

49. *The GIRVAN SUCCESSION.* By CHARLES LAPWORTH, Esq., F.G.S.,
Professor of Geology and Mineralogy, Mason Science College,
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I. INTRODUCTION.

1. *Lower Palæozoic Strata of Girvan and the Southern Uplands of Scotland.*

That portion of Scotland which lies to the south of the metamorphic area of the Highlands is composed of two very distinct physiographical regions—the plateau of the Southern Uplands, and the low-lying district of the central valley of Lanark and Midlothian. In all their grander features, physical, geological, and economical, these two regions are strikingly contrasted. The Upland region is an elevated tableland, with a smooth, flowing contour of alternate hill and dale; its grass-clad surface, almost destitute of arboreal vegetation, is devoted to pasturage, and supports but a scanty and sparsely scattered population. The surface of the Lowland region, on the other hand, is picturesquely diversified by steep hill-ranges, which are adorned with plantations of oak and fir, and enclose wide and fertile plains, highly cultivated, and inhabited by a numerous and wealthy population. Again, the Upland region is a land of *Lower Palæozoic* rocks, composed of an endless repetition of dingy greywackes and shales, which repeat the monotony of the surface in the sameness of their petrographical characters. The valley-region is, by contrast, a land of *Upper Palæozoic* strata, of sandstones, limestones, coal, and volcanic rocks, as diversified in their mineralogical features as is the picturesque scenery to which they have given origin. Finally, the *Lower Palæozoic* rocks of the Uplands may be traversed for miles without affording a trace of a fossil or an interesting mineralogical specimen; and only in one very limited locality are their minerals of the slightest economic value. The *Upper Palæozoic* strata of the great valley, on the other hand, are, alike in their fossils and minerals, among the most productive in the island.

From the eastern sea-board near Dunbar, across the entire breadth of Scotland to a point almost within sight of the North Channel, it may almost be said that this violent contrast in the structure and natural characteristics of the two regions is maintained unbroken. The huge grass-grown slope, with its softly undulating sky-line, which marks the northern margin of the Upland, rises upwards like the edge of a vast terrace, and looks out far and wide over the Lowland region to the northward, with its varied surface of hill and dale.

But at the south-western extremity of this marked boundary-line lies a district which it is impossible to assign satisfactorily either to the Upland or to the Lowland region. This is the beautiful district of Carrick—the land of Craigs—which forms the south-western division of Ayrshire, and is drained by the waters of Girvan and Stinchar. In its physiographical aspect this district partakes of the characters of both the Upland and the Lowland regions. Its higher grounds repeat the flowing, mound-like, grass-grown forms of the Upland hills, with the straggling village, the

remote pasture-farm, and the lowly sheiling of the shepherd. Its open valleys and less elevated grounds are those of the Lowland region, relieved by steep ridges clothed with copses of oak and fir, and sheltering fertile corn-lands and busy villages, inhabited by a population employed in mining and agriculture.

To a large extent this union of the diverse peculiarities of these two physical regions in one and the same area is owing to the fact that there is an alternation of the distinctive strata of the two regions within its limits—its more elevated portions being formed of Lower Palæozoic rocks, and its low-lying sections floored by faulted patches of the more diversified Upper Palæozoic strata. But, strange to say, the majority of the diversified strata of this Carrick district are of the same general geological age as the monotonous Lower Palæozoic rocks of the Uplands, and many of the more abrupt physical features of the district are actually due to the local peculiarities of those strata as here exhibited. It is, indeed, true that upon several horizons in its succession we meet with strata whose dingy colours, monotonous lithological characters, and utterly barren nature are identical with those of the generality of the Silurian rocks of the Uplands; but, as a rule, the Lower Palæozoic strata of the Carrick district are vastly different in all their characteristics from their Upland counterparts. In their petrographical features they are fully as diversified as are the Upper Palæozoic strata of the central valley; and this diversity in structure is accompanied by an astounding increase in the abundance and variety of their organic remains. Among the rocks of the Southern Uplands limestones are practically unknown, conglomerates and shelly sandstones are only occasionally present; the interminable succession of barren greywackes and shales is but rarely interrupted by the occurrence of an insignificant seam of black mudstone affording a few Graptolites. In the corresponding strata of Carrick, however, fossils of all the invertebrate classes, Hydroida, Actinozoa, Trilobita, Brachiopoda, and Cephalopoda, are more or less plentifully distributed throughout the entire succession, and, upon several horizons, even swarm in extraordinary profusion. Shelly sandstones and sandy grits, carbonaceous shales and Graptolitic mudstones occur in great force; limestone is developed to an extent unequalled elsewhere among the Lower Palæozoics of the south of Scotland; while the massive conglomerates and tumultuous boulder-beds attain a thickness and a geological importance as yet unparalleled in the Lower Palæozoic world.

In a further and yet more salient feature the rocks of this area are trenchantly contrasted with their counterparts of the Southern Uplands. In the Upland region, if we except the scattered trap-dykes and the intrusive granitic bosses of Cairnsmore and the Kells, igneous outbursts, either contemporaneous or subsequent, may be said to be unknown. In the west of the Carrick district, on the contrary, we find exhibited one of the most interesting igneous areas in Britain, whether we have regard to the diversified nature of its products, to their enigmatical mode of occurrence, or to

the ingenious and mutually destructive theories that have been framed respecting their manner of origin and their relationship to the aqueous strata in which they are enveloped.

The physical geologist and stratigraphist, repulsed by the unattractive features and non-fossiliferous character of the rocks of the Southern Uplands, has always turned to this Carrick district with sanguine anticipation. Convinced of the excessive difficulty and even uselessness of reducing the monotonous Upland strata to their natural order, he is the more readily persuaded that here, at least, is a region where his labours will be repaid with interest. Among rocks so varied and so attractive, and so prolific of fossils, the detection of the true key to the succession must surely be a delightful task, whose steps must be all easy and pleasurable, and whose end must be success.

Within the last thirty years the rocks of this district have been studied, in whole or in part, by many of the most successful British geologists—by J. C. Moore, Nicol, Sedgwick, Murchison, and Geikie: and they have been carefully mapped in detail by the officers of the Geological Survey. Their fossils have been collected in the field and studied in the closet by McCoy, Salter, Wyville Thomson, Davidson, Etheridge, Nicholson, and by a host of minor palæontologists, past and present. They have been painfully tabled in catalogues and figured in monographs; and their more striking zoological types have long been classic in the palæontological world. In brief, a blaze of scientific light has been concentrated upon this little district, more intense and sustained than upon any other Lower Palæozoic area of equal extent in Britain. Nevertheless our knowledge of the true sequence and characteristic life-groups of the natural divisions of its fossil-bearing strata seems today as far off as ever. Of all the diverse theories of the succession held at present, officially and non-officially, there is not one that is not implicitly acknowledged to be vague, tentative, and unsatisfactory; while the most popular and best-supported theory of all, that of Murchison himself, has long been known to be incompatible not only with the physical evidences obtainable within the district itself, but with that special palæontological gradation which is now universally recognized among the corresponding Lower Palæozoic rocks all over the world.

The causes of this unsatisfactory result are not far to seek, and they are both physical and palæontological in their origin. Precisely as in the Lower Palæozoic rocks of the Uplands, the strata of the Carrick region are so convoluted by folds, and so intermingled by faults, that it is impossible to rely upon evidences of superposition derived from longitudinal sections traversing extended areas: and British geologists, trained in the less complicated Upper Palæozoic regions, have not hitherto found time or patience to work out the sequence in the only way in which success is possible, namely, painfully and elaborately, zone by zone, and bed by bed.

The frequent repetition of strata identical in lithological characters upon many distinct horizons in the vertical succession affected by

these folds has resulted in the confounding of beds vastly different in geological age. The numerous longitudinal faults which cut through the district along the strike of the beds have brought into unnatural juxtaposition strata widely separated in the true vertical series; and, even where the sequence is the natural one, the predominating inversion has forced the conscientious stratigraphist to give the physical testimony an erroneous interpretation.

The palæontological evidences, as they have been hitherto construed, have led to a confusion of opinion even more perplexing and disheartening. By far the larger proportion of the fossils recorded from this district have been obtained from a few limited areas, and at most from half a dozen different horizons, while all the intermediate and less fossiliferous strata have remained practically untouched. The unfortunate habit of collectors of grouping together fossils according to the area whence they were procured, instead of the individual stratum to which they belong, has here been carried to excess. We find in the same local list species elsewhere of Wenlock, Llandovery, Caradoc, and even of Llandeilo age, all tabled together as if they had been obtained from one and the same stratigraphical zone. This has had its inevitable result, not only in hiding from view the defective stratigraphy, but in casting ridicule and even odium upon palæontological testimony in general. Even Professor Ramsay, the former head of the Geological Survey, whose life has been mainly spent in the study of the Lower Palæozoic rocks, unable to reconcile the numberless discrepancies between the apparent sequence, palæontological and stratigraphical, as here developed and that worked out by himself in the regions of Siluria, has been driven to the conclusion that these enigmatical Scottish rocks belong to an episode of a date between that of the Bala and the Llandovery, unrepresented among the fossil-bearing rocks of the South of Britain.

Nor, until very recently, could any available light be brought to bear upon the difficulties which beset the study of the strata of Carrick, derived from testimony obtained among the Lower Palæozoic rocks that lie outside the district itself. The inevitable intermingling of the fossils of distinct zones in the tables of such classical works as Murchison's 'Siluria,' M'Coy's 'Palæozoic Rocks and Fossils,' Barrande's 'Système Silurien,' and in the publications of the Geological Survey, ran so fully in harmony with the supposed facts obtainable in Carrick, that no definite palæontological error was discernible of sufficient moment either to cast doubt upon the supposed physical sequence, or to stimulate inquiry into the less universally accepted theory of the intermixture in the same beds of so many distinct types of fossils.

But, within the last few years, a more detailed study of the minor groups of strata recognizable in the Lower Palæozoic rocks of Wales has been most successfully inaugurated by Dr. Hicks. The subsequent investigation of the correspondent strata of Scania and Dalarne by the Swedish geologists has resulted in proving to demonstration that, even in sediments of such contracted vertical

dimensions as are there developed, the change of life-type seems to have been strictly dependent upon the progress of geological time, the successive fossil assemblages differing in facies among themselves in proportion to the geological interval which separates them. These discoveries have thrown a new light upon the magnificent results long since obtained by Barrande in Europe, and by Hall and his brother geologists in America, and have led some of the more sanguine students of British Geology to hope that, not only would the grand rock-systems of Lower Palæozoic age on this side of the Atlantic admit of a rude parallelism in areas now widely separated geographically, but that even their formations, subformations, and more important zones of life might in time be synchronized with average accuracy, and an ascending geological scale be thus constructed comparable with that which has proved so valuable in correlating the Mesozoic strata of Britain and the continent.

The further discovery that organisms of such a lowly type as the Graptolites followed the same law of slow development, specific culmination, and extinction as that long acknowledged to be characteristic of the life-periods of the higher groups of animals, has added great force to these views. It has allowed us to unravel with comparative ease the ascending sequence in one of the most complicated districts among the contorted strata of the Southern Uplands and has shaken the fashionable and mystifying doctrine of Colonies, as interpreted by British geologists, to its foundations. The host of proofs which the detailed study of these fossils has disclosed that the supposed extended range and confused intermingling of their species does not actually exist, but is due, primarily, to defective stratigraphy, has led myself and others to suspect that the species of the remaining groups of Lower Palæozoic fossils will ultimately be found to have a similar restricted range in geological time, and, as a consequence, an equivalent value as indices of the systematic place of their containing stratum, and that palæontological evidences are destined soon to regain their ancient place in the regard of the working geologist among the older sedimentary rocks. The new interest and illumination thus cast upon the study of the Lower Palæozoic rocks are, it is hoped, certain to lead to the working out of these ancient strata upon a new and more minute plan, with the result of the discovery of a host of correspondencies at present unsuspected between British and foreign Lower Palæozoic sediments, and the gradual development of a detailed scheme of classification of widely extended application.

Now, not only are these Lower Palæozoic rocks of Carrick of all-absorbing interest to the palæontologist and geologist from their highly fossiliferous nature and their enigmatical stratigraphy, but they afford all the elements necessary for a crucial test of these special opinions. If the asserted heterogeneous intermixture of fossil assemblages of all types, elsewhere characteristic of distinct horizons, were actually found to obtain amongst them, palæontology might well abandon her claim to be the unfailing handmaid of stratigraphy among the more ancient formations. If, on the

other hand, the cautious study of these deposits led to the demonstration of the contrary opinion, *i. e.* that their distinct fossil assemblages were restricted, as in other lands, to different stratigraphical zones, British geologists would feel justified in attempting the correlation of their own Lower Palæozoic subformations with their nearest representatives all over the world.

In the following pages I shall give the results of a personal study of these Carrick rocks as they are exposed in the area which lies immediately to the east and south of the sea-port town of Girvan. If the testimony here brought forward be accepted, we are not only forced to the conclusion that these Lower Palæozoic strata attain a thickness and a geological importance hitherto unsuspected, while in the definiteness and gradation of their component subformations and in the abundance of their special fossils they bear favourable comparison with the classic deposits of Siluria itself, but we are also compelled to acknowledge that in the vertical sequence of these subformations, in the direction and amount of the development of life—even in the grouping of certain genera and species and in the restriction of defined assemblages to special zones—they correspond to a most remarkable degree with the homotaxeous or synchronous deposits hitherto studied in detail in Southern Britain, Europe, and America.

2. *General Characteristics of the Girvan Region.*

The fossiliferous Lower Palæozoic strata which will be noticed in the present memoir lie within and around the extensive and more or less elevated tableland which separates the lower portions of the river-valleys of the Girvan and Stinchar. Westward, this plateau is abruptly truncated by the waters of the Firth of Clyde. Its seaward margin is formed by a line of almost vertical cliffs, based upon a coast platform, which is alternately a raised beach and a submerged fringe of dangerous reefs and skerries. Eastward, its limits are defined with tolerable distinctness by the commencement of a superimposed terrace, composed essentially of more recent volcanic rocks, of the general age of the Old Red Sandstone. The south-western portion of the plateau itself forms the *subdistrict* of Ballantrae, which is occupied by igneous and altered rocks of undetermined age, and which will be therefore only casually referred to in the present paper. The major portion, or main Girvan plateau, to which our attention will be chiefly directed, and which is based upon the fossiliferous deposits, has a length, from the coast near Girvan to the edge of the Volcanic Terrace of Garleffin, of about 12 miles, and a breadth, from the edge of the Uplands to the southern slopes of the Girvan valley, of about 8 miles.

In addition to this main exposure, the Lower Palæozoic rocks make their appearance at the surface within the Girvan region in two subordinate and supplementary areas, *viz.* those of Craighead and Straiton. The *Craighead*, or Mulloch-Hill area, is formed of the wooded ridges lying to the north of the Girvan valley. It is a

partially faulted inlier of about six miles in length, by one and a half in breadth, bounded on all sides by Old Red and Carboniferous strata. The *Straiton* area is a faulted strip of Silurian rocks five and a half miles in length, by half a mile in breadth, lying several miles to the east of the main district, and forming the northern edge of the Old Red Sandstone terrace of Garleffin.

The southern boundary of the principal Lower Palæozoic area, or main Girvan plateau, is formed by the deep and narrow valley of the river Stinchar. Throughout the whole of its course in this region, from Barr to Ballantrae, the greatest width attained by this depression is about half a mile. To the south of this valley, the hills of the Southern Uplands are seen sweeping upwards in rounded grass-clad forms into the barren moorland area of Beneraird and the Merrick. To the north, the valley-slopes are steep and frequently abrupt, a range of picturesque heights, some 1500 or 1600 feet in elevation, overhanging the valley from Barr to Pinwherry. The numerous windings of the stream below enclose patches of fertile alluvial flats, or haughlands, which have long been under cultivation. A few woodlands and thickets margin the river, and creep partly up the hill-sides, while farmsteads and cottages are more than ordinarily numerous; but the valley in its general aspect is of the same peaceful pastoral character as those of the Southern Uplands.

The valley of the river Girvan, on the other hand, which bounds this main plateau on the north, is altogether much wider, and is wholly different in its physiographical aspect from that of the Stinchar. Along its southern margin the grassy steep of the Hadyard, Saugh, and Straiton Hills plunge suddenly downwards from a height of several hundreds of feet, in a long straight line 10 or 12 miles in length running from Girvan to Straiton. Northward the depression is bounded by the wooded slopes of the inlier of Craighead and Mulloch. Between these limits the level valley has a breadth of from four to six miles, and stretches eastward into the interior as far as the eye can reach. Innumerable woodlands and numerous parks and mansions diversify its surface; and the frequent villages, hamlets, and farmsteads testify to the industry and wealth of its inhabitants.

At the mouth of the river-valley itself lies the little sea-port town of Girvan, which gives its name to the entire district. Its inhabitants are largely of Irish extraction, and are employed in fishing and agriculture.

The few streams that drain the Girvan plateau conveniently divide it into several well-marked *subareas*, individualized by certain local peculiarities of scenery or rock-structure. The shallow upland valley of the water of Assel (Plate XXIV.) effectually isolates the mound-like area of *Benan* and Auchensoul. The rapid stream of Penwhapple has excavated a gorge, three miles in length and nearly a hundred feet in depth, across the very centre of the northern section of the plateau, sharply separating it into the two subdistricts of *Saugh Hill* and *Knock-gerran*. A fourth or coast-area is formed by the raised beach of *Shalloch* and Ardmillan, to the south of the

town of Girvan; a fifth by the narrow strip of Lower Palæozoic rocks forming the northward slope of the *Hadyard* and *Garleffin* Hills; and a sixth by the lenticular inlier of *Craighead* and *Mulloch Hill* near *Dailly*.

The whole of the important subarea of the *Benan* and *Milljoan* Hills, together with much of the adjoining subareas, is flooded by sheets of boulder-conglomerates of enormous thickness and remarkable composition, amid which lie patches and lines of fossiliferous limestones scattered confusedly over the face of the country. The *Saugh-Hill* and *Knock-gerran* subareas are composed of repetitions of flagstones and grits of variable composition, occasionally interspersed with shell-bearing pebble-beds and seams of purple and green mudstone. The shelly sandstones and *Trinucleus*-shales, for which the Girvan district has long been famous, occur only in the *Craighead* and *Mulloch-Hill* area which lies to the north of the Girvan valley. The barren strata exhibited in the fringing subarea of *Dailly* and *Straiton* to the south of that valley remind us of the greywackes and flagstones of the Southern Uplands.

The *strike* of the Lower Palæozoic rocks of the Girvan district is uniformly from N.E. to S.W. The *dip* of the beds varies. In the northern parts of the main plateau they dip steeply to the south-east, while to the south they have as distinctly a north-westerly inclination. Hence the majority of geologists have hitherto regarded the rocks of this plateau as forming a regular synclinal trough, whose oldest strata lay along the outer edges of the plateau and the newest in its centre.

Two gigantic *faults* have long been recognized as affecting the stratified rocks of this district. These occur on the opposite slopes of the valley of the Girvan, running approximately parallel to the general course of that stream, and throwing down between them a broad band of Carboniferous strata, from two to four miles in width. The northern, or *Craighead* fault, has been proved for a distance of about 21 miles; while the southern, or *Bargany* fault, is in all probability of equal longitudinal extent. The general direction of these faults is from N.E. to S.W.; in other words, their courses coincide with the general strike of the Lower Palæozoic rocks of the region. They are, in reality, *strike-faults*, whose existence would long have remained unsuspected were it not for the fact that, with respect to the overlying Carboniferous strata, they are more or less *dip-faults*, abruptly truncating the gently inclined Carboniferous beds, and flinging them down along two comparatively straight lines among the perpendicular or highly convoluted Lower Palæozoic rocks below.

A third fault, running along the southern slope of the valley of the *Stinchur* and having the same general N.E. to S.W. trend as the foregoing, was detected by Prof. A. Geikie during his detailed mapping of the district. By the officers of the Geological Survey the fault was originally looked upon as forming the southern limit of the Girvan district proper. The barren and monotonous strata lying to the south of this fault were classed as being of *Llandeilo* age, while

the more varied and richly fossiliferous deposits lying to the northward were assigned to the Caradoc.

