch Hill beds are referable to the Lower or Upper Llandovery formation.
3. The Penkill beds contain a peculiar mingling of species of trilobites, the majority indicating the lower part of the Upper Silurian system.
4. The trilobites of the Balclatchie mudstones and grits have a strong Caradoc facies, though a few forms are equally typical of other horizons.
5. The trilobites from Ardmillan Brae are mainly Caradoc.
6. The matrix at Penwhapple more or less resembles that at Balclatchie, and the beds are probably Caradoc.

7. The Drummuck mudstones will probably turn out to be of Lower or Upper Llandovery age from the evidence afforded by the trilobites — a suggestion which will be dominated by the mollusca found in association with them.
8. The beds in Thrave Glen are probably of Llandovery age.
9. The Aldons Limestone, in accordance with Professor M'Coy's conclusion, is assigned to Lower Bala time (Llandeilo).

The statements made in the foregoing paragraphs will be sufficient to show the divergence of opinion among palaeontologists regarding the age of some of the prolific fossil-bearing zones in the Girvan region; but though no reliable order of succession had been established, the various investigators were agreed that there are representatives of Llandeilo, Caradoc, and Llandovery strata in the Lower Palozoic rocks of Girvan.

In connection with the development of palaeontological research among the Silurian fossils of Girvan, special reference ought to be made to the magnificent collection of organic remains from the Silurian rocks of that region, made by Mrs. Robert Gray and various members of her family. This unique collection, numbering about 30,000 specimens, was placed at the service of Professor H. A. Nicholson, Mr. Etheridge, jun., Professor Lapworth, and others to aid them in their investigations; indeed, the authors of the Monograph of the Silurian Fossils of Girvan frankly acknowledge their great debt of gratitude to Mrs. Gray, without whose co-operation that work could not have appeared. In the preparation of the Palaeontological Appendix to the present volume, Mrs. Gray has rendered great service by drawing out a list of organic remains from the Lower Palaeozoic rocks of Girvan; the various localities being furnished by herself, and the stratigraphical grouping being based on the order of succession established by Professor Lapworth.

An important contribution was made by Professor Bonney in 1878 to the study of the crystalline rocks of Ballantrae, in which he demonstrated the truly igneous character of the serpentine, gabbro, porphyrites, &c., of that region.<ref>On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast. Quart. Jour. Geol. Soc. Vol. XXXIV. p. 769.</ref> From a consideration of the field evidence and the results of microscopic examination he arrived at the following conclusions:

1. That the serpentine of this district is intrusive and, like so many others, is an altered olivine rock.
2. That there is no hypersthene rock, but gabbros of two ages, both of igneous origin, the first extraordinarily rich in diallage, so that it can hardly be called a gabbro, the second much resembling the later gabbro of the Lizard, Cornwall.
3. That the porphyrites of Balcreuchan and Pinbain Hill are true igneous rocks, and very probably remnants of lava-flows associated with tuffs or agglomerates.
4. That several of the rocks into which the serpentine is intrusive are also igneous, and are augitic, not hornblendic.
5. That there are some doleritic and basaltic dykes of later date than all the above.

Regarding the age of the rocks, he suggested that the last-named basalts are probably Miocene, that the porphyrites are probably outliers of Middle Old Red Sandstone age, and that the serpentine is intrusive in the Lower Silurian rocks of the region, and therefore of later date.

In 1882, Professor Lapworth communicated the results of his detailed mapping of the Girvan area to the Geological Society of London. Having established the vertical range of the graptolites in the Moffat Shales, and having defined the stratigraphical equivalents of their main divisions in Wales and other regions, he approached the study of the stratigraphy of the Girvan rocks from a fresh standpoint. The following is a summary of his main conclusions regarding the order of succession:

1. Selecting the Benan Hill conglomerate as the primary horizon of reference, he shows that it is merely the central member of a series (the Barr series) of boulder beds and conglomerates, with intercalary zones of limestone and fossiliferous shales. It includes the Craighead or Stinchar Limestone as a subordinate member near its base, where it is divided from the underlying Ballantrae Rocks by a calcareous conglomerate and breccia of irregular thickness.
2. The Barr Series is overlain by the Ardmillan Series composed throughout of graptolite flagstones and shales, which nevertheless arrange themselves naturally in several distinct sub-formations. The higher and lower divisions (the Ardwell, Barren Flagstone and Drummuck beds) have their respective positions fixed by stratigraphical evidence. The proper relations of its central divisions (the Cascade and Whitehouse beds), the strata of which are usually inverted,

are established mainly by geographical considerations.