I shall show in the sequel that these great faults are accompanied by a host of others, some of which are of even greater geological importance, and that to the presence of these gigantic dislocations many of the most vital difficulties which beset the study of the stratigraphy of this region are primarily due.

3. *History of Previous Discovery and Opinion.*

The earliest notice of the fossiliferous Lower Palæozoic rocks of Carrick occurs in a memoir on "Some Fossiliferous Beds in the Lower Palæozoic Rocks of Wigtownshire," contributed to the Geological Society of London by Mr. J. Carrick Moore, in 1849, and published in the Quarterly Journal of the Society for the following year. The author, after describing the Graptolitic strata of the Gallo-way coast in some detail, gives a brief account of a fossiliferous limestone he had detected among the so-called Silurian rocks of Carrick. This limestone he had personally examined in five different localities in the valley of the Stinchar, and had procured from it many well-preserved fossils, principally Brachiopoda. These fossils he submitted to Mr. Salter, who at once assigned this Stinchar Limestone to the general epoch of Murchison's Lower Silurian, and paralleled it with that of the Wrae Hill in the Uplands of Peebleshire, which had been recently brought into notice by the discoveries of Professor Nicol. In Salter's description and figures of these Carrick fossils, published as an Appendix to Mr. Moore's paper, we find the earliest notice of the genus *Maclurea* in Britain, together with incidental references to the collateral results of Professor Sedgwick's simultaneous discoveries in the Carrick rocks north of the Stinchar valley.

At the meeting of the British Association held at Edinburgh in 1850, Professor Sedgwick gave a verbal description of his partial study of these Carrick rocks, which he had studied in the field a year or two previously, and from which a large suite of fossils had already been collected under his superintendence. From the brief abstracts of his remarks subsequently published in the Report of the Association* and in the 'New Edinburgh Philosophical Journal'†, we gather that Sedgwick recognized two successive groups of Lower Palæozoic strata in this region—a *South-Girvan Group* and a *North-Girvan Group*. His South-Girvan Group, which included the Stinchar Limestone and all the remaining strata of the plateau south of the Girvan valley, was assigned, with doubt, to the Llandeilo formation of Murchison. His North-Girvan Group, which embraced all the strata of the Craighead inlier to the north of the Girvan valley, was more confidently paralleled with the shelly limestones then supposed to lie between the Llandeilo Flags and the higher Silurian rocks of South Wales.

* Report British Association, 1850, pp. 103 &c.

† Edinburgh Philosophical Journal, vol. li, pp. 253, 254.

Fired by Sedgwick's animated descriptions of the strata of the Girvan region, Sir Roderick Murchison visited the district immediately afterwards, in company with his friend Professor Nicol, and made a most careful investigation of its Lower Palæozoic rocks. Like Sedgwick, he brought away with him a large collection of the most characteristic fossils. These were subsequently submitted to the examination of the veteran Silurian palæontologist, Mr. Salter; and, fortified by the corroborative evidence afforded by these forms, Murchison published his results in his general memoir on the "Silurian Rocks of the South of Scotland," read before the Society in 1850, and issued in their *Quarterly Journal* for 1851*.

This memoir is characterized throughout by all Murchison's keen geological insight, comprehensive grasp of detail, and brilliancy of generalization; and it remains to this day not only classic in respect of its origin, but the clearest, most comprehensive, and, if we have respect to the date of its appearance, the most reliable paper that has yet been published upon the Lower Palæozoic rocks of this region.

According to Murchison the Silurian strata here displayed consist of three main groups—an upper group of schists and flagstones, a middle group of shelly sandstones and conglomerates, and a lower group of limestones and schists. The highest strata were supposed by him to lie in the trough of the apparent synclinal formed by the rocks of the great plateau between the valleys of the Girvan and Stinchar, and to have their northern representatives in the Trilobite (*Trinucleus*)-shales of Drummuck in the Craighead inlier. His middle division embraced the prolific shelly sandstones of Mulloch Hill, the *Pentamerus*-gritstones of Saugh Hill, and the barren boulder-conglomerates of Kennedy's Pass. His lower division was supposed to be formed by the limestones of Craighead and the Stinchar with their characteristic *Maclurea* and associated volcanic and trappean rocks.

His highest zone, or Orthoceratite-flagstone, had no definite geological date assigned it; but Murchison had no hesitation in paralleling the middle or shelly sandstone division with his typical Caradoc Sandstone of Siluria, which at that time included the *Pentamerus*-beds, or Llandovery rocks, as a subordinate member. The Stinchar limestones he placed in the Llandeilo, in the lowest or Arenig division of that formation as then received, which was supposed to be characterized by its many interbedded trappean rocks.

Murchison's conclusions, strengthened as they were by many clear sections worked out in the field, were in perfect harmony with the ideas then generally entertained with respect to the physical and palæontological succession among the typical Silurian areas of Wales and the west of England, and were at once accepted by the majority of geologists.

In 1854 Professors Sedgwick and M'Coy made their famous discovery that the May-Hill, or Upper Caradoc Sandstone, or *Pentamerus*-beds of Siluria, had no connexion, either physically or

* *Quart. Journ. Geol. Soc.* 1851, pp. 137 *et seq.*

palæontologically, as believed by Murchison, with the Bala formation*, but actually formed the base of Murchison's Upper Silurian system. This was soon followed by Murchison's erection of the *Pentamerus*-bearing strata into the transitional formation of the Llandovery, and the extension of this improved classification to the corresponding strata outside the typical areas.

In 1867 appeared the fourth edition of Murchison's *Siluria*†, in which the veteran geologist incorporated and systematized these and other advances in the classification of the Lower Palæozoic rocks necessitated by the results of the researches of the officers of the Survey under his direction and their amateur contemporaries. In this work these Girvan strata are noticed in some detail; and, assisted by Professor A. Geikie, Murchison attempted a more detailed correlation than that suggested in his earlier memoir. But, though not expressly advocated in words, the same general order of succession is retained unmodified, except that the higher beds are referred to the newly instituted formation of the Llandovery, and are described as indicating a passage into the base of the Upper Silurian.

Confirmed in his original views of the general order of succession in this region by the new data supplied to him by Professor Geikie, Murchison again confounded the two distinct faunas of the shelly sandstones of Mulloch Hill on the north of the Girvan valley and the *Pentamerus*-gritstones of Saugh Hill on the south, and placed the much older fauna of the Ardwell and Penwhapple flagstones above both. Nevertheless he recognized most distinctly the heterogeneous character of the fauna of his middle group, and accounted for it on the theory that here "as in England and Wales, particularly as we ascend the series, we meet with rocks in which the upper and lower types of fossils are mixed together"‡.

In the following year Professor A. Geikie§ published a brief *résumé* of the conclusions already reached by geologists respecting the sequence in the Girvan area, pointing out with great clearness and effect the tantalizing nature of the evidences obtainable in the district.

In 1869 the detailed examination of the strata of the region by the officers of the Geological Survey having been completed, sheets 7 and 14 of the one-inch maps of the district were issued to the public, accompanied by brief explanatory memoirs.

In sheet 14 and its accompanying explanation we are presented with much that is new and of great value. The anticlinal disposition of the strata of the Mulloch-Hill inlier is shown with great distinctness; the superposition of the Mulloch-Hill sandstones to the *Trinucleus*-shales of Drummuck established beyond dispute; while a sufficiency of palæontological evidence is adduced to make it evident that the former appertain to some portion of the Llandovery forma-

* Phil. Mag. ser. 4, vol. viii. p. 301.

† *Siluria*, 4th edit. 1867, pp. 155-158.

‡ *Siluria*, 4th edit. p. 157.

§ Transactions Geological Society of Glasgow, vol. iii. p. 74.

tion*. At the same time the existence of the long strip of Silurian strata near Straiton is made known for the first time, and a well-founded suggestion thrown out that it is of Upper Silurian age.

The new material supplied by sheet 7 and its explanation, which bears upon the rocks of the great plateau to the south of the Girvan valley, is, on other hand, comparatively unimportant. The rocks south of the Stinchar valley are described as of Llandeilo age, while the strata of the plateau itself, including the Stinchar Limestones and metamorphic rocks, are assigned to the Caradoc, with the dubious exception of some indefinable patches of Lower Llandovery. The limestone of the region is said to occur in lenticular patches imbedded in conglomerates. Beyond a suggestion that the section seen upon the coast-line near Shalloch is a synclinal form†, and thus corroborative of Murchison's opinion that the Ardwell Graptolitic flagstones are the highest visible beds upon the plateau, no evidence is adduced of an ascending sequence; and the description of the complicated rock-structure of the district is deferred until the publication of the neighbouring sheet 8, which has not as yet (1881) made its appearance.

This deficiency, however, is supplied to a large extent by Professor Geikie's section of the rocks of the southern plateau inserted in the fourth edition of 'Siluria'‡. From this we gather that the synclinal recognizable upon the shore-line is prolonged into the interior of the country, and that, as Murchison originally asserted, the Penwhapple Graptolitic flagstones occupy its centre. To the northward these are underlain by the *Pentamerus*-gritstones and pebble-beds of Camregan and Saugh Hill. The area of Benan Hill and of the Stinchar is occupied by a massive conglomerate having no clear relations to the foregoing, and including two distinct bands of limestone. To the south of the Stinchar valley this limestone- and conglomerate-series is faulted against the barren greywackes of the Uplands, while to the north of the valley it is transgressively overlain by the boulder-beds of the higher ridges of Benan Hill, which are assigned to the epoch of the Middle Old Red Sandstone.

The remaining publications treating of the sequence of the Lower Palæozoic rocks of Girvan may be dismissed in a few words, as they contain no definite physical evidences in support of the views advocated in them. In 1874 Mr. D. J. Brown, in a general paper on the Silurian rocks of the South of Scotland, advanced the opinion that the Caradoc of Girvan would be found to overlie the Llandeilo unconformably, and that the Mulloch-Hill strata are the only beds that can with propriety be assigned to the Llandovery§.

In 1876 the country was hastily examined by myself and its strata noticed in brief in the opening chapter of the 'Catalogue of Western Scottish Fossils,' where the beds superior to the Limestone were arranged by me in two main groups, the Graptolitic flagstones

* Explanation Sheet 14, Geol. Survey of Scotland, pp. 8 and 10.

† Explanation Sheet 7, Geol. Survey of Scotland, pp. 1-11.

‡ Siluria, fourth edition, p. 156.

§ Transactions Edinb. Geol. Society, 1874, pp. 316 &c.

of Penwhapple and Ardwell and the *Trimucleus*-beds of Drumnuck being there placed for the first time in their proper relative position, but erroneously assigned to the Llandovery*.

The same year Professor A. Geikie published his Geological Map of Scotland, extending his classification of the Lower Palæozoic rocks of the Uplands into the Girvan region, replacing the Benan boulder-beds in the Silurian, and restricting the Caradoc colour to the Benan zone and the northern inlier of Mulloch Hill and Craighead.

The host of *palæontological* works already published treating of the Lower Palæozoic fossils of this region make frequent references to the probable geological age of the more prolific fossil-bearing zones. The large collections originally made for Professor Sedgwick afforded many of the most striking types of Silurian organisms figured in Sedgwick and McCoy's 'Palæozoic Rocks and Fossils.' Throughout that classical work are scattered frequent allusions to the probable parallelisms of Girvan beds and their prototypes in Wales and the west of England. In the Supplement to this work, issued under Salter's care, subsequent to the death of Professor Sedgwick, these references are most accurate and valuable.

The four successive instalments of Mr. Salter's unfinished Monograph of the British Trilobites contain several peculiar types of Crustacea from this area: and the author, founding solely upon the palæontological evidence before him, as interpreted by his intimate knowledge of the vertical distribution of Trilobites in the Lower Palæozoic rocks of Wales, invariably assigns the Stinchar Limestone to the Llandeilo, the Penwhapple Grits to the Caradoc, and the Mulloch-Hill Sandstone and the *Pentamerus*-beds of Saugh Hill to Murchison's transitional formation of the Llandovery.

The corresponding Monograph of the Silurian Brachiopoda, which forms the final division of Mr. Davidson's great work, is greatly enriched by forms derived from the Girvan region: and though the author is naturally less confident in his geological deductions than Mr. Salter, his correlations are generally identical with those of that palæontologist.

In 1867, Professor Wyville Thomson described and figured some forms of Graptolites from the Girvan area, and on palæontological grounds suggested a material modification of Murchison's views of the succession, expressing his own opinion that the whole of the Girvan rocks belong to Murchison's Lower Silurian, and that the Orthoceratite-flagstones of Penwhapple should be placed at the base instead of the summit of the series, and are probably followed in ascending sequence by the Mulloch-Hill Sandstones, Craighead Limestones, and *Pentamerus*- or Saugh-Hill Grits.

The officers of the Geological Survey of Scotland have made important collections from the rocks of the Girvan district. A list of their species is appended to the "Explanation of Sheet 3," published in 1873; and upon the ground of the palæontological evidences they afford, Professor Geikie rightly concludes that in the "south-

* Catalogue of Western Scottish Fossils, 1876, pp. 13 and 2. Compare also Lapworth, Trans. Geol. Soc. Glasgow, 1879, pp. 78-84.

west of Ayrshire there occur representatives of Upper Silurian, Llandovery, Caradoc, and Llandeilo rocks" (p. 5).

During the last twenty years the more prolific fossil-bearing strata of the Girvan region have been most successfully searched by Mrs. Gray, the wife of Mr. Robert Gray, F.R.S.E., of Edinburgh, herself a native of this beautiful district. Aided by the various members of her family, she has collected from these beds a magnificent series of organic remains of all types, numbering at present between 20,000 and 30,000 specimens. This collection, which has been most generously placed at my service by Mrs. Gray, is at present under process of description in the well-known 'Monograph of the Silurian Fossils of Girvan' of Nicholson and Etheridge, and will be noticed more fully in the second portion of the present memoir.

In the three instalments of this important Monograph of the Girvan fossils by Professor Nicholson and Mr. R. Etheridge, Jun., a view of the general sequence on the same lines as those sketched out by Salter is advocated, and an attempt made to fix with more definite precision the geological date of some of the more fossiliferous zones. Founding upon the vertical distribution of the Trilobites, Mr. Etheridge suggests a Lower Bala age for the Stinchur Limestone, and a Caradoc age for that of Craighead and the Trilobite-flagstones of Penwhapple, and unites the *Trinucleus*-shales of Drummuck, the shelly Sandstones of Mulloch Hill, and the *Pentamerus*-Grits in the Llandovery. Professor Nicholson, on the evidence of the Corals, parallels the Craighead Limestone and Penwhapple beds (Balclatchie) with the upper part of the Trenton of N.E. America, and classes the Mulloch-Hill Sandstones and *Pentamerus*-gritstones and their equivalents in the Upper Llandovery or May-Hill group.

The remaining palæontological works treating of the fossils of the district will here be passed over, as none of them deal seriously with the vexed question of the ascending succession*.

II. PHYSICAL RELATIONS OF THE LOWER PALÆOZOIC ROCKS OF THE GIRVAN REGION.

(A) THE BENAN CONGLOMERATE AND ITS ASSOCIATED STRATA.

In attempting the development of the true physical relationship of strata so crumpled and dislocated as those of the Girvan region, our first task is to select some definite stratigraphical zone, as general datum-line or horizon of reference, from which to commence our labour, and to which to refer, as often as occasion requires, the several results of our more detailed investigations. An horizon suitable for this purpose must, almost of necessity, be composed of strata of a lithological character sufficiently striking to be identifiable upon all occasions with ease and certainty. It should be of sufficient thickness to form, at least, a distinctly marked

* A list of 21 palæontological memoirs bearing upon the Girvan fossils will be found in the Bibliography appended to the chapter on Silurian Geology inserted in the 'Catalogue of Western Scottish Fossils,' 1876, pp. 25-28.

feature in the ascending sequence: and, to be completely satisfactory for our special purpose, it should be of wide horizontal extent, so that it may afford a large number of points of reference upon the ground itself, that there may be no possibility of doubt or ambiguity as respects its true relationship to the remaining members of the succession.

It is, in truth, most fortunate for the student of the stratigraphy of the Girvan rocks that all these desiderata are afforded him by what is actually the most remarkable formation in the Girvan region—the great Boulder-conglomerate of Benan Hill; its extraordinary petrological character, composed, as it is, of masses of rounded boulders heaped tumultuously together in a faintly stratified sandy matrix, renders it identifiable at a glance in the field: its great thickness, as displayed in Milljoan and Pinjerroch, where its almost horizontal beds are apparently piled one above the other to more than 1000 feet in height, makes it, geologically, one of the most important members of the Girvan succession: lastly, in its geographical extension it excels all its sister formations, stretching in one vast and almost continuous band more than a mile in width from end to end of the entire region.

Selecting, therefore, this great Boulder-conglomerate as our general horizon of reference, we commence the description of the Girvan succession by an account of the stratigraphy of those subareas where its true relationships are most effectively displayed.

(a) *Description of the Typical Sections of the Valley of the Stinchar.*

The subarea which most satisfactorily exhibits the development and interrelationships of the great Boulder-conglomerate and its associated strata within the Girvan region is the mound-like ridge lying to the north-west of the little village of Barr and its bounding valleys of the Assel and Stinchar. The general contour of this area rises in successive steps from the average level of these valleys in the west, to a height of nearly 1200 feet in the east, where it merges into the elevated Old Red Sandstone terrace of Garleffin. Its three rounded summits of Benan Hill, Pinjerroch, and the Mull of Milljoan rise in succession abruptly from the southern edge of the long straight valley of the Stinchar to the respective heights of 900, 1000, and 1100 feet, forming between them a broadly rounded ridge, which occupies a superficial area of at least 15 square miles.

The whole of this ridge, together with its outlying dependencies of Barr and Balclatchie, from the low-lying river-valleys that bound it to the summit of its highest point, is composed almost entirely of one continuous sheet of the coarse Boulder-conglomerate. It is here made up of rounded masses of stone of all dimensions, from blocks several feet in cubical extent to chips the size of a marble. These blocks are generally of igneous origin, consisting of granites, porphyries, serpentines, and various felsites; they are occasionally intermixed with pieces of white and red quartz, and with rarer

fragments of hardened rocks, sandstones, and greywackes. These are all intermingled confusedly together in a sandy or ashy paste, composed of the same materials as the included pebbles, and usually of a dull greenish colour, but occasionally purple and sometimes almost black. All the included blocks are well rounded and smoothed by aqueous action; angular chips are extremely rare, and the grains of the matrix itself, except when distinctly ashy and crystalline, bear evidence, in their rounded forms, of long-continued attrition by water.

The physical geologist who attempts the study of this area finds, scattered confusedly over the surface of the ridge, patches of limestones and calcareous shales, trenchantly individualized by many well-marked lithological peculiarities, but having the most enigmatical relations with respect to the surrounding conglomerates. In their topographical distribution these calcareous rocks at first sight appear most capricious. In one locality an interrupted line of exposures of these peculiar beds can be traced for some distance; but suddenly it dies out in the most unexpected manner; and in the direction in which we should naturally expect its prolongation we find, instead, the great conglomerate extending continuous and unbroken. Nor do the many sporadic sections of these calcareous beds seem to possess any definite characteristics in common that would allow of their being paralleled in detail and brought into any thing like intelligible interrelationships among themselves. In one spot we find a mass of flaggy limestone 50 feet in thickness, without a trace of other fossiliferous strata; in a second, a similar thickness of calcareous shales bears it company; in a third, shelly sandstones and grits are also present in force. But while no two consecutive exposures offer us a succession precisely similar among the beds distinct from the great conglomerate, they all agree in the one fact that both above and below them the great conglomerate itself is seen in force with all its characteristic features, its gentle dip, and persistent N.E. and S.W. strike.

Nor are these the only difficulties. In some spots the conglomerate is separated from the flaggy limestones by several feet of concretionary shales; while in other spots not a trace of these shales is visible, but in their place the strata afford proof of an apparent unconformability. Boulders and nodules of the limestone are found in the lowest beds of the immediately overlying conglomerate; and the latter seems to repose irregularly in the hollows of the eroded upper face of the limestone itself.

Recognizing these complexities, and impressed mainly by the two grand facts of the interrupted nature of the calcareous beds and the apparent erosion at their summit, the officers of the Geological Survey, after mapping this subdistrict, adopted the only conclusion that seemed open to them, and taught originally that the limestones were irregular and sporadic phenomena, that they were imbedded in the great conglomerate, and that the combined mass was progressively overlain by a second conglomerate, which, to judge from its gentle inclination, was probably of Old Red Sandstone age. When

subsequently they detected proofs of a possible unconformability at the base of the Caradoc beds of the Uplands, this Benan unconformability seemed to be very naturally accounted for, and its theoretical age was altered to the epoch of the Lower Bala.

Now, to a geologist who studies the strata in a general way, the foregoing conclusions are inevitable; and upon this ground the officers of the Survey were amply justified in their deductions. But when these enigmatical calcareous zones are studied foot by foot, and each exposure is compared minutely with its neighbours, very different conclusions are arrived at, and the stratigraphist is soon delighted to discover incontrovertible proofs of an orderly sequence, explanatory of the visible phenomena in every locality, and exhibiting the most perfect harmony in all its parts.

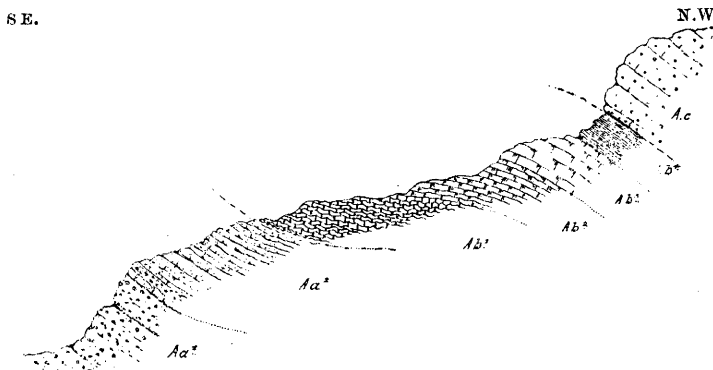
In the steep slopes of the hills of Benan and Auchensoul, which overhang the north bank of the valley of the Stinchar, a line of ancient lime-quarries is visible. These mark the place of a thick band of limestone, which ranges uninterruptedly from the farmstead of Minuntion to that of Auchensoul, a distance of about three miles. Throughout this extent, the limestone, beyond occasional and insignificant local slips, is unbroken by dislocations, and is fully exposed to the investigator in numerous artificial excavations, and in the beds and banks of the many little brooklets that drain the grassy summits of the Benan Hills. From end to end of this line, the limestone plunges into the hill-side at an angle of about forty-five degrees, below the wide-spreading and continuous mass of coarse Boulder-conglomerate already noticed, of which the higher points of Benan Hill and the neighbouring heights are composed.

1. *Benan Burn*.—About midway along its course the limestone and its associated beds are admirably exposed in the banks of the little stream of the Benan Burn, where the highly instructive section is displayed which is generalized in the accompanying figure (fig. 1).

The coarse green boulder-conglomerate of the region, which occupies the high ground of the ridge above, forms here a semicircle of steep slopes, partly enclosing a cirque-like area in the hill-side, where four little streams take origin that unite to form the Benan Burn. These steep grass-clad slopes show miniature cliffs of naked rock, composed of well-bedded masses of the great Benan conglomerate, showing all its characteristic features and dipping steadily into the hill-face at an angle of from forty to fifty degrees. The four rills unite in the centre of this cirque-like area; and a few yards above their point of confluence the coarse conglomerate suddenly ceases, and the naked banks of the most westerly rill show that we have here reached its basal beds, and that they repose upon a set of greenish concretionary shales and mudstones having the same trend and inclination as the conglomerate itself.

Didymograptus-shales.—These shales (Ab⁴) have a collective thickness of about 30 feet. They are of a greenish-blue colour, hard, nodular, and more or less concretionary in structure, but of a fine texture and distinctly laminated. Under the hammer they break up into well-rounded nodules and irregularly concentric flakes. They

Fig. 1.—*Typical Section of the Strata of Benan Burn.*



Ac. Green Conglomerate of Benan Hill.

Ab. Stinchur Calcareous group:—

Ab⁴. *Didymograptus*-shales.

Ab³. Compact Limestones.

Ab². *Machurea*-beds.

Ab¹. *Orthis-confinis* Flags.

Aa. Kirkland group:—

Aa². Red and grey Sand-stones.

Aa¹. Purple Conglomerate.

are more or less calcareous throughout, effervescing distinctly on the application of acid.

They contain a few fossils, principally Graptolites, and those Linguliform Brachiopoda which are generally found in Graptolitiferous deposits. The Graptolites are procurable in fragments only, owing to the easily shattered nature of the shales and their concretionary structure, which render it a matter of impossibility to obtain a flat surface of large extent parallel to the line of bedding. But this defect is more than counterbalanced by the fact that the few fragments obtainable are all preserved in their full relief, allowing of their immediate specific identification.

The forms of Graptolites collected by myself from these green shales at this spot include:—

Didymograptus superstes, Lapw.

Dicellograptus sextans, Hall.

Clathrograptus cuneiformis, Lapw.

Glossograptus Hineksii, Hopk.

Cryptograptus tricornis, Carr.

Diplograptus rugosus, Emm.

The Brachiopoda are of few species, and embrace *Acrotreta Nicholsoni*, Dav., *Siphonotreta micula*, and a few forms of Lingulidæ.

Compact and nodular Limestones.—Below these *Didymograptus*-shales we come suddenly to a mass of pale limestones (Ab²+³) admirably exposed in the beds of the little rills, in several artificial quarries, and in many occasional exposures seen below the cliffs of conglomerate in the surrounding slopes. The masses of pale limestone, pitted with innumerable superficial depressions, due to the

long-continued action of the weather, contrast trenchantly with the dark-green conglomerates of the cliffs above. The limestone is distinctly bedded in strata of flag-like character, from a few inches to two feet in thickness. The planes of bedding are, as a rule, perfectly regular; but occasionally their upper surface is more or less wrinkled or undulated, and the little hollows thus formed are filled with flakes of greenish shale, calcareous, and more or less concretionary in structure.

The thicker limestones, when split open, show, on rare occasions, an irregularly laminated interior, and the mass admits of being broken down into irregular flakes or sheets of an inch or so in thickness. But, as a general rule, the interior of the rock is quite homogeneous. It is of a dull grey tint, passing into black in its more compact parts, and shading off into a dull greyish green where of a more open character. In texture it is usually firm and compact, detached plates ringing under the hammer like clinkstone. When fractured it flies off in conchoidal fragments having much the appearance of hornstone or flint, with clouded surface and translucent edges.

In the more massive beds no trace of a fossil is discernible, and even in the less hardened parts there is generally little evidence of their presence beyond certain dim nebulous outlines, hardly suggestive of specific form. When greatly weathered, however, as in the many stone walls of the neighbouring fields, the fossiliferous nature of the nodular limestones is apparent at a glance; the faces of the bedding-planes are covered with elevated knots and patches, due to the former presence of corals and shells, the finer structure of the former and the half-obliterated outlines of the latter being easily recognizable by the eye. The spiral lines characteristic of the natural sections of the beautiful genus *Maclurea* are by no means rare under these circumstances; and the delicate structure of the peculiar coral-like *Tetradium* is even more abundant: while on rarer occasions we find patches covered with the roe-like *Succamina*, occasional fragments of Trilobites, fractured Brachiopoda, and the like.

These limestones fall very naturally into two main subdivisions—a *higher* group of hard limestones (Ab^3), with rare dividing seams of calcareous shale and but few fossils; and a *lower* group of impure nodular and flaggy beds (Ab^2), which show, when fully weathered, abundant shaly partings and frequent examples of *Maclurea Logani*.

In these compact and nodular beds the calcareous matter is tolerably pure, and the limestones admit of being burnt for agricultural purposes; while in the underlying laminated beds next to be described the strata are largely impregnated with aluminous matter, and are of no special economical value.

It is difficult, if not impossible, to give an exact estimate of the united thickness of the compact and nodular limestones. To judge from the space they cover upon the ground, and from their vertical extent when plotted in section, it cannot be less than 60 or 70 feet; but in no locality elsewhere do they actually reach this thickness.

Orthis-confinis Flags.—In the locality under description the

impure *Maclurea*-limestones, already noticed, pass downwards into a similar thickness of calcareous flagstones, with way-boards and intercalated seams and flakes of greenish or brownish shales and mudstones (Ab¹). These are well exposed in the banks and bed of the little stream of Benan Burn; and their inferiority to the limestones is demonstrated by the fact that they can be followed by the eye coming out from below the latter in the steep slopes in regular order, and insensibly graduating from them in their petrographical characters.

In the upper limestones, as we have shown, the texture of the rock is usually firm and compact; and the calcareous matter being evenly distributed, the rock itself is solid and homogeneous throughout. In these underlying flagstones, on the other hand, the lime is not only much smaller in amount, but it is much more capriciously distributed, and the rock weathers more irregularly under the influence of the atmosphere. Instead of the hard, white, compact, and flinty-looking sheets of the upper beds, we now find the strata degenerating into a kind of impure flagstone or calcareous sandstone, containing nodules of limé, and assuming in places a honeycombed structure, whose hollows are filled exteriorly with soft rottenstone, which gives to the group a peculiarly dull olive-brown colour. In the steeper cliffs the soft rottenstone becomes wholly washed away, and the deeply honeycombed flaggy rock puts on a most peculiar and characteristic appearance.

In the compact limestones above fossils are, as we have shown, rare and excessively difficult of extraction; in these impure flagstones below they are, on the contrary, generally abundant and easily procured. They are, however, almost exclusively Brachiopoda, viz. *Orthis confinis*, Salter, *O. alternata*, Salter, *Strophomena grandis*, &c. Of these the species *Orthis confinis*, Salt., is emphatically the most abundant and characteristic, occurring everywhere throughout the region where these strata are exhibited, and occasionally abounding to the exclusion of all others.

Transitional Sandstone.—The bottom beds of these *Orthis-confinis* flagstones take on a dull purple colour, and, as we descend the succession, they gradually part with their calcareous nodules and degenerate into a group of purple grits and flagstones (Aa²), which, in many of their essential features, remind us of some of the typical beds of the Old Red Sandstone.

In the present locality these purple sandstones are very fairly exposed, and have an estimated thickness of about forty feet. As a rule, they are simply coarse-grained, well-bedded grits, including many seams of coarse sandy shales. Above, they pass insensibly upwards into the *Orthis-confinis* flagstones last noticed; below, they contain seams of pebbles, first about the size of a marble, next of the size of the fist, till finally they graduate downwards into a massive purple conglomerate, which will be described in the sequel.

Such palæontological characters as these purple sandstones possess ally them to the overlying *Orthis-confinis* flagstones. An occasional seam is met with amongst them, affording a few casts of *Orthis con-*

finis and *Strophomena*; and the sandstone group is best regarded as the zone of transition between the *Orthis confinis*-flagstones and the deep-seated purple conglomerate we shall next consider.

Purple Conglomerate.—Immediately below the basal beds of these *O. confinis* sandstones a massive conglomerate suddenly sets in of most extraordinary petrological characters (*Aa*¹). In the present locality the contrast between this older conglomerate and the great boulder-conglomerate of the summit of Benan Hill is most striking. The Benan-Hill rock is of a dull greenish or greyish colour where freshly fractured, becoming more or less yellow upon its weathered surface. Its matrix is of a sandy, or ashy, and more or less open texture, and offers not the slightest indication of the presence of calcareous matter. In the much older conglomerate under description, which supports the *O. confinis* sandstones, we see a rock of a wholly different character: its matrix is of a bright purple colour, and it is so highly calcareous that the mass is filled with patches of lime and veins of white calcareous spar. The included pebbles are of all sizes and all colours; green and grey porphyrites predominate, but granites, metamorphic rocks, limestones, and unaltered sandstones are all present and in no small abundance. The whole mass is intensely hardened and compacted together, so that it is next to impossible to detach a pebble from the general mass, the plane of fracture of the indurated rock traversing the pebbles and vitreous matrix alike. The brilliantly purple matrix of this conglomerate, veined with innumerable streaks of milk-white spar, forms a most exquisite contrast to the included masses of foreign material, green, grey, brown, and white, with which it is filled. The beautiful sight presented by a sheet of this rock, when seen at its best in the wetted cliffs of the many waterfalls that dash over it, lingers long in the memory of the investigator.

Of this purple conglomerate no great thickness is visible in the burn itself, but its beds may be followed by the eye in the rugged slopes of Craigbickarrae a few yards to the west, coming out steadily from below the *Orthis confinis* sandstones, and continued in unbroken mass downwards into the wooded slopes below, for a thickness of at least 150 feet.

This purple conglomerate forms the basal member of the Girvan succession as exposed in this locality. Its lowest beds are lost in the alluvial flats of the Stinchar below the base of Craigbickarrae, and no further rock-exposure is visible for more than a mile to the southward.

Summary.—In this locality, therefore, we have evidence that the great green Benan conglomerate is conformably underlain by a series of older strata of very distinct petrological characters, namely:—

(1) A calcareous group, about 100 feet in thickness, composed of three members—(*a*) a set of nodular shales with Graptolites and Lingulidæ, (*b*) a set of comparatively pure and compact flaggy limestones, and (*c*) a set of impure calcareous flags.

(2) A purple conglomerate of great thickness and remarkable aspect, which graduates downwards from the foregoing group through a transitional zone of pebbly sandstones.

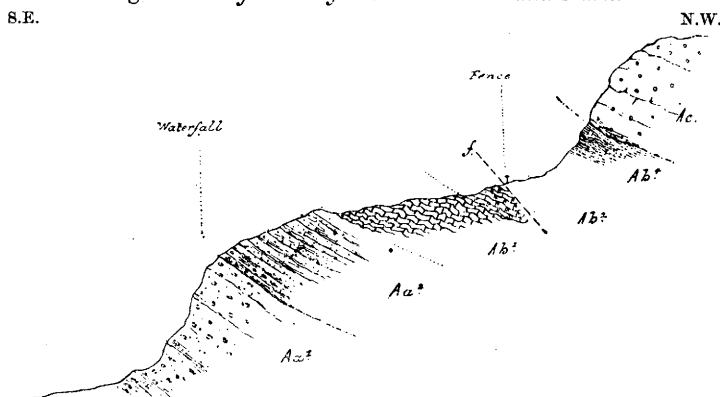
These results are epitomized in the following table:—

- Ac. Benan-Hill (or Green) Conglomerate.
- Stinchur Limestone group:—
 - Ab⁴. *Didymograptus*-shales.
 - Ab³. Compact Limestones.
 - Ab². *Maclurea*-beds.
 - Ab¹. *Orthis-confinis* Flags.
- Kirkland group:—
 - Aa². Transitional Sandstones and Grits.
 - Aa¹. Purple (or Kirkland) Conglomerate.

I shall next proceed to show that the sequence thus indicated is that which obtains throughout the entire Benan area.

2. *Kirkland Burn*.—An excellent confirmatory exposure of the majority of the strata just described is to be seen in the neighbouring stream of Kirkland Burn, which has cut a deep channel down the slope of Benan Hill, about half a mile to the eastward of our former section. In this locality, however, the green Benan conglomerate is shown merely in a few scattered patches upon the hill-tops, the line of junction between the calcareous group and the Benan conglomerate is invisible, and merely a few fragments are seen of the *Didymograptus*-shales (Ab⁴) and of the upper parts of the Compact Limestone (Ab³) (see section below, fig. 2).

Fig. 2.—Confirmatory Section in Kirkland Burn.



- Ac. Green Conglomerate of Benan Hill.
- Ab⁴. Green Graptolitic Shales.
- Ab². Impure flaggy Limestones.
- Ab¹. Calcareous and nodular Flagstones, with *Orthis confinis*, *Strophomena*, &c.
- Aa². Purple Sandstones, Grits, and sandy Shales.
- Aa¹. Purple Conglomerate filled with veins of calc-spar.

The highest beds visible appear to be the lowest zones of the *Maclurea*-beds (Ab²), which are well shown where a small fence crosses the stream. From this point downwards into the heart of the deep-seated Purple Conglomerate (Aa¹) the section is tolerably con-

tinuous, and the strata exposed admit of fairly exact admeasurement. We find evidences of some folds in the strata, and traces of slight faults, hitches, and wrinkles; but it is very doubtful if any of the beds are actually repeated, so that the following measured section may be relied upon as being approximately correct:—

	feet.
Ab ² . Nodular Limestones, thin-bedded, hard, unfossiliferous ...	22
Ab ^{1''} . Calcareous Flagstones, full of nodules of limestone, more or less hardened, and only rarely fossiliferous	45
Ab ^{1'} . Calcareous Flagstones, weathering to a russet-brown colour, and filled with seams and patches of rotten- stone	26

The section here fails us for some 13 feet of thickness,
below which we find

Aa ^{2''} . Purple Sandstones, Grits, and Shales, with seams of pebbles, but no recognizable fossils	43
Aa ^{2'} . Purple Sandstones and Grits	24
passing down into	
Aa ¹ . Purple Conglomerate, full of rounded masses of igneous rocks, im- bedded in a matrix of sandy and calcareous matter, veined with irregular seams of lime and calc-spar.	

The basal conglomerate is well exposed at a small waterfall overlooking the farmsteading of Kirkland. It will therefore be hereafter referred to under the alternative title of the Kirkland Conglomerate.

The ground to the south of the farm is covered with the alluvium of the Stinchar, and no older strata are visible.

3. *Auchensoul &c.*—In following the outcrop of the calcareous series along its line of strike towards the west, we find it become so greatly interfered with by a network of small faults that it is a matter of the utmost difficulty to map out the true place of the shattered fragments upon the ground. When, however, this task has been finally accomplished, it becomes evident that after leaving the Kirkland Burn, the limestone group begins to curve round rapidly towards the south-west, almost at right angles to its original course. It sweeps obliquely down the southern slopes of Auchensoul Hill, and crosses the valley of the Stinchar opposite the farmstead of Dupin, near which it is found dipping at a steep angle to the southward, and striking to the westward, in the wooded slopes of the hills on the southern side of the river, parallel to its original direction in Benan Hill. From its disposition upon the ground it may therefore be inferred that it is actually sweeping round the outer curve of a steep anticlinal arch, the main axis of which coincides with the line of the river Stinchar.

In the grassy slopes of Auchensoul Hill four main groups of exposures are recognizable. On the lateral terrace above the ruined church of Kirkdominæ, the Compact Limestone (Ab³) is well displayed in some deserted quarries. In the most northerly of these, the highest zones of that division, immediately below, the *Didymo-*

graptus-beds (Ab^4) are laid open, and the dividing seams of calcareous shale contain an abundance of fairly preserved fossils.

The commonest forms are *Leptæna sericea*, *Orthis calligramma*, *O. bifurcata*, *Turrilepas*, sp., *Cythere aldensis*, *Asaphus*, *Encrinurus*.

These beds dip to the eastward at a small angle, and below them, in their natural position, we find the red sandstones (Aa^2) in an old cart-track on the hill-face above the ruins of Kirkdominæ.

In Kirkdominæ Burn the *Maclurea*-beds (Ab^{2+3}) are discernible, preserving generally their original line of strike, but greatly shattered and folded. Below we find a large development of the Purple Conglomerate (Aa^1) which is exhibited in the stream-course.

A well-marked N.E. and S.W. fault throws down a patch of the calcareous beds in their proper position below the Benan Conglomerate in the higher reaches of the little burn, on both sides of which the Compact Limestone (Ab^3) has formerly been excavated. To the west also the line of junction of the Benan Conglomerate (Ac) and the Calcareous Series (Ab) is visible for some distance upon the grassy hill-side. The green calcareous and concretionary *Didymograptus*-shales (Ab^4) are shown in their normal transitional position in several natural exposures.

In Auchensoul Burn, which lies about a quarter of a mile to the eastward of Kirkdominæ Burn, all that the many faults of this spot have left visible are certain lime-beds, full of pebbles of igneous rocks, imbedded in a matrix so highly calcareous that it almost deserves the title of a limestone. These possibly belong to the Purple Conglomerate of Kirkland (Aa). They are seen in the stream-course close to the farmsteading of Auchensoul.