3. The graptolite series of Ardmillan is followed by the Newlands Series, consisting of Brachiopod-sandstones, *Pentamerus* grits, and *Monograptus* shales. The position of the first sub-division of the series (Mulloch Hill beds) is fixed by its relation to the terminal beds of the older Ardmillan series, and the place of the highest division (the Camregan group) by its relation to the newer Dailly series. The position of the central division (the Saugh Hill group) is deduced with equal certainty from its intermediate place in the series. The sequence, however, of the component strata of this central division is rendered so dubious, by inversion, faulting, and local unconlormities, that only a provisional classification of its minor zones is possible.
4. The Dally Series forms the fifth [sic "fouth"] division, being at once the thickest and most homogeneous series in the Girvan succession, comprising the Penkill, Bargany, and Straiton beds.

One of the remarkable features of Professor Lapworth's investigations in the Girvan area is his identification there of certain graptolite zones which are characteristic of the Moffat Shales and overlying Bala group. For example, in the shales associated with the Stinchar Limestone series, he records the presence of *Didymograptus superstes, Dicellograptus sextans,* &c., which are typical of the Glenkiln division (Moffat); in the Ardmillan series he finds *Climacograptus caudatus, Dicellograptus Forchhammeri, Leptograptus flaccidus, Pleurograptus linearis, Diplograptus truncatus,* &c., indicating Hartfell horizons; in the Newlands series he chronicles *Diplograptus modestus, Monograptus Sedgwicki,* and *Rastrites maximus,* &c., some of which are zonal forms of the Birkhill division; in the Dailly series he notes *Grossopodia, Protovirgularia, Monograptus exiguus, Monograptus galaensis, Cyrtograptus Grayi, Monograptus priodon, M. vomerinus,* &c., occurring partly in the Gala group and partly in the Wenlock beds. The discovery of these graptolite zones in the Girvan area threw a flood of light on the stratigraphical horizons of that complicated region. He was thus enabled to demonstrate that Murchison had been misled by the apparent synclinal arrangement of the strata on the plateau on the south side of the Girvan valley, and that he had thus erred in placing the *Pentamerus* grits of Saugh Hill on a lower horizon than the graptolitic flagstones of Ardwell and Penwhapple Glen (Ardmillan series). Over much of that region the beds are inverted, and hence no reliable conclusions can be based on mere superposition.

In his paper on "The Girvan Succession" Professor Lapworth further states that the Girvan rocks appear to repose, at their base, on the generally older igneous and altered rocks of Ballantrae, but they had been too imperfectly studied to hazard any conclusion regarding their age. He made the important announcement, however, that fragments of Ballantrae igneous rocks occur in the Kirkland or purple conglomerate at the base of the Girvan sequence, and hence many of the Ballantrae volcanic rocks must be older than the basement beds of the Girvan succession. He suggests that these pre-Girvan lavas and ashes must either represent the Arenig and Llandeilo volcanic rocks of Wales and Cumberland, or must be of more ancient date. On the other hand, rocks which are unquestionably of true Girvan age occur at many localities within the typical Ballantrae region itself, while the patches of altered or so-called Ballantrae rocks found outside that area almost certainly include some greatly altered Girvan rocks.

In addition to the unconformability at the base of the Girvan succession, Professor Lapworth showed that the sequence of the Girvan rocks is broken by one fairly distinct unconformability, viz., that at the base of the Craigskelly conglomerate. He adds that the presence of boulder beds at the base of the Mulloch group, at the base of the Saugh Hill grits, and elsewhere, renders it probable that other local breaks may be detected.

In the January number of the Geological Magazine, 1889, there appeared Professor Lapworth's final contribution to the stratigraphy and palaeontology of the Silurian rocks of the Southern Uplands.* In Part I of this communication Professor Lapworth states that the Ballantrae rocks have been regarded by him as a complex formed of: (a) the Stinchar Limestone and conglomerate series, (b) a stratiform series of sedimentary and volcanic rocks of much earlier date, (c) intruded igneous masses of subsequent but unknown geological age. In order to study the Ballantrae rocks in greater detail, and to establish on palaeontological grounds the pre-Girvan age of these members of the Ballantrae complex which were held by him to he of higher antiquity than the basement beds (Upper Llandeilo) of the Girvan succession, he paid a visit to this district in 1885, when he obtained evidence which led him to the following conclusions:

1. The diabases, syenites, gabhros, and serpentines occurring in the altered patches within the limits of the Girvan district are mostly, if not all, of post-Girvan age. They occasionally traverse, harden, and alter such of the Lower

Girvan rocks as they are locally associated with, and they have intruded themselves mainly in sheets along the many anticlinal arches into which the Girvan rocks are thrown, either between the Girvan rocks and the Ballantrae rocks proper, or among the limestones and conglomerates which make up the basal members of the Girvan succession.