4. *Dularg &c.*—Crossing the alluvial flats of the Stinchar, which are here only about 150 yards in width, we again come upon the calcareous series, dipping off the anticlinal arch to the south-east. They are exposed in the bed and banks of the river and in the wooded slopes around the farmsteading of Dularg.

In the bed of the river itself the greatly contorted *Orthis confinis* flagstones (Ab^1), and patches of the *Maclurea*-beds (Ab^2), together with portions of the underlying Purple Sandstone and Conglomerate (Aa), are well displayed. In spite of their shattered character, the flagstones are, as usual, tolerably fossiliferous, and yield, among others, *Orthis confinis*, Salt., *Maclurea Loganii*, Salt., *Strophomena grandis*, and fragments of *Orthocerata* and Corals.

The gentle eastward inclination of these strata is rapidly exchanged for a steeper one to the S.W., and their curving strike for a direct trend to the S.W., parallel with the normal range of all the strata of the region. The effect of this is that the limestone (Ab^3) next makes its appearance in two quarries close to the farm of Dularg, dipping steadily at a steep angle to the S.E., parallel in strike, but diametrically opposite in dip, to its position on the opposite side of the Stinchar valley in the slopes of Auchensoul. The limestones in these quarries at Dularg are of a purple colour and are greatly hardened, veined, and altered. These appearances are possibly due to the presence of

the enormous strike-faults which are known to affect the strata here, and which finally cut out the limestone band altogether a few yards west of the farmstead.

5. *Craigbickarae Hill*.—Returning to the opposite side of the Stinchar, we resume our description of the unbroken line of the Benan and Auchensoul Limestone band at the point where we originally commenced. A few yards to the west of our typical section of the Benan Burn we find the calcareous series fairly exposed in the cliffs and upper terraces of the projecting mound of Craigbickarae. From the steep southern cliff of Craigbickarae itself the purple conglomerate looks out in great force over the valley. In the grass-grown terrace above the cliffs the *O.-confinis* flags (Ab^1) and their more arenaceous associates are buried beneath turf and surface-soil; but the overlying purer limestones (Ab^{2+3}) are shown in several small exposures, and, owing to the form of the ground, cover a large space upon the hill-side. The beds are much broken by faults and slips; but nevertheless the entire group may be easily followed upon the ground from point to point, everywhere emerging in its natural order and position from below the great mass of Benan conglomerate (Ac) which forms all the more elevated portions of the hills above. The line of contact between the limestone and conglomerate is, however, nowhere visible, the *Didymograptus*-shales (Ab^4) being either faulted out or overgrown with grass and vegetation.

In the small burn of Auchlewan the Compact Limestone is fully laid open, and in the steep hill-face to the right of it the *Orthis-confinis* Flagstones &c. are displayed and are abundantly fossiliferous, yielding chiefly *Orthis confinis*, Salt., *Strophomena*, *Maclurea*, *Tetradium*, sp.

The whole of the calcareous rocks dip steadily into the hill-face to the southward, at an angle of about 45 degrees, and are distinctly underlain by masses of the Purple Conglomerate and Sandstone (Aa), which are exposed for some distance in the channel of the little burn below.

6. *Auchlewan*.—In an exposure upon the line of junction of the Benan Conglomerate and the Calcareous Series, which is apparent a few yards to the west of the Auchlewan Burn, some remarkable phenomena are observable. In an old quarry above the outer fence of the enclosed and formerly cultivated area the line of contact of the limestone and conglomerate is plainly visible. The flaggy and compact limestones dip into the hill at their normal inclination, and are irregularly surmounted by a solid mass of conglomerate dipping in the same direction, but at a slightly inferior angle. The line of contact is most irregular. The limestone has all the appearance of having been greatly eroded previous to the deposition of the conglomerate. The regular beds of the limestones strike abruptly at the lower portions of the pudding-stone, and patches of the former are found adhering irregularly to the weathered basal beds of the latter. The conglomerate itself is almost destitute of any thing like bedding; but some of the natural planes of deposition are shown by the linear arrangement of bands of small pebbles. In its

lowest beds a few fragments of limestone are visible, of the general size of marbles. The appearances seen are difficult to explain upon the hypothesis of a fault, owing to the presence of the patches of limestone in the conglomerate; but if they are actually due to an unconformability we have to suppose that within the insignificant distance of about 200 yards the entire thickness of the *Didymograptus*-shales must have been eroded previous to the deposition of the basal beds of the Benan Conglomerate, and in addition some slight thickness of the Compact Limestone itself. It will be seen from the map that an important fault traverses the strata at this locality, and to its effects, combined with certain peculiarities of the basal beds of the conglomerate, which will be described in the sequel, the visible phenomena are most unquestionably due.

From this point the calcareous series is prolonged in a straight line to the south-west, descending the slopes diagonally towards the farmstead of Minuntion and the valley of the Stinchar. The nodular and Compact Limestones (Ab^{2+3}) are exposed in two fine artificial sections immediately to the west of the ruin of Auchlewan, dipping steadily into the hill-face below the masses of Benan Conglomerate, which crop out continuously in the higher parts of the overhanging slopes above. The usual fossils of the limestones may be collected with difficulty in the quarries and from the weathered masses of limestone in the neighbouring stone-dykes. Unfortunately the actual line of junction of the Calcareous and Conglomerate series is obscured, and it is impossible to collect any available evidence with respect to the apparent unconformability or fault-line of Auchlewan to the east.

In the steep ridges some distance north of the farm of Minuntion the limestone is seen in a shattered condition, suggestive of faulting along the junction-line. Immediately in the neighbourhood of the farmstead the Purple Sandstones (Aa^2) are visible in their natural position with respect to the limestone, preserving their steady dip of 45° into the hill-slope.

From the hill-quarry last mentioned the limestone may be followed in occasional exposures in a slanting direction down the slopes into the cliffs overhanging the stream of the Stinchar. Here we meet with a magnificent section in a large quarry, which until very recently was worked for the extraction of lime for the use of the farmers of the district.

7. *Minuntion*.—In this quarry the highest zones of the Compact Limestone group (Ab^3) are not exposed. The only strata quarried are the lower division of the *Maclurea*-beds and the underlying *O. confinis* flags (Ab^1). The latter are well shown in the floor and sides of the quarry; they weather to their usual russet-brown colour, and are pitted with the usual hollows filled with rottenstone. The *Maclurea*-beds contain the usual characteristic fossils in abundance; the *Orthis confinis* beds swarm with well-preserved Brachiopoda, &c.

The commonest forms include *Orthis confinis*, *O. bifurcata*, *Bellerophon*, *Strophomena expansa*, *Triplexia Grayi*, *Illenus latus*, &c.

This quarry may be regarded as the typical exposure of the *O. con-*

finis beds. In no other locality known to myself are they so clearly exhibited, or their fossils so easily procured or so well preserved.

This quarry lies at the south-western extremity of the continuous band of limestone we have followed from Auchensoul and Benan Hill along the north slope of the Stinchar valley. The band here comes to an abrupt conclusion. It is bent back in a sharp curve, with an accompanying fault, and is thrown into an abrupt synclinal from below which rise the underlying strata of the deep-seated Purple Conglomerate.

This is well exposed in the floor of a small stream which here descends the slopes of the hill to the northward. It presents all the peculiar features of this remarkable formation as exhibited in the typical section of Kirkland and Benan. In the little wood we recognize it by its deeply purple matrix, marbled with veins of calcite, and filled with boulders of green porphyrites, grey granites, and fragments of altered rocks. Hard and firmly compacted, it is beautifully polished by the waters of the cascade, and forms a most striking floor to the darkened stream-course.

The synclinal and fault at this locality bring the typical line of the Stinchar calcareous series to an abrupt termination in the westerly direction, as do the anticlinal and accompanying faults of Dularg the same line in the opposite direction to the east. Before proceeding to the study of the scattered exposures of the strata of this group in the more complicated district to the northward, it may perhaps be advisable to re-summarize the points already established in the Girvan succession as here exhibited.

We find, that is to say, in the northern slopes of the Stinchar valley, that the great Benan conglomerate is underlain by a thick series of more or less calcareous strata, constituted of the following members in ascending order:—

	feet.
Kirkland Beds:—	
Aa ¹ . Purple Conglomerate of Kirkland	(at least) 150
Aa ² . Transitional zone of Purplish Sandstones.....	(possibly) 50
Stinchar Limestone group:—	
Ab ¹ . Impure Calcareous Flagstones with <i>Orthis confinis</i>	40
Ab ² . <i>Maclurea</i> -beds	30
Ab ³ . Compact Limestones, less fossiliferous	30
Ab ⁴ . <i>Didymograptus</i> -shales with Graptolites.....	30
	<hr/> 330

That all these relations are retained essentially unmodified among the remaining exposures of this series in the Girvan district will next be demonstrated.

(b) *Description of the Confirmatory Exposures of the Calcareous Series in the Valley of the Assel Water.*

The whole of the great Benan-Hill ridge lying to the northward of the uninterrupted line of calcareous rock just described is, as we have already pointed out, composed of a continuous sheet of the dark green or Benan Conglomerate (Ac), which in our typical localities immediately overlies the *Didymograptus*-shales (Ab⁴). From the

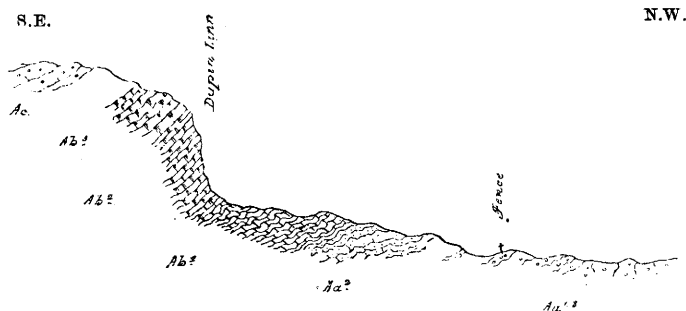
great quarry at Minuntion last noticed, eastward as far as the summit of the Mull of Milljoan, this conglomerate is exposed in every stream that has laid bare the strata below the grassy covering of the hill-tops. It varies much in colour, from black through dark green and yellow, and even purple; but we find few traces of an approach, either in colour, composition, or texture, to the beautifully marbled basal conglomerate of Kirkland and the Stinchar.

Throughout much of this extended area the Benan Conglomerate dips at very low angles and is even occasionally perfectly flat: indeed in the higher parts of the area, especially along the central ridge, this may be said to be the normal position of the rock.

As we approach the exposures of the calcareous series on the opposite sides of the ridge, the angle of inclination of the conglomerate increases irregularly to an average of about 45° . Along the typical Minuntion and Auchensoul line, as we have shown, this dip is universally to the *northward*. In the line of exposures between Dupin and Brockloch, which we have next to notice, the dip is in the opposite direction, or to the *southward*. This renders it highly probable, even at this early stage of our inquiry, that the Benan-Hill Conglomerate of this area will be found to be arranged in a synclinal form, and that the calcareous rocks which rise out from below it to the northward in the valley of the Assel will prove identical with those of our typical calcareous series of Minuntion and the Stinchar.

1. *Dupin*.—The first series of these exposures of calcareous beds is disposed in a broken line stretching from the Barr road near the foot of Pinjerrach Hill, down the southern slope of the valley of the Assel to Daldowie, and thence across the river-valley into the woods of Letterpin and Pinmore. The most satisfactory of the exposures

Fig. 3.—Section of the Strata of Dupin Linn.



Ac. Green Conglomerate of Benan Hill.

Stinchar limestone group:—

Ab³. Flaggy Limestones; fossils rare.

Ab². Impure Limestones with *Maclurea*.

Ab¹. Nodular calcareous beds with *Orthis confinis*, *Strophomena*, *Ilænus*, &c.

Kirkland Beds:—

Aa². Purple and grey sandy beds, much shattered.

? Aa¹. Purple and green Conglomerate, broken and faulted.

along this extended line is that visible in the west glen of Dupin, a short distance above the edge of the alluvial trough of the Assel opposite the great lime-quarry of Tramitchell.

(1) *Dupin West Burn* (fig. 3).—About a quarter of a mile above the mouth of the little stream of the glen, coarse dark-green conglomerates are visible on its banks, dipping at varying angles to the southward, and apparently continued uninterruptedly above to the summit of the Benan ridge. A few yards below the most northerly of these exposures, thick beds of flaggy limestone are seen plunging into the hill-face at the same general angle of inclination as the green conglomerates. Where they cross the glen these limestones give origin to the small waterfall of Dupin Linn. They are fairly exhibited to a depth of about thirty feet, and repose upon a similar thickness of flaggy and more or less impurely calcareous beds, clearly the *Maclurea*-beds (Ab^2) of our typical sections of the Stinchar valley. These are underlain in their turn by nodular calcareous flags (Ab^1), which yield examples of *Orthis confinis*, *Strophomena expansa*, *Illeenus*, &c. Next follow the unfossiliferous Transitional Sandstones (Aa^2), which graduate downwards in their turn into purple and green Conglomerates (Aa^1), varied with calcareous seams. In other words, if we except the easily eroded *Didymograptus*-shales, which are obscured by gravel, we find that all the members of the Calcareous series which we have studied to the southward are visible at this locality in their natural order and with their relative thickness.

Fig. 4.—Section of the Strata of Dupin Mid Burn.



- Ac. Benan Conglomerate in its typical form.
- Ac*. Conglomerate with limestone nodules.
- Ab. Green calcareous shales with *Graptolites* and *Lingule*.
- Ab. Limestones much distorted and faulted.
- A?. Green and grey flaggy Sandstones.

(2) *Dupin Mid Burn* (fig. 4).—The limestone of Dupin Linn may be followed across the grass-grown slopes to the north-eastward into the succeeding stream-course in that direction, where a second exposure of the band is laid open. Short as is the interval, the strata are much shattered and disjointed by small faults, and in the stream-bed itself only fragments of the band are visible. The highest strata seen are the coarse boulder-beds of the great Benan Conglomerates (Ac) of the usual character. The lowest bed of the Conglomerate (Ac*) is here filled with rounded nodules of limestone. To judge from the appearances observed, it is evident that these enclosures have not been derived from a local erosion of the inferior limestone, but that there has been a distinct continuation of the

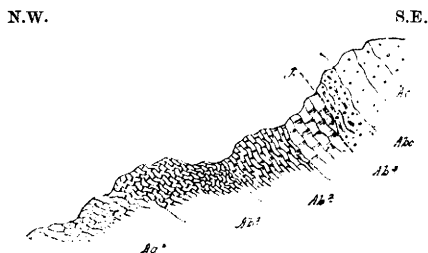
limestone-yielding conditions for a time into the era of production of the conglomerate itself. These nodular beds succeed a patch of calcareous shales (Ab^4) representative of the *Didymograptus*-beds, which contain a few characteristic fossils, principally Lingulidæ. This zone is irregularly underlain by the compact and nodular limestones, which are exposed in a small side quarry, and are, especially in their lower portions, greatly contorted and shattered. The section is terminated below by a series of sandy grits, probably those of the lower zones of the *O.-confinis*-beds. They afforded me no fossils, but they present the hollows and seams of rottenstone characteristic of the zone.

In the succeeding runnels which cross the prolongation of the limestone band to the eastward, the calcareous and conglomeratic groups are shown in a more or less shattered condition. The Benan Conglomerate (Ac) occupies the higher parts of the stream-courses. It is underlain in the natural order by patches of the limestone beds, which in their turn are supported by fragments of the underlying sandy gritstones. The rapidity with which the higher zones of the limestones part with their calcareous matter as we pass to the eastward is most remarkable, the whole of the upper beds showing a tendency to degenerate into a group of nodular shales.

2. *Craigwells or Brockloch Quarries*.—After traversing a short interval devoid of rock-exposures, we again meet with the calcareous band in a group of old limestone-quarries lying to the east of the farmhouse of Brockloch.

In the quarry situated at the disused limekiln of Craigwells we have the following section (fig. 5).

Fig. 5.—*Brockloch Quarry*.



Ac . Benan Conglomerate.

Abc . Conglomerate with nodules of lime.

Ab^3 . Compact Limestone, 20 feet.

Ab^2 . Impure flaggy Limestones.

Ab^1 . Nodular Limestones.

Aa^2 . Calcareous Flagstone.

To judge from this section, it would appear, at first sight, that the Compact Limestones (Ab^3) are surmounted immediately by the basal beds of the Benan Conglomerate (Ac), while the *Didymograptus*-beds (Ab^4) are absent from the section, having apparently been eroded, and that the overlying conglomerate rests unconformably upon an undulated face of the Compact Limestone, fragments of which occur

in abundance in the conglomerate itself. But the line of contact is clearly a fault, while the patches of lime in the conglomerate lie in regular seams, and have the appearance of being merely nodular concretions, as if the conditions favourable to the deposition of calcareous matter, which marked the epoch of the formation of the limestone series, were continued into the earlier stages of the period in which the Benan Conglomerate was laid down.

That this is the correct interpretation is placed beyond question by a careful comparison of the phenomena presented by the succeeding quarries to the north-west of this locality. In some of these the *Didymograptus*-shales (Ab⁴) are lost through faulting; in others they are well displayed, and are found to possess all their usual characters, lithological and palæontological. Sections of the two most important of these exposures are given on the opposite page.

In the first of these (fig. 6) the *Didymograptus*-shales (Ab⁴) are formed of a group of greenish shales and impure nodular limestones, and lie, precisely as in the Stinchar valley, between the *Compact Limestones* and the Benan Conglomerates. The basal beds of the latter are filled with limestone nodules, arranged generally along the lines of stratification, and weather to a light yellow or orange-colour.

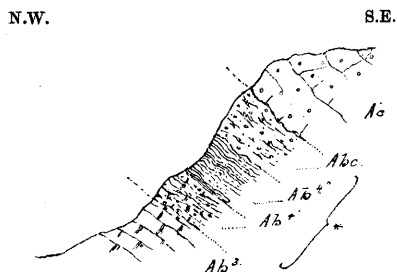
In the second (fig. 7) the *Didymograptus*-zone is most effectively displayed, and is seen to be composed, as usual, of bands of grey and green shales, which graduate from the *Compact Limestones* below, through a series of nodular beds, into the Benan Conglomerate above, the basal zones of the latter being filled with seams and patches of calcareous nodules, and weathering of the usual buff or orange tint.

The *Didymograptus*-shales themselves yield the characteristic fossils *Didymograptus superstes*, *Climacograptus nanus*, *Acrotreta Nicholsoni*, &c.

Summary.—Our study of this portion of the Dupin-Brockloch band has taught us that along this line there is no line of irregular erosion at the base of the Benan Conglomerate. In Dupin, midway along its course, the *Didymograptus*-beds (Ab⁴) are present in force, and with their typical aspect as exhibited in the Minunition and Stinchar area. As we pass eastward along the deserted quarries of Brockloch and Craigwells, their place is distinctly occupied by a thin group of nodular limestones and Graptolitic shales, surmounted by conglomerates full of seams and balls of calcareous matter. These overlying beds, though they appear to be derived partially from the reconstructed débris of the calcareous series, are rather interpretable as evidence that the era between the period of deposition of the Stinchar calcareous series and that of the Benan Conglomerate was a period of oscillation, and that the lime-producing conditions which prevailed during the time of deposition of the Stinchar calcareous series were prolonged into the earlier stages of the epoch in which the tumultuous Benan Conglomerate was formed.

To the north of that portion of the Dupin-Craigwells limestone

Fig. 6.—Section of Quarry North-east of Craigwells.



Ac. Benan Conglomerate (here weathering of an orange tint).

*. *Didymograptus*-zone or passage-beds between Stinchar Limestone group and Benan Conglomerate.

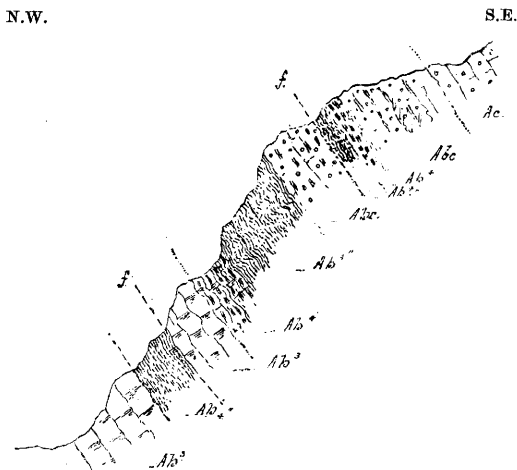
Abc. Yellow Conglomerate with limestone-nodules.

Ab'''. Green calcareous Shales with *Lingula*.

Ab''. Nodular and impure flaggy Limestones.

Ab³. Compact Limestones.

Fig. 7.—Section of Quarry between Brockloch and Little Lane Toll.



Ac. Benan Conglomerate, weathering of an orange tint, 4 feet.

Passage-beds or *Didymograptus*-beds:—

Abc. Yellow Conglomerate with nodules of limestone, 6 feet.

Ab'''. Green calcareous Shales, 8 feet, with *Lingula*, *Acrotreta Nicholsoni*, *Diplograptus*, &c.

Ab''. Nodular and impure flaggy Limestones, 4 feet.

Ab³. Compact Limestones, without visible fossils.

ff. Faults.

band we have last described the green and yellow beds of the Benan Conglomerate are visible, extending, so far as can be ascertained, in an unbroken mass from the limestone band to the sluggish stream of the Assel Water. Hence it may be regarded as almost certain that this southerly dipping limestone band is here brought to the surface by a sharp anticlinal, ranging from N.E. to S.W., a small fault running along its summit and depressing the strata to the north. On that side, except at Dupin Linn, nothing is visible of older date than the Benan Conglomerate (Ac). On the south-east margin, however, as we have seen, various thicknesses of the Stinchur calcareous series are recognizable, the deepest strata visible being the Purple Conglomerate and Sandstones (Aa) of Dupin Linn, which we identified at the point where we commenced our study of the band.

This anticlinal and its accompanying fault are probably prolonged continuously to the south-westward in the same general straight line; but as the Benan Conglomerate is seen in some small exposures in this direction immediately west of Dupin Linn, while the limestone is found in place along a parallel line some 500 yards to the southward, it is possible that the fault varies much in throw, and is accompanied by parallel dislocations of equal extent.

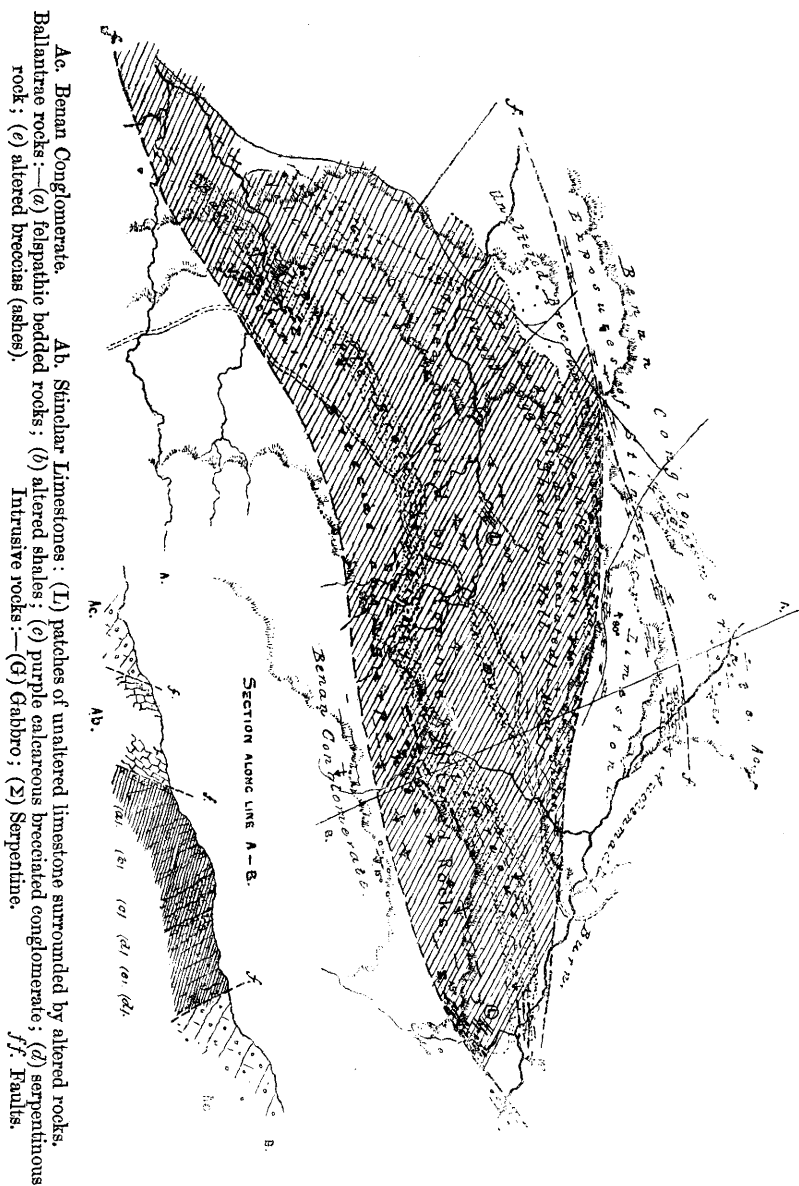
3. *Shalloch-Hill Exposures*.—Less than a mile to the west, however, the calcareous series again makes its appearance in the exact prolongation of the Craigwells fault, as we are presented with a fairly continuous section half a mile in length and of very great interest.

The limestone is seen in several old quarries excavated in the north slope of Shalloch Hill. In the easternmost of these quarries the strata are much dislocated, and their junction with the interesting rocks to the southward is obscured. In the second quarry the limestones lie between calcareous flags weathering with a honey-combed surface, probably the *O.-confinis* flags (Ab²), and soft shales and nodular grits representative of the transitional zone of Craigwells and Brockloch. Westwards the same flaggy limestones are seen projecting from the surface of ploughed fields, and eastwards in the bed of the small burn of Auchenmaddy.

These calcareous beds are succeeded to the north by the great Benan Conglomerate; while to the southward they are in contact with the remarkable mass of Shalloch Hill, which will be presently described. Difficult as it is to discern any stratigraphical evidence of value in the Shalloch exposures of these limestones, a study of their geographical distribution, as shown upon the map, renders it almost certain that they are brought to the surface by the Craigwells anticlinal and fault.

Immediately to the south of these quarries we meet with a most remarkable exhibition of the Stinchur calcareous beds and their underlying purple conglomerate, in the rugged area of Shalloch Hill itself (fig. 8), which forms one of the outer buttresses of the Benan ridge. Within this area, which is about a mile in length and

Fig. 8.—Plan and Section of the Shalloch-Hill area.



half a mile in breadth, occur patches of limestones, felspathic grits and breccias, and bedded igneous rocks, all intensely crumpled and crushed together, and pierced by dykes of diorite and serpentine. This area is limited by faults both on the north and south, outside of which lie the unaltered beds of the Benan Conglomerate.

On both margins of the area we find the beds of the calcareous series; and the general disposition of the greatly wrinkled strata is that of an irregular anticlinal.

Shalloch Hill.—All the central part of this remarkable area is formed of grey and purple felsites, breccias of igneous rocks, altered shales, and a peculiar purple brecciated conglomerate. This last-named rock forms the longitudinal axis of the area, and is well displayed in open quarries and prominent bosses of naked rock. Except in its excessive induration and the presence of much serpentine and serpentinous matter, it irresistibly reminds us of the basal conglomerate (Aa¹) of Kirkland. The pebbles of igneous rocks enclosed are generally smaller than those of the Stinchar rock; but the brilliantly purple matrix, highly calcareous and traversed by innumerable veins of spar, is identical.

The associated felsites, breccias, and gabbros are, however, most distinctly those of the much older *Ballantrae Series*, in which corresponding calcareous breccias (calcareous and serpentinous ash-beds) occur at several localities. At the same time the hardened and altered rocks of the present area are fringed to the N.W. (see plan, fig. 8) by unaltered breccias, similar to those of Millenderdale, which lie apparently between the conglomerate and the *Ballantrae Series*. I am therefore inclined to the opinion that the whole of the hardened and igneous rocks and dykes of this Shalloch-Hill area are of older date than the Kirkland Purple Conglomerate (Aa¹), and are here brought to the surface along a faulted anticlinal.

Nevertheless there are difficulties even upon this theory; for calcareous strata belonging to the *Orthis-confinis* Flagstones (Ab¹) are visibly entangled among the purple beds in the very centre of the area and afford several of the characteristic fossils in a fair state of preservation. They are even better exhibited in the neighbourhood of the Dupin fault near the edge of Auchenmaddy Burn on its north-east margin, where *Orthis confinis* and *Strophomena alternata* are not uncommon.

4. *Little Letterpin.*—The Craigwells fault, which forms the northern boundary of this area, is prolonged from the Shalloch quarries across the valley of the Assel into the elevated ground to the west of the farm of Little Letterpin, where the limestone was formerly worked for agricultural purposes. In this locality we have a repetition in miniature of the phenomena of Shalloch Hill. The limestone seen in the old quarry consists merely of a few feet of very impurely calcareous rock, greatly shattered, dipping irregularly to the southward, and faulted abruptly against the main mass of Benan Conglomerate to the south. The higher points of Little Letterpin Hill consist of the purple grits and breccias of the altered series.

These are prolonged for nearly a mile to the south-west, and are much interfered with and hardened by protrusions of gabbro, which has been forced through the beds in a complicated plexus of dykes and veins.

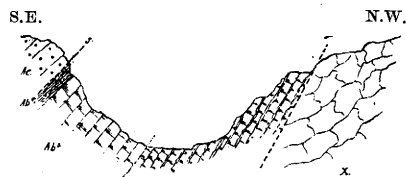
The Stinchar beds of this locality lie apparently between two converging faults, which appear to be the prolongations of those which bound the Shalloch-Hill area. These unite to the south-west into a single line, which may be most conveniently regarded as part of the Craigwells dislocation, which is continued in this direction into the metamorphic rocks of the valley of the Lendal.

(c) *Description of the Supplementary Exposures south of the Girvan Valley.*

1. *Aldons Quarry.*—Before entering upon the study of the scattered exposures of the Stinchar calcareous series to the north and west of the Benan-Hill ridge, it will be advisable to turn aside for a while, and examine the magnificent exhibition of these rocks in the quarries at Aldons and their extension in the south-west. The massive conglomerates of Benan Hill are continued uninterruptedly from the highest points of the Benan ridge across the lower valley of the Assel Water into the steep slopes of Aldons Hill west of Pinmore. About a mile south-west of Pinmore Bridge the great conglomerate is reduced almost to a point between two converging faults, which have thrown it down in a narrow synclinal among the Ballantrae metamorphic and igneous rocks. The limestone is seen coming out from below the Benan Conglomerate on both sides of this synclinal; and its relations to the rocks above and below are admirably shown in the large quarries which have long been opened at this locality.

In the north-west quarry and in the sides of the roadway leading thence towards the valley of the Stinchar we have an excellent exhibition of the rocks.

Fig. 9.—Section of Large Quarry, Aldons.



Ac. Benan Conglomerate.

Ab¹. Shaly beds with *Ampyx*, *Leptæna*, &c.

Ab². Compact Limestones.

Ab². Impure flaggy Limestones with

Maclurea Loganii, *Cythere al*
densis, &c.

x. Igneous rocks of the Ballantrae Series.

This quarry (fig. 9) is opened along the line of fault between the Ballantrae rocks and the Girvan Series. The lowest bedded rocks

exposed are impure calcareous flagstones (Ab^2). These are greatly shattered and crushed by the fault, and weather down into small irregularly shaped fragments, which, upon the dissolution of their included calcareous matter, subside into a black mud. They are actually thin-bedded limestone-flags, with a wrinkled, pitted surface, the irregularities of which are filled up with soft dark mud of a flaky texture. They yield many examples of *Maclurea Logani* of large size, together with myriads of the minute crustacean *Cythere aldensis*, M'Coy. It is difficult to estimate the thickness of these *Maclurea*-flagstones, but it cannot be less than 30 or 40 feet.

They are succeeded by the Compact Limestone beds in thick strata, clearly identical with the Compact Limestones of Benan Burn. No reliable estimate can be formed of their original thickness at this locality, but it must have been somewhat less than that of the subjacent flagstones.

At the east end of the quarry a fault has brought down the more gently inclined Benan Conglomerate against these Compact Limestones; but as we trace the fault in its course along the face of the quarry to the west, some of the intermediate beds make their appearance below it. These consist of thin-bedded greenish-grey shales of some ten or twelve feet in thickness, clearly representative of our *Didymograptus*-beds of the Kirkdominæ band and the corresponding zone of Craigwells (Ab^4). They are here abundantly fossiliferous, being crowded with casts of fossils of the genera *Agnostus*, *Illænus*, *Remopleurides*, *Lingula*, *Acrotreta*, and *Leptaena*, together with *Cythere* and fragments of Euerinites. The remaining quarries of this locality are opened along the southern line of fault, where the calcareous series is seen in contact with the igneous rocks, but too greatly shattered to afford fossils.

It would be superfluous to point out how easily the succession in this locality is interpreted by the facts we have already obtained in the Benan-Hill area, and how complete is the identity of the various zones of strata as here exhibited with the corresponding rocks of the typical calcareous band of Auchensoul and Minution. The inferiority of the Stinchar calcareous series to the Benan Conglomerate and the natural arrangement of the members of that series having now been satisfactorily determined, we turn with the confidence born of certainty to the study of the remaining exposures of these beds in the Girvan district, treating of each exposure as briefly as is consistent with the object we have in view.

The great fault in the southern quarries at Aldons is well shown in the railway-cutting above Pinmore Bridge. Here a few feet of the Compact Limestones are seen in a shattered condition between the metamorphic or igneous rock and the overlying sheet of Benan Conglomerate, the whole dipping at a gentle angle to the north-west.

The same fault is seen in the Stinchar near Pinmore Bridge; but there is no trace of the limestone.

Several exposures of the calcareous series occur, however, in the prolongation of this line to the north-west. In the heights to the

north of Kilpatrick the limestone is seen in several localities, in thin courses and in several neglected quarries, greatly interfered with by protrusions of gabbro, and having no definitely regular relation to the surrounding sheet of the Benan Conglomerate (see map 2, Plate XXV.). Faulted patches of the same rock are visible along the extension of the Aldons dislocation to the north, as far as the summit of Daldowie Hill. Their geographical disposition may be gathered from a study of the accompanying map of the region.

2. *Tramitchell Quarries &c.*—By far the most important exposure of the Stinchar Limestone south of the Girvan valley, from an economic point of view, is undoubtedly that presented in the great lime-quarries at Tramitchell in the valley of the Assel. Here the limestone is quarried in a steep cliff which overhangs the roadway for a distance of at least 200 yards. It seems at first sight altogether much thicker and purer than in any other exposure in the entire Girvan region; and next to the quarry of Craighead, to be noticed in the sequel, this quarry certainly affords the chief supply of lime for the district. It is mined in large quantities, burnt in the kilns upon the spot, and led upon a tramway to the railway-station at Pinmore.

At a first glance it would appear that at least 100 feet of Compact Limestone are developed at this locality; but this apparently abnormal thickness is delusive, and the limestones are actually of no greater vertical extent than elsewhere. A long strike-fault bounds them to the north, throwing down against them the highest zones of the overlying Benan Conglomerate. The limestones, which include also the whole of the *Maclurea*-zone, are crumpled up against this fault in a broken anticlinal form, and dip with several small step-slips, visible in the quarry-face, steadily to the southwards, as if passing below the Benan Conglomerate of the flats of the Assel.

The sharp anticlinal in the neighbourhood of the fault is well seen at the eastern extremity of the exposure. Some of the more impure and nodular beds on the floor of the quarry take on an oolitic structure, a very rare phenomenon among the limestones of this region.

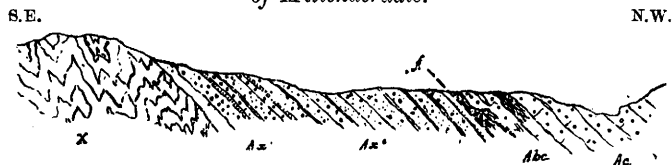
In the purer flaggy limestones at the summit of the anticlinal occur the peculiar fossils *Saccammina Carteri* and *Girvanella problematica*, which, together with fragments of *Encrinites* and *Tetradium*, are very abundant. The lower *Maclurea*-flagstones in the centre of the quarry yield *Maclurea Logani*, *Ecculiomphalus Bucklandi*, *Orthis calligramma*, *Strophomena corrugatella*, and their usual associates.

The wide-spreading and continuous mass of Benan Conglomerate of the upland area of Benan and Auchensoul, to which we have hitherto restricted our description, seems originally to have expanded to the westward into a broad sheet many square miles in superficial extent, around and above the metamorphic and igneous rocks of Lendal and Ballantrae. The powerful dislocations which have affected the Girvan district have, however, shattered this broad sheet into four distinct fragments. Two of these, forming the high

grounds of Millenderdale and Laggan, are still continuous with our typical mass of Benan Hill. The remaining two, which occur upon the ridges of Trowier and the Byne Hill, are now separated from the Benan ridge and each other by two gigantic strike-faults, which have thrown down between them strata of much later geological age. Not only is the present geographical arrangement of the rocks of these areas almost demonstrative of their original continuity, but their detailed study shows, as might have been expected, that they agree precisely in all their petrological characters with their prototypes of Benan Hill, and are similarly underlain by a group of calcareous beds answering exactly to our limestone series of Auchensoul and the Stinchar.

3. *Millenderdale area*.—The most southerly of these supplementary areas is formed by a narrow prolongation of the Benan Conglomerate, about three miles in length by half a mile in width, which stretches from the typical area at Kinclaer viaduct upon the water of Assel, into the heart of the Ballantrae rocks upon the water of Lendal. It is distinctly interposed between these igneous rocks and the sheet of Graptolitic flagstone which everywhere succeeds to the Benan Conglomerate in the Girvan district. The peculiar relations of this strip of conglomerate to the neighbouring Ballantrae rocks need not detain us here. It will be sufficient for our present purpose to state that a careful mapping of the area makes it clear that it forms, generally speaking, a faulted anticlinal. Near its western extremity the Stinchar Limestone emerges from below it in a group of old quarries and natural exposures near the farmstead of Millenderdale. A few specimens of *Saccamina Carteri*, and *Tetradium Peachii* are procurable from these limestones. In the deserted quarry west of the steading, in spite of the shattered state of the beds, we recognize with certainty the Nodular Flags (Ab^2) at its northern extremity, followed by the Compact Limestones (Ab^3), for the extraction of which the excavation was made, and finally a few feet of the superior greenish shales of the *Didymograptus*-beds (Ab^4) are seen in the stream-course to the south-west.

Fig. 10.—*Basal Zones of the Girvan Succession, south-west of Millenderdale.*



Ac. Benan Conglomerate.

Abc. Graptolitic shales with *Diplograptus rugosus*, *Crypt. tricornis*, &c.

Ax. Base of Girvan Conglomerate.

Ax². Well-bedded ashy conglomerates and sandstones.

Ax¹. Coarse breccias of fragments of igneous and altered rocks, with interstratified purple sandstones and red and green grits and shales.

x. Igneous and altered rocks of *Ballantrae Series*.

f. Fault.

In the bed and banks of the small stream which drains the grassy heights to the south-west of this locality an interesting section of what appear to be the basal breccias and sandstones of the Girvan succession is laid bare. The lithological characters and physical relationships of these beds will be apparent upon a study of the foregoing section (fig. 10), but their detailed description is reserved for a future occasion.

4. *Dinvin and Laggan Hill.*-- Northward of the anticlinal and fault of Letterpin and Brockloch a long tongue of the Benan-Hill Conglomerate runs westward from the quarries at Tramitchell along the north side of the Assel, and, expanding rapidly as it is followed in this direction, finally forms a broad rounded mass more than two square miles in area, in the rugged heights of Laggan and Dinvin. The beds of this sheet of conglomerate are thrown into innumerable undulations, which are well seen in a host of natural exposures; but none of these are of sufficient magnitude to bring the underlying calcareous series to the surface. Westward, however, the conglomerate area is bounded by the complicated group of dislocations which surround the Old Red Sandstone outlier of Glendrissoch; and in their neighbourhood we find exposed the basal beds of the conglomerate, together with a few feet of the infrajacent calcareous series.