2. The Ballantrae rock-complex further includes contemporaneous volcanic and sedimentary rocks, some of the last of which are distinctly of pre-Girvan date, for they contain locally a well-marked graptolitic fauna of middle Arenig age, occurring in black shales on the sea-shore at Bennane Head. A list of the fossils is given, together with a Table showing their distribution. Professor Lapworth further states that the Ballantrae series forms a complex of stratified, altered, and igneous rocks of very different geological ages (Arenig, Llandeilo, and Post-Ordovician), the common facies of the pseudo-series being mainly the result of the common interfolding, alteration, and intrusion which its rocks have undergone.

In Part II of this communication he indicates the distribution and physical relations of the various rock formations entering into the structure of the Southern Uplands.

Disregarding the lowest strata (the Ballantrae or Arenig rocks), which are supposed to come to the surface only within the limits of the Ballantrae district, and the highest strata (Wenlock-Ludlow), which merely skirt the upland plateau on its north-west and south-east flanks, Professor Lapworth arranges almost the whole of the Lower Palaeozoic strata of the uplands in two grand lithological divisions.

1. A lower Terrane (Moffat Terrane), including strata ranging from the Upper Llandeilo to the Upper Llandovery.
2. An upper Terrane (Gala or Queensberry Terrane), embracing strata generally of Tarannon age.

The rocks of the Lower or Moffat Terrane attain their maximum development in the Ballantrae–Girvan district, where they include (a) the Barr or Stinchar series (Bala–Llandeilo), (b) the Ardmillan series (Bala–Caradoc), and (c) the Newlands series (Llandovery). These groups are composed of strata of variable lithological characters, containing an abundant fauna of the usual Lower Palreozoic life types, with an aggregate thickness of about 4000 feet. Followed across the uplands towards the south-east, they rapidly diminish in thickness as they reappear in various anticlines, till in the Moffat district they are reduced to 300 or 400 feet in thickness. Here the Moffat Terrane, consisting mainly of black, grey, and white shales, is represented by (a) Glenkiln shales, (b) Hartfell shales, (c) Birkhill shales, charged with a fauna almost exclusively graptolitic.

The members of the overlying Gala or Queensberry Terrane are represented in the Girvan district by the Dally series, upwards of 2500 feet thick, consisting mainly of repetitions of grey grits, flagstones, and red and purple shales. The strata grow thicker and coarser as they are followed eastwards across the uplands, but in the central parts of the plateau a lower (Queensberry) and a higher (Grieston) division can still be roughly made out. Still further to the south-east the beds become finer in grain and decrease in thickness till they plunge underneath the Wenlock Rocks of Riccarton and Kirkcudbright. After stating that the main mass of the visible rocky floor of the Southern Uplands is formed of members of the Gala Terrane, Professor Lapworth proceeds to indicate that the pseudo-synclinal arrangement of the strata in the Leadhills area is an example of the "fan structure" of mountain areas (endocline) where we may naturally expect to find the deepest strata, and that the pseudo-anticline of the Hawick line is due to inverted "fan structure" (exocline) where the highest strata may occur.

The exposures of pre-Gala strata are disposed in broad geographical bands or zones, ranging north-east and south-west, of which the following three are specially conspicuous: (1) the south-east band of Wigtown, Moffat, and Melrose, (2) the central band of Portpatrick. Leadhills, and Lammermuirs, (3) the western zones of Ballantrae and Girvan. In the Moffat–Melrose anticlines the members of the Moffat series appear as narrow "inliers" among the Gala rocks, while in the anticlines of the Leadhills–Moorfoot band the exposures are often more than a mile across. In the latter region the strata of the locally thick Moffat series are occasionally laid bare to a depth of at least 2000 feet down to the calcareous strata at their base (Duntercleuch and Wrae). In the Girvan region the locally massive Moffat series forms a belt four or five miles across; the beds are exposed from base to summit, and the underlying Arenig rocks are laid bare.

In working out the order of succession throughout the uplands, Professor Lapworth states that graptolites must play the chief part, as they are almost the only fossils met with in the strata of this wide region. The known restriction of the entire

family of the *Monograptidae* to Silurian strata (Upper Silurian, Murchison and the Geological Survey) affords the means of determining the outcrop of the upland boundary between the Ordovician (Lower Silurian, Murchison and the Survey) and the Silurian (Upper Silurian) rocks. He suggests that tie outcrop of the main boundary line between the strata of these two systems will be found to pass obliquely across the tableland from near Dunbar, by the south of the Moorfoots, the valley of the Tweed, near the Crook, to the sea-coast south of Portpatrick. North of this line, the mass of the strata will be found to be Ordovician (Lower Silurian); such (Upper) Silurian rocks as occur forming outliers parallel with the great boundary fault. South-east of this line, the mass of the strata must be classed as Silurian (Upper Silurian); the Ordovician (Lower Silurian) rocks occurring only locally as long lenticular inhere, gradually diminishing in systematic importance as they are followed across the country from north to south and from east to west.

Professor Lapworth gives various sketch sections across the uplands, illustrative of his views of the general disposition and inter-relationships of the strata, together with a "Table of Correlation", showing the more important palaeontological data which bear on the question of the upland sequence.

In the spring of 1888 the re-examination of the Southern Uplands was begun by the Geological Survey. Messrs. Peach and Horne, accompanied by Mr. Macconochie, mapped the sections at Ettrickbridge-end, in the Tima Water, and south-west to Wamphray; and, in the northern part of the tableland, the tract between Abington and the Culter Water, south to the valley of the Tweed. An official report embodying the results of their work was forwarded in the same year to the Director-General, in which they finally abandoned the order of succession hitherto followed by the Survey. The following points, among others, were given in this report:

1. In the course of the survey of the Abington area they discovered a series of volcanic rocks (diabase lavas and agglomerates) associated with a prominent zone of cherts and the Glenkiln black shales charged with typical graptolites of that division. In the field, Mr. Peach observed numerous minute organisms in the cherts, which were subsequently determined to be radiolarians by Professor H. A. Nicholson and Dr. Hinde. The volcanic rocks come to the surface along anticlinal folds, and occupy a lower horizon than any beds in the Moffat area; being in all likelihood of the same age as the contemporaneous lavas and tuffs at Ballantrae, Ayrshire.
2. The fossiliferous grits and conglomerates (Duntercleuch, Glendowran, &c.)
3. are associated with the Glenkiln–Hartfell black shales, and are apparently of Caradoc age; the Lowther shales with the lenticular bands and nodules of limestone (Wrae Limestone) are probably the equivalents of the Barren Mudstones of the Moffat series (Upper Hartfell), and therefore of Caradoc age.
4. The northern outcrop of the base of the Llandovery Rocks (Queensberry Grits and Dalveen Group) is indicated by flaggy shales with bands of dark or black shales yielding dwarfed forms of graptolites, probably representing the basal beds of the Birkhill division.
5. In such a highly contorted region as that of Abington, the apparent order of superposition is entirely misleading, and the only method of determining the succession is by means of the graptolite zones established by Professor Lapworth in the Moffat region.

In 1890, Dr. Hinde published the results of his examination of the collection of cherts obtained by the Geological Survey from the Abington area, which was submitted to him for determination.<ref>Annals and Magazine of Nat. Hist., July 1890, p. 45 *et seq.*</ref> He concludes that this "chert may be fairly considered to be due to the accumulation of the tests of radiolaria, and is thus a pure radiolarian rock equally as much as the Tertiary beds of Barbadoes and Nicobar Islands, which, according to Haeckel, correspond to the recent radiolarian ooze and are of deep-sea origin, having probably been deposited at depths greater than 2000 fathoms. If the same conclusion is applicable to this fossil chert, it may represent, as Professor H. A. Nicholson<ref>Trans. Edin. Geol. Soc. Vol. VI., Part I., p. 56.</ref> has already pointed out, a true deep-sea deposit in the Palaeozoic period, the existence of which in the geological series has of late been disputed. The beds of fine-grained red and green mudstones associated with this chert likewise favour the same view of its origin in deep water".

In 1889,<ref>Report on the effects of Contact-Metamorphism exhibited by the Silurian rocks near the town of New Galloway. Proc. Roy. Soc., London. Vol. XLIX. (1889), p. 79.</ref> a paper was contributed to the Royal Society of London by Mr. Allport and Professor Bonney, on the contact metamorphism of the Silurian rocks by the granite west of

New Galloway. In 1890,<ref>Contact alteration near New Galloway. Quart. Jour. Geol. Soc. Vol. XLVI. (1890), p. 569.</ref> another important communication was made by Miss Gardiner to the Geological Society of London, in which she described the alteration of Silurian sediments into sillimanite-gneiss in contact with the New Galloway granite. These parrs are more specially referred to in the chapter dealing with contact metamorphism.