From the farmhouse of Pinnacher for some distance towards the narrow gorge of Laggan Gill the deepest beds of the conglomerate dip at a gentle angle to the south-eastward below all the overlying masses of Dinvin. Rising out from beneath these, in their natural order, we find the Stinchar Limestone in two disconnected spots. The first of these is an old quarry, a hundred yards north-west of the steading of Pinnacher, where hard compact limestones form a rude anticlinal, the eastern side of which is overlain by calcareous flaggy shales dipping towards the great conglomerate of Dinvin. The only fossils I have collected from these beds are undeterminable Brachiopoda; but the officers of the Geological Survey have been more fortunate, as they enumerate in their list of organic remains from Pinnacher the characteristic and peculiar Stinchar forms *Maclurea Loganii*, Salt., and *Lyopora favosa*, M'Coy.

In the second exposure, which occurs in a deep bay of the conglomerate, about half a mile to the north-eastward, a fairly satisfactory section is seen, showing the beds of transition between the calcareous series and the Benan Conglomerate. At this locality the basal beds of the Benan rock dip at a medium angle to the eastward below the continuous mass of the neighbouring slopes; they weather with the orange-yellow tint characteristic of the corresponding beds along the northern margin of the Benan area. the nodular calcareous seams of the Brockloch zone at the base of the Benan rock here unite into a distinct band of limestone, more than a foot in thickness, which is both overlain and underlain by coarse conglomerates, thus affording us a complete demonstration of the conformability of the Stinchar and Benan strata.

A short distance to the south a branch of the Glendrissoch fault steps forward the conglomerate of Dinvin into the mound of Laggan

Hill, and an altered patch of the *Ballantrae* calcareous series comes out from below it at the head of the Laggan Gill.

5. *Trowier Hill*.—The summit and south-west scarp of Trowier Hill, which lies between the two forks of Piedmont Burn, about half a mile north of the last-mentioned locality, are formed of an irregular dome of the Benan Conglomerate. The south-western limits of the conglomerate area, as expressed upon the map (Pl. XXIV.), are purely inferential, as the natural surface of Piedmont Hill itself is obscured by moss and vegetation. In the centre of the dome of Trowier itself, however, we have distinct evidence of the presence of a calcareous series in place, in the numerous excavations formerly made for the purpose of extracting lime, in the existence of an old lime-kiln, and in the abundance of scattered fragments of altered calcareous rock. Such fragments as are capable of interpretation give no evidence that the higher Compact Limestones have been obtained at this spot; but seem to belong rather to the impure and more or less ashy and serpentinized band of the *Ballantrae Series*.

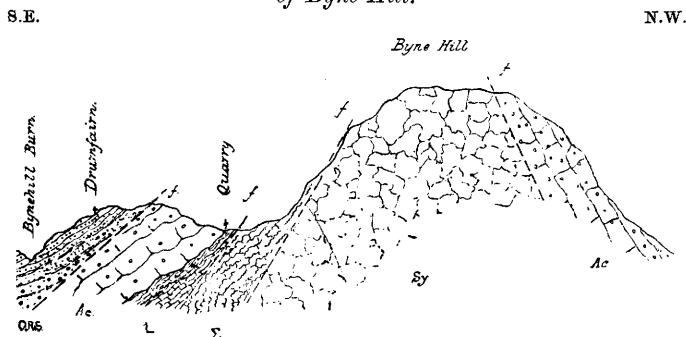
6. *Dow Hill*.—A marked and most symmetrical anticlinal of the same Benan rock forms the conspicuous knoll of Dow Hill, a short distance lower down the water of Piedmont. No great thickness of the conglomerate is here exposed, but its infraposition to the surrounding strata of the neighbouring slopes (the Graptolitic flagstones and shales to be presently described) is most perfectly exhibited.

7. *Byne Hill and Kennedy's Pass*.—The most conspicuous and best-known of the many exposures of the Benan Conglomerate in the Girvan district is undoubtedly that of the Byne Hill and Kennedy's Pass. It forms the northern and steeply descending flank of the igneous ridges of Grey Hill and Pinbain, in an unbroken sheet about four miles in length. It is beautifully displayed in the rugged mound of the Byne Hill (fig. 11), which forms the most conspicuous object in the picturesque view of this ridge and the old sea-terrace at its foot from the town itself. The arrangement of the rocks in this hill will be understood from the following generalized section. Its core is formed of a mass of syenitic granite, which is followed to the south-eastward by a strip of the peculiar serpentinous rock so abundant in the *Ballantrae* region. These igneous rocks are flanked on both sides by the Benan Conglomerate, which is composed of the usual tumultuous masses of boulders of igneous rocks imbedded in a greenish and more or less ashy paste, and occasionally divided by seams of coarse sandstone and bedded grit. On the north side of the hill the beds in contact with the syenite differ in no essential respect from those constituting the main mass of the conglomerate; but on the south-eastward slope we find certain calcareous beds rising out from below.

A limestone is seen in an old quarry on the line of fault between the serpentine and the conglomeratic area of Drumfairn, at the head of a small tributary of the Byne Hill Burn. About 10 feet of Compact Limestone is visible, dipping 60° or 70° S.E., shattered and more or less serpentinized where it is in contact with the fault-line

below, and passing upward regularly into flaggy and more shaly beds above. These are at once surmounted by the Benan Conglomerate.

Fig. 11.—Section across the Ballantrae and Girvan Rocks of Byne Hill.



O. R. S. Conglomerates and sandstones of Old Red Sandstone age.

Ac. Benan Conglomerate in its ordinary characters.

L. Crushed and altered limestones of doubtful age.

Σ. Serpentine.

Sy. Syenitic granite of Byne Hill.

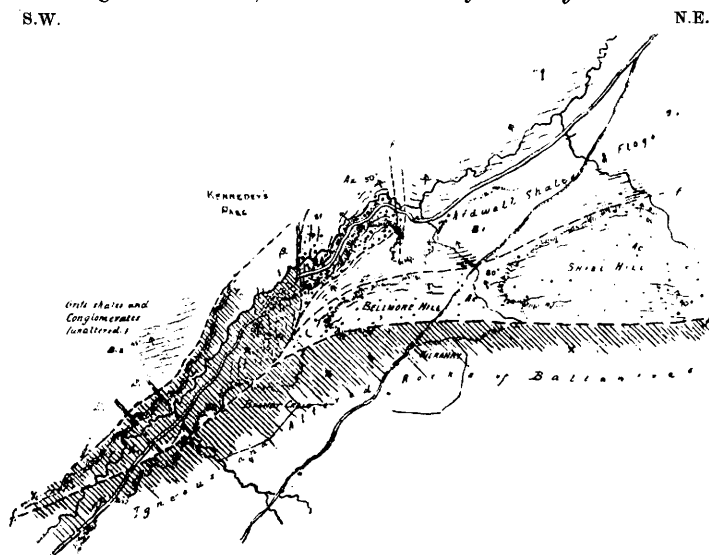
ff. Faults.

The same beds may be traced a short distance in both directions, and are possibly cut out to the south-west by a transverse fault passing through the farmhouse of Drumfairn.

From Byne Hill the Benan Conglomerate is traceable in an unbroken strip to the sea-shore at Kennedy's Pass (fig. 12). It varies much in its transverse diameter throughout this extent; but as it nowhere exhibits any of the naturally underlying limestones, so far as may be inferred from the phenomena exhibited in the few exposures upon the hill-slopes, it seems probable that throughout the whole of this extent its south-western edge is faulted down against the igneous series of Ballantrae.

The dividing basal fault is well seen where the conglomerate comes upon the sea-shore, and is traceable for some distance in a south-westerly direction, running almost parallel with the shore-line. Where it finally disappears beneath the water it is joined at an acute angle by a second strike-fault coming down the coast-line from Shalloch and Ardwell. In the angle formed by these two converging faults there is a grand exhibition of Conglomerate at the well-known locality of Kennedy's Pass, where it was first studied by Murchison and Nicol, and where it has been frequently examined by recent students of the rocks of this region. In the roadway and cliffs at this point the numerous transverse dislocations which have affected it admit of easy recognition, and the conglomerate itself

Fig. 12.—*Plan of the Faulted Area of Kennedy's Pass.*



Girvan rocks:

- B¹. Graptolitic shales and flagstones of Ardwell.
- Bx. Green flagstones, shales, and conglomerates, non-fossiliferous.
- Ac. Benan Conglomerate.
- Ax. Basal Conglomerate of Kennedy's Pass.

Ballantrae rocks:—

- x. Ashes and breccias, igneous rocks, amygdaloidal traps, &c.
- y. Band of altered limestone and calcareous breccia.
- f.f. Faults. B B. Basaltic dykes.

is laid open to view in one of its most typical forms. The matrix of the basal division is finer and altogether less calcareous than in the interior districts, while the pebbles are generally smaller and by no means so numerous; but in all its essential features the mass cut through by the roadway reminds us of the ashy Basal Conglomerate of Millenderdale and the Stinchar, while that which occurs upon the ridge above is identical with our typical conglomerate of Benan Hill and Auchensoul.

(d) *Description of the Fossiliferous Exposures north of the Girvan Valley.*

1. *Craighead Quarries.*—Next to our typical exposure of the calcareous series in Benan Burn and Auchensoul in the valley of the Stinchar, by far the most important exhibition of the Stinchar Limestone is that afforded us in the great lime-quarries of Craighead on the north side of the valley of the Girvan. These quarries are

excavated in the south-west flank of the prominent ridge of Craighead and Quarrel Hill, in the immediate neighbourhood of the Glasgow and South-western Railway, about a mile to the east of the railway-station of Killochan. The gigantic fault which here forms the northern limit of the Carboniferous basin of the Girvan valley runs at this point parallel to the railway, immediately in front of the quarries themselves. Several loop-faults or inosculating branches of this grand dislocation are given off along its course to the north-westward; and caught up between these, and abruptly collocated with strata of comparatively recent geological age, we find long lenticular masses of the conglomeratic and calcareous division of the Girvan succession we have been studying to the southward. The most important of these loop-faults surrounds the mound-like hill of Craighead, enclosing a lenticular mass of rock of peculiar character, a mile in length and half a mile in breadth. The main mass of the lenticle, which forms the hill itself, is clearly identical with the enigmatical rocks of Ballantrae, and, like them, is formed of a congeries of rocks partly aqueous and partly igneous, the latter, again, being partly bedded and contemporaneous, partly intrusive and subsequent. At the eastern end of the lenticle, however, these rocks are surrounded by a mass of limestone and calcareous strata, of a semicircular form, limited at both ends by the bounding faults, and dipping generally from off the igneous and hardened rocks.

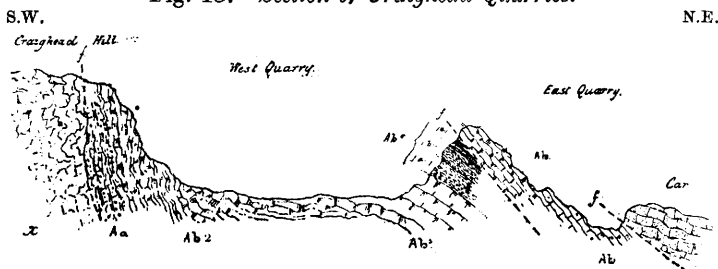
It is in this semicircular mass of limestone that the Craighead quarries have been excavated. They are two in number—an older quarry lying on the southern curve of the semicircle, and a newer quarry running along its eastern edge. The former has been long exhausted of its superficial and more easily excavated limestones. The latter is in constant working to supply the demands of the agriculturists of the neighbourhood, the lime being burnt in kilns upon the spot, and delivered by special tramway at the railway-station of Killochan.

The general arrangement of the calcareous rocks of this locality will be apparent on a study of the following section (fig. 13).

The two sets of calcareous strata excavated in the quarries form, with respect to each other, a rude synclinal, which has been broken along its central line. Their physical arrangement is best displayed in a section drawn through the south quarry parallel to the great fault.

At the south-western end of the quarry calcareous and ashy conglomerates, representative of the basal conglomerates of Kirkland (Aa), are seen in vertical and even partially inverted position in contact with the igneous rocks of Craighead Hill. They pass below a thick group of nodular beds (Ab¹ and Ab), which, arranged in a basin-like form, run in perpendicular cliffs round the western and northern faces of the quarry. These are actually concretionary limestones, rendered very impure by the presence of much soft green and grey mud. They contain an occasional *Maclurea*, and are crowded with an abundance of corals, the beautiful tracery of which may be made out by the lens in all the white seams and bands that traverse the face of every new-made fracture of the beds.

Fig. 13.—Section of Craighead Quarries.



Stinchur Limestone Group.

Ab⁴. *Didymograptus*-zone:—

(c) Shivery shales with *Encrinurus*, *Ampyx*, *Leptæna*, &c.

(b) Blue calcareous and slightly carbonaceous shales with *Climacograptus bicornis*, *Diplogr. rugosus*, &c.

(a) Nodular and highly calcareous shales crowded with fossils.

Ab³. Compact Limestones, fossils rare.

Ab². Impure flaggy and nodular limestones, greatly shattered and folded, with rare *Maclurea Logani* and abundant corals.

Ab. Sandy and flaggy limestones with *Orthis*, *Leptæna*, &c.

Kirkland Conglomerate.

Aa. Basal brecciated and calcareous conglomerate and grit.

x. Igneous and altered rocks of Craighead Hill.

Car. Lower Carboniferous sandstones of the Girvan valley.

ff. Faults.

The floor of the quarry itself and the little cliff supporting the roadway to the south is composed of the purer and more compact limestones which give the quarry its economic value. They are here greatly hardened and have a pale greyish-white tint when freshly broken. They contain a larger proportion of carbonate of lime than elsewhere, and seem to have been quarried in thick and heavy masses. A few of the same fossils are procurable from them as those found in the muddier beds below, but they are much more difficult of extraction.

The terminal beds of these compact limestones are seen at the foot of a boss of unexcavated rock which at present divides the two quarries from each other. This boss owes its existence to the circumstance that the strata of which it is formed contain too little lime to be available for burning; and they have been allowed to remain, while the surrounding limestones have been quarried away. The strata seen in this boss are, however, of great value to the stratigraphist, as they enable him to complete the entire section of the calcareous series visible at this locality.

In the western cliff of this mound the Compact Limestones are seen to be overlain by about 10 feet of grey and black Graptolitic shales, identical in mineralogical character with the *Didymograptus*-shales (Ab⁴) of the Auchensoul band. They contain a few Graptolites and shells. Of the former, Mrs. Gray has here collected *Cryptograptus tricornis*, Carr., sp., and *Diplograptus foliaceus*, Murch.

In the grass-grown flank of the boss on its south-west aspect these Graptolitic shales pass upwards into an equal thickness of hard

greyish-yellow shales crowded with casts of fossils of the genera *Encrinurus*, *Ampyx*, *Trinucleus*, *Leptæna*, *Strophomena*, *Orthis*, and *Cythere*.

Above these we find traces of the usual nodule-bearing conglomerate.

These fossiliferous shales are truncated at an acute angle by the strike-fault which runs along the axis of the synclinal between the two limestone-quarries. On the opposite side of the fault we find the more muddy and concretionary *Maclurea*- and coral-beds. The tramway and grassy slopes below hide the main mass of these from sight; but when we search the roadway beneath we find evidence that they have in turn been underlain by green and purple sandstones, more or less pebbly, resembling the *Orthis-confinis* Sandstones of the Stinchar (Ab¹) in appearance and composition, and in the presence of calcareous nodules, as well as in stratigraphical position. They contain the usual forms of *Orthis*, *Leptæna*, and *Strophomena*, and terminate the visible section.

It is needless to insist upon the fact that we have in this locality a section similar in all its details to that typical of the Stinchar calcareous series of the district to the south of the Girvan valley, the natural members of the succession corresponding precisely in both districts in their position in the vertical series and in their petrological and palæontological characters, and differing merely in local thickness.

In one grand respect, however, the calcareous rocks of Craighead differ in a most extraordinary degree from their counterparts of the Stinchar plateau. In the latter district, these strata, though rarely affected by igneous protrusions, are, as a general rule, strangely barren of organic remains throughout their entire vertical extent. In the present locality, though the beds have been greatly shattered and hardened by faulting and crushing, fossils occur in profusion. The indefatigable researches of Mrs. Gray at this locality have been rewarded by the discovery of at least 100 different species of fossils of all the chief Lower Palæozoic groups, affording the palæontologist of the present day a more complete view of the fauna of the period than he would be able to construct from all the zoological data hitherto collected in Britain bearing upon the rocks of Craighead age.

These fossils will be treated of in detail in the second part of the present memoir, and it will only be necessary here to make a few notes upon the remaining exposures of the calcareous beds seen in this locality.

The strata in the new or eastern quarry are folded and faulted repetitions of those already described, crushed up against the igneous strata of Craighead Hill on the west, and passing out of sight below the roadway and clay-covered ground to the east.

2. *Calcareous beds of Thunderton and Glenrochie.*—The same calcareous series is seen at several points along the Craighead fault, both to the south-east and north-east of the quarries themselves; but few of the sections seen are worthy of an extended notice. Near the farmhouse of Glenrochie, a line of deserted quarries affords

good exposures of the shattered beds of the calcareous group. The purple, veined, and brecciated basement conglomerate of Kirkland and Millenderdale is well exhibited, distinctly lying between the Ballantrae rocks and the calcareous series. The latter displays both the impure sandy zone of the *Orthis-confinis* beds and the overlying concretionary flagstones, yielding occasional examples of *Maclurea Loganii*.

(B) THE GRAPTOLITIC FLAGSTONE SERIES OF ARDMILLAN AND
PENWHAPPLE.

Having completed our description of the chief exposures of the great Benan Conglomerate and the calcareous strata which naturally underlie it, our next task is the determination of the nature and vertical distribution of the several groups of strata which immediately succeed it in the ascending order.

The difficulties which confront us in our quest are almost insignificant when contrasted with those we have had to overcome in our study of the calcareous zones below. The outer or superior edge of the great Benan Conglomerate is usually defined with tolerable clearness upon the ground. The highest zones of its massive boulder-beds dip almost everywhere below an overlying series of Graptolitic flagstones and shales of a totally distinct petrological character.

These Graptolitic flagstones occupy the whole of the Lower Palæozoic area south of the Girvan, with the exception of that filled by the Benan-Conglomerate group and a narrow zone lying to the northward of the parallel of Saugh Hill. They are magnificently exposed in the deep gorge of Penwhapple and along the coast-line between Shalloch and Ardwell, while numberless confirmatory sections occur elsewhere.

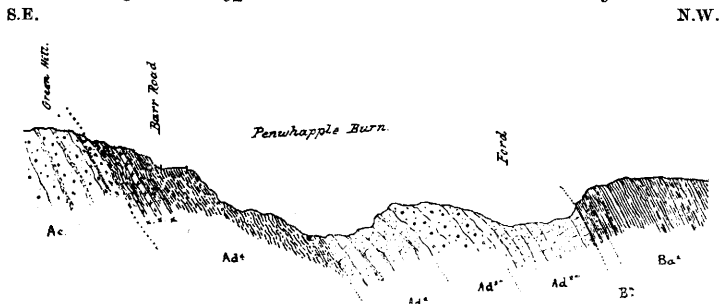
Everywhere along the boundary-line between the Benan Conglomerate and the Graptolitic-flagstone series, where the sequence is unbroken, we find an intermediate zone of highly fossiliferous strata, which, both petrologically and palæontologically, partakes of the characters of the underlying conglomeratic group and the overlying flagstone series, and which therefore it will be more convenient to treat of in this place before entering upon the description of the typical sections of the Graptolitic series.

(a) *Description of the Transitional Zone of Balclatchie.*

At the extreme north-western boundary of the continuous conglomeratic sheet of Benan and Milljoan it is crossed by the infant stream of Penwhapple, which has excavated a narrow gorge in its highest beds near the Assel road, between the grassy slopes of Knockgerran and Balclatchie, exposing a most instructive section of their junction with the basal beds of the dark Graptolitic flagstones and shales of the overlying series.