Since 1888, the re-examination of the Southern Uplands, in the light of Professor Lapworth's researches, has been carried on at intervals by the Geological Survey as the exigencies of the work in the Highlands permitted. In the Central Belt, between St. Abbs Head and the Mull of Galloway, all the known exposures of the Moffat series were re-examined, their structural relations ascertained, and fossils were collected sufficient to determine the horizons of the main divisions of that series. The important structural line marking the northern limit of the Llandovery and Tarannon rocks of the Central Belt has been traced across the uplands from the slopes of the Lammermuir Hills to the western headlands of Wigtownshire — a labour attended with considerable difficulty, owing to the gradual disappearance of the Birkhill shales with most of their fossils and their replacement by coarser sediments. In the Northern Belt, from the Laminermuir Hills to Loch Ryan and Portpatrick, all the known exposures of the Moffat shales were likewise re-mapped, the respective boundaries of the Arenig volcanic rocks and overlying radiolarian cherts were traced, and fossils were gathered to fix the horizons of the succeeding Glenkiln–Hartfell shales. Again, in the Girvan area, the volcanic and plutonic rocks of Ballantrae were re-mapped, and their relations to the Arenig igneous rocks and radiolarian cherts of the uplands were ascertained, while the main sections of the Girvan succession, mapped and described by Professor Lapworth, were re-visited. During the prosecution of the re-survey portions of the large granite masses and of the aureoles of contact metamorphism were re-examined, and materials were obtained for petrographical description. Finally, the Upper Silurian inners of Lanarkshire and the Pentland Hills were re-traversed, the sub-divisions of the Downtonian rocks in these areas were ascertained, and their fossiliferous zones successfully traced. Sheets 16 and 8 of the one-inch map of Scotland have been published in the course of the re-survey, and a revised edition of Sheet 7 has just appeared.

The results of the re-examination of the Southern Uplands by the Geological Survey have, from time to time, been summarised in the Annual Reports of the Director-General, and may be briefly recapitulated as follows:

1. The occurrence of a series of Arenig volcanic and plutonic rocks on various anticlines over an area of about 1500 square miles.
2. The existence of a well-marked band of radiolarian cherts and mudstones, overlying the foregoing volcanic series, which has been traced over a part of the uplands measuring about 2000 square miles.
3. The main band of radiolarian chert and mudstone, though about 70 feet thick, represents the succession of deposits which, elsewhere in Britain, intervene between the Middle Arenig and uppermost Llandeilo strata.
4. The occurrence at various localities over a limited area of volcanic rocks of Llandeilo and Caradoc age.
5. During the examination of the various black shale outcrops throughout the uplands, a great amount of detailed evidence has been obtained, confirming the order of succession established by Professor Lapworth, and the lateral variation of the strata between Moffat and Girvan.
6. The inclusion of the Downtonian strata of Lanarkshire and the Pentland Hills in the Silurian system, owing to the discovery of fishes, eurypterids, &c., resembling those occurring in the Ludlow rocks of Lanarkshire and other regions.

Summary. In the foregoing pages we have endeavoured to give a historical account of the development of research in the Silurian rocks of the Southern Uplands, from which it will be seen that considerable detail has been introduced in order that justice might be done to the various investigators. Before concluding this sketch it is desirable to place clearly on record the distinctive features of Professor Lapworth's achievements, both palaeontological and stratigraphical, which resulted in establishing the true order of succession of the strata.

1. From the outset he clearly recognised that a detailed study of the vertical distribution of the graptolites might furnish the key to the true interpretation of the structure of the region.
2. While collecting the fossils, zone by zone, in the Moffat region, he found that certain forms occur as distinct and consecutive faunas, which always preserve the same relative sequence though the strata may be inverted by folding.
3. When tracing the black shale bands throughout the uplands, he proved, by means of the successive graptolite faunas, a remarkable variation in the character of the contemporaneous sedimentary deposits; the black shales of the Central

Belt (the Moffat series), which do not exceed 300 feet in thickness, being represented in the Girvan area by several thousand feet of sediments.

4. By his researches on the geological distribution of the Rhabdophora he showed that the sequence of graptolite faunas established in the Southern Uplands likewise extends over Europe and North America.
5. The determination of this faunal sequence disposed of the order of succession of the Silurian rocks of the South of Scotland based on Barrande's doctrine of Colonies, corrected erroneous estimates of the thickness of the strata, and enabled the structure of the uplands to be worked out in the most highly complicated districts.