1. *Balclatchie Bridge* (fig. 14).—At the highway-bridge of Balclatchie, which there spans the gorge, and for about a hundred yards below it, the Benan Conglomerate is recognizable in all its charac-

Fig. 14.—*Typical Section near Balclatchie Bridge.*



Ba. Ardwell Graptolitic Shales and Flags.

a¹. Dark carbonaceous and iron-stained shales, with *Graptolites*.

(n) Basal zone of calcareous and carbonaceous shales, with *Climacograptus Scharenbergi*, *Lastograptus Harknessi*, and *Cryptograptus tricornis*.

Ad². Balclatchie Grits and Conglomerate.

d²ᵐ. Ashy gritstones and flaggy beds, fossiliferous.

d²ᶜ. Calcareous boulder conglomerate, with *Lingula canadensis*.

d²ᶜ. Green flaggy gritstones, calcareous, fossiliferous.

Ad¹. Balclatchie Shales.

Grey and green calcareous and nodular mudstones, highly fossiliferous — with *Barrandia*, *Remopleurides laterispinifer*, *Ampyx Hornei*, *Asaphus gigas*, *Siphonotreta micula*, *Dicranograptus tardiusculus*, &c.

Ac. Benan Conglomerate.

Coarse conglomerate and interbedded sandstones, with boulders of quartz and felsite.

*, *, *. Basaltic dykes.

teristic features. Boulders of quartz, granite and felstone, often of large size, are confusedly huddled together in a greenish matrix composed of a sandy or more or less ashy material, which weathers on the surface to a dull orange tint. Its highest beds are well exposed in some small cliffs that overhang the roadway to the north of the bridge, where they exhibit distinct evidence of their bedded nature in the visible arrangement of the rounded balls of white quartz and grey porphyrite in regularly parallel lines, and in the distinct alternation of coarse conglomeratic bands with others of a sandier texture. These all dip steadily to the northward, at an angle of from 50 to 60 degrees, and distinctly follow each other in unbroken sequence.

The highest beds of the conglomerate proper can be studied foot by foot in these cliffs. Towards their termination they become somewhat looser in texture, and the matrix of the rock grows more sandy. At their summit, where they are pierced by three small basaltic dykes of a most interesting character, they pass up conformably into an overlying group (the *Balclatchie Beds*, Ad) of calcareous shales and mudstones and flaggy grits, highly fossiliferous. The unbroken continuity of the sequence at this locality is easily demonstrated. The pebble-beds characteristic of the Benan Conglomerate below, and the shaly beds characteristic of the Balclatchie zone above, distinctly alternate with each other in a curious group

of passage-beds, in which the characteristic Balclatchie fossils may be collected from the shale bands lying below the terminal pebble-beds that mark the final disappearance of the peculiar physical conditions which gave origin to the Benan conglomerate.

Balclatchie Shales, Ad¹.—The lowest division of this overlying fossiliferous group is composed of about 40 feet of concretionary mudstones of a dark bluish-green colour, and excessively jointed. They are somewhat calcareous, usually effervescing upon the application of an acid, and weather down into shivery fragments, the joints of which are coated by the yellow oxide of iron. They are well exposed upon the roadside; but they are even better displayed in a small cliff on the opposite side of the stream-course, a few yards distant. In the cliff, however, and in the floor of the stream at its foot, they are but slightly weathered, and they compose a tough homogeneous mass, which flies into rough conchoidal fragments only after repeated blows of the hammer. These green mudstones (which resemble the greenish *Didymograptus*-mudstones at the base of the Benan Conglomerate in all their petrographical characters), contain a profusion of organic remains, generally fragmentary, but always in an excellent state of preservation. This spot has long been known to palæontologists for the abundance and beauty of its fossils; and the fauna of these green shales has been more completely worked out than that of any other single horizon (with the exception perhaps of the Craighead Limestone) in the Girvan region.

The more characteristic fossils obtainable here are:—

<i>Dicranograptus tardiusculus</i> , <i>Lapw.</i>	<i>Lasiograptus Harknessi</i> , <i>Nich.</i>
<i>Dicellograptus mollatensis</i> , <i>Carr.</i>	<i>Climacograptus Scharenbergi</i> , <i>Lapw.</i>
<i>Glossograptus Hincksii</i> , <i>Hopk.</i>	<i>Lingula attenuata</i> , <i>Sow.</i>
<i>Asaphus gigas</i> , <i>De Kay.</i>	<i>Acrotreta Nicholsoni</i> , <i>Dav.</i>
<i>Remopleurides Barrandii</i> , <i>Ether.</i>	<i>Leptæna corrugatella</i> , <i>Dav.</i>
<i>Theca simplex</i> , <i>Salt.</i>	

Balclatchie Grits and Conglomerates, Ad².—The small group of fossiliferous shales is succeeded immediately by a thicker set of sandstones and conglomerates of a most distinctive lithological character.

The matrix of these overlying sandstones is of a dark green tint, passing into a blackish-blue colour upon the weathered faces. Their lowest strata are flagstones (d^{2'}), each a few inches in thickness, and partly formed of coarse irregular grains of felspar &c., as if derived from the washings of a greenish porphyry or volcanic ash.

Here and there the beds are finer; but nowhere are the component grains of sufficient fineness to reduce the rock to the nature of a shale. It is, throughout, a coarse roughly bedded sandstone, breaking up into flake-like plates an inch or so in thickness, having the irregularly wrinkled or undulated bedding-faces characteristic of laminated dykes and volcanic gritstones.

These flaggy sandstones, which yield an occasional badly preserved Brachiopod or coral, pass up into several feet of a coarse green conglomerate (d^{2''}), which is excellently exposed in a small cliff on the left bank of the stream.

The matrix of this conglomerate is similar to that of the under-

lying sandstone, consisting of rounded fragments of felstone and quartz imbedded in a greenish dust. But it is, in addition, highly calcareous along certain laminæ, and presents that peculiar mode of weathering into concentric flakes so common among basaltic dykes. The included pebbles are of quartz and several varieties of volcanic rocks, and are collectively of the same general type as those of the underlying Benan Conglomerate.

Lying buried in the sandier part of the matrix, and often scattered through the coarsest part of the conglomerate itself, occur many poorly preserved fossils. The most frequent are corals and those Brachiopoda whose shells are composed of carbonate of lime, both of which groups are practically wanting in the hard Balclatchie mudstones below. The commonest forms are :—

Lindstroemia, several species.	Leptæna sericea, <i>Sow.</i>
Fistulipora favosa, <i>N & E.</i>	— transversalis, <i>Wahl.</i>
Strophomena corrugatella, <i>Duv.</i>	Bellerophon, &c.
Leptæna quinquecostata.	

The conglomerate passes upwards into a series of dark green ashy sandstones (d'''), identical in petrological character with those below, but generally thicker-bedded, and having about twice their vertical extent. They contain a few fossils of the same type as those of the underlying conglomerate.

These green gritstones are well shown in the bed of the burn, lying at a medium angle upon the ashy conglomerate, where an old hill-road fords the stream. Immediately beyond, they are succeeded by the thick masses of dark flaggy shales and mudstones which form the bed and bounding walls of the gorge for a long distance below this locality, and which compose the first member of the overlying Ardmillan Graptolitic series (Ba), which falls to be described in the following section of this memoir. At the junction of the two groups, however, occurs a peculiar transitional band which must here be noticed. It consists of a few feet of iron-stained shales, with seams of hard calcareous and concretionary rock. The shales contain abundant Graptolites of the species

Cryptograptus tricornis, <i>Carr.</i>	Diplograptus foliaceus, <i>Murch.</i> , &c. ;
Lasiograptus Harknessi, <i>Nich.</i>	

while the calcareous band yields a few examples of Brachiopoda, chiefly

Leptæna corrugatella,	Orthis calligramma, &c.
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We learn, therefore, that in this special locality the Benan Conglomerate becomes interstratified with fossiliferous mudstones at its summit; and what may be regarded as its final member, from a physical point of view, is a thin series of green gritstones, which are divided from the typical boulder-beds of the great conglomerate below by a group of fossiliferous shales. The general identity of the matrix and enclosures of the gritstones with those of the Benan Conglomerate is suggestive of the natural union of the gritstone group with the Barr or Stinchar series, rather than with the succeeding Graptolitic flagstones of the Penwhapple. The

dividing fossiliferous shales point in the same direction ; for petrographically they are almost identical with those of the *Didymograptus*-beds which *underlie* the great conglomerate, while they are very different from the hard flaggy Graptolitic shales of Penwhapple. As will be demonstrated in the sequel, the palæontological evidence is even more strongly in favour of the union of these gritstones and shales which together make up our group of the *Balclatchie Beds*, with the Stinchar or Barr group ; for the majority of the forms known from these beds are identical with those of the Craighad limestone.

This fossiliferous group of gritstones and shales is therefore placed, in our scheme (see Table, fig. 31, p. 661), at the summit of the Barr or Stinchar Series, which constitutes the first great division of the Girvan succession, and embraces the whole of the strata lying between the base of the Kirkland Conglomerate and the summit of these Balclatchie Beds.

2. *Burbae, &c.*—The line of boundary between the great sheet of Benan Conglomerate and Graptolitic flagstone, ranging from Balclatchie Bridge to the neighbourhood of Millenderdale, has been carefully searched by myself for traces of the Balclatchie Beds ; but such exposures as do occur are very fragmentary and unsatisfactory.

These highly distinctive and continuous sheets of strata are apparently separated from each other along the whole of this extent by an intermediate band of mixed character. Long tongues of hard gritstone and breccia run irregularly into the edges of the area of Graptolitic flagstones ; and irregular patches of concretionary shales and dark Graptolitic mudstones destroy the regularity of the margins of the area of the Benan Conglomerate.

Broadly speaking, this intermediate band is largely composed of the green grits and fossiliferous mudstones of the Balclatchie Beds. On the Doon Hill, they lie apparently in a sharp synclinal in the conglomerate itself, while the fossil-bearing shales are again exposed in the roadway between the Dhu Craig and the water of Assel. At the angle of the same road about half a mile south-west of the farmstead of Balclatchie, the green fossiliferous gritstone and conglomerate are seen, containing a few shells, associated with green concretionary and dark laminated Graptolitic mudstones, and clearly interposed between the Benan rock of the east bank of the stream, and the sheet of flagstones seen in the numerous quarries opened for repairing the roadway.

Between this locality and the farmhouse of Pinmery there are numerous exposures of the Balclatchie Beds. In the steep slopes of the Assel, about a quarter of a mile west of Pinmery, the highest beds of the Benan Conglomerate are seen to the north of the Tramitchell fault in several quarries and natural exposures. They are harder than usual, and the matrix is more of the nature of a coarse greywacke. The included boulders are of great size, and are scattered irregularly through the mass of rock, in which few small pebbles are visible. Immediately above them the concretionary and shaly Balclatchie mudstones are seen in many isolated spots. They are succeeded at once by coarse green partly conglomeratic

gritstones, which pass upwards into the basal beds of the Graptolitic flagstones that fill the extended area to the north.

A short distance to the south-west we find a magnificent exposure of these conglomeratic grits near the lime-quarries of Tramitchell. The extended area of Graptolitic flagstone is there bounded to the southward by a band of coarse pebbly grit, about 50 feet in thickness, which extends in an unbroken line from Pinery to the north flank of Dalfask Hill, a distance of more than a mile and a quarter.

At its eastern extremity it is seen in a shattered state in the roadside quarries about a hundred yards from the lime quarry. It there consists of a mass of sandy gritstones filled with small pebbles of quartz, greywacke, and various species of igneous rocks, and it is associated with distinctly bedded greywackes and shales of the usual type. Fossils are procurable with difficulty, mainly *Leptæna sericea*, with a few Lamellibranchiata and fragments of Encrinites.

In the road-side close to the farmhouse of Barbae the grit is well exposed to view in the hill-face and roadway. It there abounds in fragments of quartz, and, except for its decidedly gritty matrix, has few points of resemblance to the typical Balclatchie grit. It contains a few fossils in some shaly seams at its summit. *Leptæna*, *Bellerophon* and *Ctenodonta* were here collected by myself.

At its westernmost termination the grit is exposed in some old quarries west of the Dalfask burn. In this locality it is identical in composition and texture with the Barbae bed, but is weathered to a greyish yellow tint, and is apparently more fossiliferous than usual, containing many fragmentary examples of *Leptæna*, *Lindstroemia* and Encrinites.

Crossing the broad sheet of Benan Conglomerate exposed in the hill of Dalfask and the valley of the Assel, we again come upon the Balclatchie transitional beds on the ridge of Daldowie Hill. They occupy their normal place between the Benan Conglomerate and the great mass of the Graptolitic flagstones, which here stretch in unbroken mass for many miles southwestward, across the lower valley of the Assel, into the heart of the igneous region of Lendal Water. The numerous exposures of the transitional beds shown upon the hill-face west of the mountain-road from Pinery to Minuntion present us with phenomena identical with those afforded by the corresponding geographical band between Balclatchie and Pinery. The highest beds of the Benan Conglomerate are gritty and abound with quartz pebbles, varying in size from that of a bullet to that of a man's head. These beds are repeated in anticlinal folds again and again; and in the synclinals between them occur the concretionary and Graptolitic mudstones and the coarse green sandy rocks of the Balclatchie Beds. In one or two spots the shales, which often weather to a yellowish drab colour, afford many small shells, of the general type of those of Balclatchie, such as *Strophomena corrugatella*, Dav., *Leptæna sericea*, Sow., together with *Ctenodonta* and a form of *Ampyx*.

3. *Ardmillan Braes*.—The numerous sections of the Balclatchie group we have last noticed are all greatly deficient in recognized organic remains. In all probability this is mainly due to the

fact that they lie out of the usual track of fossil-collectors. But, with the exception of the thin seams on Daldowie Hill, few of the localities would repay an extended study; for fossils, though certainly present, seem generally to be rare.

In the fine exposure of the same beds near the shore at Ardwell, next to be described, fossils are remarkably abundant, and are specifically even more crowded than in the typical shales of Balclatchie Bridge.

The great mass of Benan Conglomerate, which reposes upon the igneous and metamorphic rocks of Penbain and the Grey Hill, and stretches in a continuous sheet from Kennedy's Pass to the rugged mound of the Byne Hill, plunges at a steep angle below the great mass of Graptolitic flagstones of Ardwell shore. The line of junction between the conglomerate and flagstones is obscured for the greater part of its extent; but for a limited distance about the centre of its range the intermediate Balclatchie Beds are seen in some old quarries in the hill-face above Ardwell farm, and in the steep burn-course of the little stream which passes the ancient castle of Ardmillan.

In the old road which ascends the heights southeastward from the farm of Ardwell, the Graptolitic flagstones are seen striking from S.W. to N.E., and dipping at a steep angle seaward. On the heights above, the Benan Conglomerate is easily identified, having all its usual characters, and coinciding in its range with the more recent Graptolitic flagstones below. Midway between these two exposures, and thus occupying their usual intermediate geographical and geological position, the green concretionary mudstones of Balclatchie are visible in several quarries, trending in precisely the same general direction as the conglomerate and flagstones which enclose them. Some small streamlets which run past the quarries have trenched the superficial coating of the hill sufficiently to allow us to make out the details of the succession from the fossiliferous mudstone into the heart of the great Conglomerate.

Commencing at the summit of the section, we notice that some 40 or 50 feet of the Benan Conglomerate are exposed. The matrix has the usual gritty character of the upper beds of the formation, and shows the normal preponderance of porphyrite and quartzite pebbles.

In immediate contact with the conglomerate, but dipping almost vertically in the opposite direction, occur some 20 feet of coarse well-bedded gritstones, with a greenish grey interior, but weathering to a purplish tint upon their edges. These are succeeded by a slightly greater thickness of calcareous sandstones, abundantly fossiliferous upon several horizons. They contain *Remopleurides dorsospinifer*, *Asaphus gigas*, *Staurocephalus globiceps*, *Phacops Brongniarti*, *Orthis calligramma*, *O. Actonica*, *Leptæna tenuicincta*, *Murchisonia*, and all the characteristic Balclatchie fossils.

After a short interval of concealment we reach the green concretionary mudstones, of which 60 or 70 feet are exposed in the quarries and in the natural sections. In their mineralogical characters they are identical with the shell-bearing beds that follow immediately upon the Benan Conglomerate in our typical exposure at Balclatchie

Bridge, having the same concretionary structure, and being equally difficult of disintegration under the hammer. The fossils, too, are preserved precisely in the same manner; the majority are found in perfect relief, the chitinous forms with highly polished surfaces, and the Testacea with their shells often beautifully preserved.

The commonest forms that meet the eye of the collector in these shales are identical with those of the green mudstones of Balclatchie, The following are especially numerous :—

Theca reversa, Salt.
Bellerophon acutus.
Modiolopsis, sp.
Leptæna tenuicincta.
— *sericea*.

Strophomena, sp.
Rhaphistoma, sp.
Dieranograptus tardiusculus.
Didymograptus moffatensis.
Cyclonema crebristria.

The Graptolitic flagstones of Penwhapple are not exposed at this locality, with the exception of the basal calcareous and carbonaceous band, which yields its usual *Lasiograptidæ* in good preservation.

The relation of the fossiliferous Balclatchie Sandstones to the Benan Conglomerate at this locality is presumptive of a dislocation between the two: and if the natural sequence contains the same members here as at Balclatchie, the beds here in contact with the conglomerate must be the highest beds—the fossiliferous mudstones being the lowest strata of the transitional groups here exposed, and owing their great thickness to their being arranged in anticlinal form. The hiatus in the succession would naturally be filled by the Graptolitic mudstones, over which follow the shell-bearing gritstones in their proper sequence.

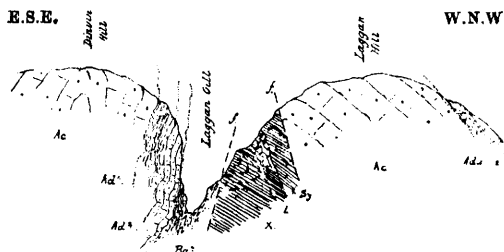
If this be the true interpretation of the visible phenomena, it follows that the shell-bearing gritstones should be repeated between these quarries and the Graptolitic flagstones visible in the roadway, or must be again cut out by a fault. That the latter supposition is in all probability the correct one is evident from the fact that where the sequence is unbroken, a quarter of a mile to the westward, it is identical with that at Balclatchie, as is also the case in Ardmillan Burn about half a mile further to the east.

4. *Ardmillan Burn*.—In the steep and narrow gorge excavated by the little burn of Ardmillan a continuous section is laid bare from the Benan Conglomerate into the heart of the Graptolitic flagstones. The Balclatchie beds themselves yield many of the same fossils as those found at Ardmillan Braes; but the phenomena they present afford us little worthy of notice as respects the stratigraphy of the group.

5. *Laggan Gill*.—In the narrow glen which separates the two masses of Benan Conglomerate that cap the points of Laggan Hill and Glendrissoch, the Balclatchie Beds are displayed in the banks of the small streamlet which passes the old hamlet of Laggan.

The section here is, in many respects, a most remarkable one. The structure will be understood from the accompanying section (fig. 15). The Balclatchie shales and gritstones are seen in inverted position in the cliffs to the west of the little gorge, and yield a few of the usual fossils, which, however, are procurable with

Fig. 15.—Section at Laggan Gill.



Ba². Basal zone of Graptolitic flagstones—soft shales, with *Lasio-graptus*, *Cryptograptus*, *Trachyderma*, &c.

Ad². Balclatchie grits and flagstones.

Ad¹. Balclatchie mudstones, much broken.

Ac. Benan Conglomerate.

Ballantrae Rocks:—

Sy. Syenitic rock.

L. Calcareous rock shattered and altered.

* Altered breccias.

difficulty. This is nevertheless by no means the case with the peculiar transitional zone at the summit of the group, which occurs here in its normal position at the base of the Graptolitic flagstone series. Its strata, although greatly folded, are crowded with the characteristic Graptolites and Brachiopoda in a state of exquisite preservation.

The commonest forms are *Cryptograptus tricornis*, Carr., *Lasio-graptus Harknessi*, Nich., *Climacograptus bicornis*, Hall, *C. Scharenbergi*, Lapw., *Diplograptus rugosus*, Emm., *D. foliaceus*, Murch., together with species of *Trachyderma*, *Cythere*, &c. &c.

This Balclatchie band is prolonged to the south-eastward of Laggan Gill, along the northern margin of the conglomeratic area of Dinvin and Dalfask, into the neighbourhood of Barbae and Tramitchell, where it has been noticed already.

6. *Dow Hill*.—Upon the inlier of Dow Hill (see map, Pl. XXV.) the Balclatchie mudstones, which there repose in their natural place upon the Benan Conglomerate, have yielded to the persevering researches of Mr. Robert Gray a large suite of fossils, identical with those of the typical locality and of Ardmillan Bracs. The same Balclatchie zone is met with in a corresponding position at several spots on both margins of the Pinmore synclinal, while the overlying transitional seam (Baⁿ) occurs at various localities within the same area, and is abundantly fossiliferous. It is needless to enter into further details of these exposures.

Summary.—The strata which next fall to be described are the Graptolitic Flagstones and Shales of Ardwel and Penwhapple. These, however, are so distinct in their lithological and palæontological features from the rocks already noticed, that it is impossible to place them in the same systematic group. We are therefore

forced to regard the first major formation or division of the Girvan Succession as being terminated above by the final zone of the Balclatchie Beds last described, the overlying Graptoliferous flagstones and shales of Ardwell forming the first member of a second and succeeding division.

The facts adduced in the preceding pages render it absolutely certain that the great Benan Conglomerate (Ac), which we originally selected as our general horizon of reference, is everywhere *underlain* by the Stinchar Limestone (Ab), and its associated basal conglomerate and sandstone of Kirkland and Craighead, and everywhere *overlain* by the transitional zone of Balclatchie (Ad). From the base of the Kirkland Conglomerate to the summit of the Balclatchie Beds, the sequence is demonstrably continuous; while the various fossiliferous subformations are united by a general community of organic remains. We therefore regard the strata within these limits as collectively constituting the first recognizable major division or formation in the Girvan Succession.

To this primary division we assign the title of the *Barr Series*, after the name of the village where its strata are most effectively displayed to the investigator. The entire division may be broadly defined as a series of conglomerates and boulder-beds, relieved by zones of limestone, sandstones, and fossiliferous shales. Its component subformations, as we have seen, vary greatly in thickness, even within the limits of the Girvan region; but they everywhere retain the same stratigraphical interrelations, lithological features, and characteristic organic remains.

The ascending order among the several members of the Barr Series is given in the following Table:—

A. BARR SERIES. (700 to 1000 feet.)

Aa. Kirkland or Purple Conglomerate and Sandstone	30-200 feet.
Ab. Stinchar or Craighead Limestone Group	100-150 "
Ab ¹ . <i>Orthis-confinis</i> flagstones.	
Ab ² . <i>Maclurea</i> -beds.	
Ab ³ . Compact Limestones.	
Ab ⁴ . <i>Didymograptus</i> -shales.	
Ac. Benan or Green Conglomerate	500-600 "
Ad. Balclatchie Beds	80-100 "
Ad ¹ . Balclatchie Mudstones.	
Ad ² . Balclatchie Grits and Conglomerate.	

(b) *Description of the Typical Section of the Graptolitic-flagstone Series of Ardmillan Shore.*

As we have already pointed out, the great Barr or Stinchar series, which is terminated above by the fossiliferous zone of the Balclatchie beds last described, is bounded everywhere on its northern or upper margin by a group of flagstones which occupy collectively a continuous area equal in geographical extent to that filled by the Stinchar series itself. The ground occupied by these flagstones extends northward from the margin of the Benan Conglomerate to a line of fault which ranges from the coast-line south of the town of Girvan across Saugh Hill inland to the Old-Red-Sandstone heights

of Hadyard and Garleffin. Throughout this extended area these beds consist essentially of thin-bedded flagstones and shales, with occasional zones of sandy and pebbly grit. Where they become carbonaceous they contain an abundance of Graptolites, generally, however, of few species. A few calcareous seams are met with at intervals; and these yield fragmentary Trilobites, Cephalopoda, and Brachiopoda. The whole of the beds are thrown into innumerable folds and contortions, are frequently inverted, and are much dislocated by local faults. But the lowest beds everywhere distinctly repose conformably upon the great sheet of Benan Conglomerate, from which they graduate through the transitional zone of the Balclatchie Beds. This fact, as we have shown, holds good, not only with respect to the main mass of conglomerate itself as seen at Balclatchie, but also in the many disconnected exposures of the same rock in the hills of Barlae, Laggan Gill, and in the terminal strip of Benan Conglomerate which descends from the Ballantrae rocks of Grey Hill, and runs out to sea in the headland of Kennedy's Pass.

It is in the last of these localities that the succeeding Graptolitic series is most completely exposed to the inspection of the stratigraphist and palæontologist. Its strata constitute the floor of the old raised shore-terrace of Ardmillan and Woodlands, and are truncated obliquely by the sea along the rocky coast-line between Kennedy's Pass and the hamlet of Shalloch, for a distance of about three miles.

An almost continuous section of the beds is laid bare along the shore throughout the whole of this extent. The strata run out to sea in a low platform which is never entirely covered by the waves and is wholly exposed to the investigator at low tide.

The main highway from Girvan to Ballantrae is carried along the seaward edge of this platform; so that the student of the geology of the district enjoys exceptional advantages in the study of the flag-like Graptolitic deposits of this locality.

The most conspicuous object upon this raised platform is the ancient house of Ardmillan, the seat of the proprietor of the neighbouring estate. It lies at the foot of the wooded slopes of Mains Hill, and about the centre of the area occupied by the flagstone group. This circumstance has suggested to me the title of Ardmillan Group as a collective name for the flagstone series, a title which marks definitely the special locality where its strata are most satisfactorily exposed.

A section drawn transversely across the rocks of this area displays the succession shown in the accompanying figure (fig. 16). The elevated heights of Mains Hill and Grey Hill are formed of the bedded and intrusive rocks of the Ballantrae region—syenitic, dioritic and felspathic. Upon these, inclined at a steep angle, leans the great sheet of Benan Conglomerate and its associated Balclatchie beds, extending to the shore-line in the cliffs of Kennedy's Pass. This occupies all the higher portions of the northern slopes of these hills, and ranges downwards to the edge of the cultivated grounds of Ardmillan and Ardwell.

1. *Ardwell Shales and Flags*.—The Conglomerate series is succeeded

immediately by the basal division of the great overlying Graptoliferous series. The lowest beds of this division are well exposed in several natural and artificial excavations along the line of section, in a magnificent and unbroken cliff-section between the farm of Ardwell and the rocks of Kennedy's Pass, and in the sides of the narrow gorge dug out by the little stream of Ardmillan itself.

The inferior zones of this lowest division of the Flagstone group may be seen dipping off the Balclatchie Beds in the gorge of Ardmillan and in the slopes of the neighbouring heights, while they agree everywhere in strike and inclination with the underlying group.

The middle beds are best exposed in the coast-section south of Ardwell, where they can be studied foot by foot in the continuous exposures washed by the sea-waves. The lowest beds are thin-bedded shales, of a dark grey colour, with a few seams or ribs of hard grey rock. They are more or less carbonaceous, and weather with a rusty exterior. They yield a few Graptolithina, chiefly *Diplograptus foliaceus*, Murch., *D. pristis*, His., *D. rugosus*, Emm., *Climacograptus bicornis*, Hall. Higher up, the rocks become rapidly coarser and more flag-like in their character, until in their highest zones near the farm of Ardwell they may be described as a series of dark-grey flagstones from four to six inches in individual thickness, separated by partings of dark grey shale. The same fossils are here met with as in the lower zones, and, in addition, *Dicranograptus ramosus*, *Corynoides calycularis*, *Eculiomphalus Bucklandi* and an occasional Brachiopod. The highest zone is formed of striped shales crowded with hosts of *Climacograptus caudatus* and *Diplograptus rugosus*. The exposure of these beds is terminated suddenly by the sandy bay of Ardwell; and the rocks which next make their appearance are the lowest zones of the succeeding group.

Although the oblique section of the Ardwell shales and flags upon the coast here between Kennedy's Pass and the farmland of Ardwell exceeds a mile in length, the actual transverse breadth of the zone is less than one fourth of a mile, so that at their average inclination of about 70° or 80° the thickness of the Ardwell Beds here exposed cannot exceed 1000 feet. It is more than doubtful, however, if the entire thickness of the Ardwell Beds is here developed, as the hiatus in the bay probably marks the position of a line of fault that cuts out a group of flaggy sandstones and grits (Cascade Beds, compare p. 606), which appear to constitute the higher parts of the Ardwell Beds in the interior of the country.

The Ardwell Beds, as seen in this typical locality, are much more intensely hardened than is generally the case in the inland sections, and fossils are rarer and more difficult of extraction. The group is well characterized, however, by its peculiar petrological features. Wherever a transverse section of beds is laid open, the strata are seen to be normally formed of thin seams of alternate grey and black or blue laminae. This gives to the beds a somewhat striped appearance, which is most characteristic. The quantity of carbonaceous matter present is comparatively large; and iron is sufficiently

abundant to cause the entire series to weather to a deep rusty colour.

2. *Whitehouse Beds*.—Crossing the sandy floor of the small bay of Ardwell, already referred to, where there is a break in the section of about 100 feet in calculated thickness, we enter next upon a group of strata of a totally distinct petrological character. This new group has here a collective thickness of about 200 feet; and its strata are easily studied at many points along the coast-line between Ardwell and Shalloch Mill. Their entire thickness, however, is shown only in the present locality, along the shore-line between Ardwell Bay and the old ruin of Whitehouse, which is built upon them, and after which I have named them.

These Whitehouse Beds consist of a series of shales and mudstones, of colours varying from bright red and purple to greyish green and black, and showing numerous intercalary ribs and zones of grey flagstone. But by far the most characteristic feature of the formation is the frequent presence of impure calcareous bands or “cement-stones,” crowded with fragmentary Brachiopods and Trilobites.

The entire group falls very naturally into two main divisions—a *lower* division of grey shales and striped flagstones, and an *upper* division of purple and green mudstones.

Lower Whitehouse Beds (Bb¹).—The basal band of this subgroup is formed of striped grey and green somewhat carbonaceous shales, much softer than those of the underlying *Ardwell* group, from the terminal beds of which they are divided by the sandy beach of Ardwell Bay. They contain abundant examples of *Dicellograptus Forchhammeri* &c.

The middle subdivision is characterized as a whole by the presence of numerous ribs of calcareous matter, filled with small pebbles, and yielding a few fragmentary Brachiopoda. These calcareous zones are imbedded in masses of barren greenish-grey flagstones, separated by striped shales destitute of all traces of organic remains.

The commonest fossils I have been able to collect from these cement-beds are:—

Leptæna transversalis.
—— *sericea*, Sow.

Orthis calligramma.
Strophomena, sp.

As we ascend the succession the hard flaggy ribs become more closely approximated, but otherwise the character of the beds remains essentially unmodified for about 100 feet of thickness.

They are followed by a final group of some 50 or 60 feet of strata of a most peculiar character. These consist of soft green mudstones, filled with a multitude of hard siliceous ribs, about an inch in thickness and one or two inches apart. The action of the sea-waves has dug away the soft mudstones to some depth, leaving the intervening hard ribs projecting in long jagged parallel lines upon the floor of the sea-platform, giving a most striking appearance to the little group as here exhibited.

Upper Whitehouse Beds (Bb²).—Next succeeds the *Upper* and most

characteristic division of the Whitehouse beds. It consists of about 80 feet of brightly coloured mudstones, shales, flags, and calcareous beds, remarkable not only for their unique petrological features, but also for the variety and abundance of their organic remains.

The lowest beds of the division consist of 15 feet of dark-green mudstones, filled with lines and bands of purple shale. They are succeeded at once by a thickness of about 30 feet of soft mudstones of a brilliant purple colour. These are soft and easily disintegrated, and have here been worn away by the sea-waves into a deep hollow between the underlying and overlying intractable grits and flagstones. They are totally barren of fossils throughout. So far as can be made out by piecing together the greatly shattered beds at this spot, they pass insensibly upwards into a particoloured zone of mudstones, about 15 feet thick, purple and green like those at their base, and equally barren of organic remains.

Finally we have a zone of 20 feet, hard flaggy beds, of which only disconnected patches are visible at this locality. These consist of flaggy-looking and sandy beds, which stand up on edge amid the sea-waves as several prominent bosses, and are only accessible at low tide. They are almost wholly composed of platy shales and flagstones, more or less calcareous, striped by thin seams of carbonaceous matter, and including several highly fossiliferous seams crowded with fairly preserved Trilobites and Graptolithina.

The commonest forms I have procured from these beds at this locality include:—

Dionide Lapworthi, *Eth. jun.*
Cyclopyge rediviva, *Burr.*
— armata, *Barr.*
Dindymene, sp.
Agnostus perrugatus, *Barr.*
Turrilepas Peuchii, *Eth. jun.*

Dicellograptus Morrisi. *Hopk.*
— complanatus, *Lapw.*
Diplograptus socialis, *Lapw.*
Climacograptus tubuliferus, *Lapw.*
Dicryonema.
Ganocladium.

This fossiliferous zone is succeeded immediately by the thick-bedded flagstones of the overlying Barren-flagstone group (Bc), to be noticed later on. Only a few feet, however, of these overlying flagstones are here exposed to view, and their description is best deferred until we have completed our study of the distribution of the Whitehouse Beds along the coast-section of this neighbourhood.

It will be apparent on a study of the map (No. 3, Pl. XXV.) that these Upper Whitehouse Beds, with their remarkable seams of purple shales and ribbed mudstones, can be followed as a continuous band running along the general line of the coast from Whitehouse to the mouth of the Byne-Hill Burn, for a distance of about a mile. They are much interfered with locally by small dislocations; but the continuity of the band is never actually interrupted, throughout its entire length.

At the head of Port Cardloch, close to the lodge-gate of Ardmillan House, some of these local dislocations are well shown; and a thin set of hard green conglomeratic grits makes its appearance at the base of the series, forming a conspicuous vertical wall of rock.

After crossing the cultivated angle of Woodland Point, we again

come upon the band of purple and green mudstone in Woodland Bay. Here only a few feet of the ribbed shales are discernible, projecting from the sand of the beach; but there seems to be a fairly unbroken section from these ribbed beds into the basal beds of the succeeding Barren-flagstone group, through the purple mudstones and *Dionide*-seams, though only a few fragmentary Graptolites are obtainable among the shattered and sodden strata.

For the next quarter of a mile the Whitehouse Beds are generally hidden from sight below the sandy beach of Woodland Bay; but where they next put in an appearance, viz. in Myoch Bay, upon the shore-line near Shalloch Mill, we have by far the most complete and satisfactory exposure of their upper zones in the Girvan district.

The geographical relations of these beds upon the ground are given in the following sketch plan (fig. 17); and the interrelationship of the various component zones will be evident upon a study of the accompanying section.

Myoch Bay.—The deepest strata shown in the continuous section laid open from S. to N. across the exposure in the floor of Myoch Bay, are the coarse, thick-bedded and gritty sandstones recognized by us in the faulted patch at Port Cardloch. Next succeed the green shales, with ribs of harder and gritty flags. Of these at least about forty feet are exposed, forming some jagged reefs to the right of the little grassy headland south of the bay.

Above follows the first band of the Upper Whitehouse group, consisting of about 15 feet of soft green mudstones and shales, with lines of purple mudstone. These are easily followed for some distance round the corner of the little headland to the south, much interfered with, however, by numerous longitudinal and transverse faults.

The central parts of the bay are wholly occupied by the Upper Whitehouse Beds. To the S.E. lies the zone of purple mudstones. These are bent into innumerable folds and wrinkles, and are dug out into the usual broad hollow. It is difficult to estimate their thickness; but this cannot be more than about 30 feet. They are followed to the north by the second transitional zone of green mudstones with purple seams, which passes upwards into the fossiliferous division that terminates the banded series. These Upper transitional beds have an estimated thickness of about 20 feet.

The final or fossiliferous subgroup is greatly contorted and broken; but when carefully mapped in detail the following succession is easily made out:—

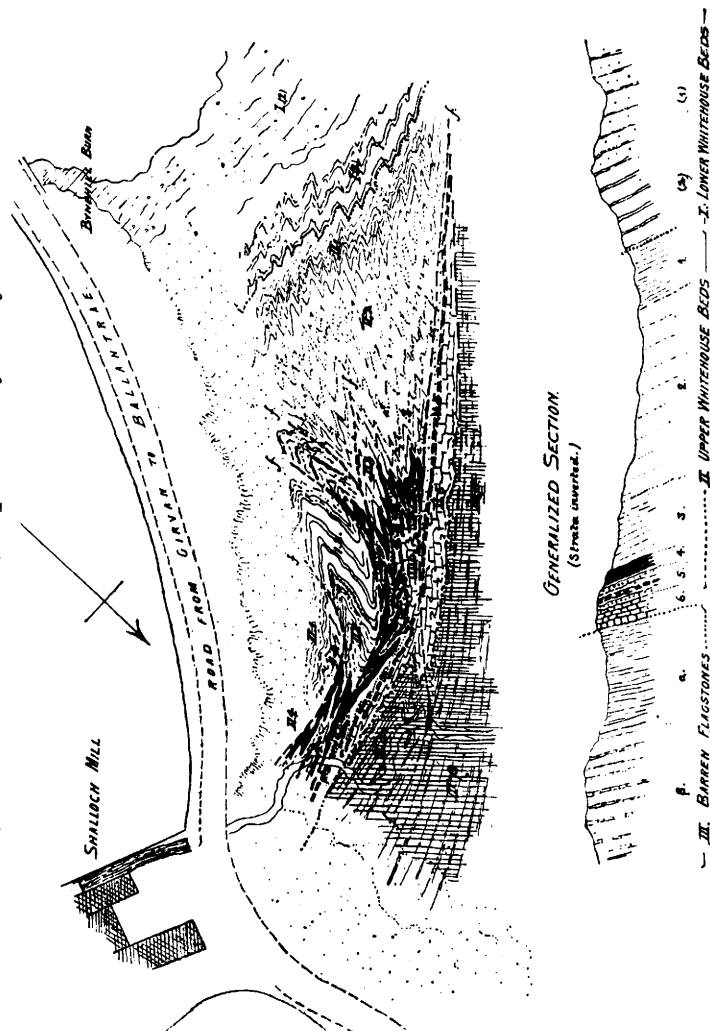
(1) *Dicellograptus complanatus* zone. Black shales, highly carbonaceous, with a few seams of grey mudstone and calcareous grit, crowded with Graptolites (5 feet).

Diplograptus socialis, Lapw., is the commonest form, and occurs in hosts. Less frequent are the forms named in the following list:—

Climacograptus tubuliferus, Lapw.
Dicellograptus complanatus, Lapw.
—— *Morrisi*, Hopk.

Theca triangularis, Portlock.
Lingula.

Fig 17.—Plan and Section of Exposure at Myoch Bay.



- III. Barren Flagstones.
 β. Flaggy grey shales with ribs of grey flagstones.
 α. Thin shales and mudstones, with *Nematolites Grayii*, *Dicellograptus Morrisi*, &c.
 II. Upper Whitehouse Beds.
 6. Nodular, grey, calcareous mudstones, highly fossiliferous—*Trinaculus*, *Allemus*, *Agnostus*, *Dionide*, &c. (*Dionide*-band).
 5. Flaggy shales, with hard calcareous ribs—*Dictyonema*, *Gaenocladium*, &c. (*Dictyonema*-bed).
 4. Black carbonaceous shale, crowded with Graptolites—*Dipl. socialis*, *Dicellograptus*, *D. complanatus* (*D. complanatus*-bed).
 3. Transitional zone of banded purple and green mudstones and shales.
 2. Purple mudstone, barren of fossils.
 1. Transitional zone of banded purple and green mudstones and shales.
 I. Lower Whitehouse Beds.
 (2). Green shales and mudstones, with ribs of hard grey flagstone.
 (1). Grey and green shales, flags, and thick-bedded grits.

(2) *Dictyonema*-zone.—Hard flaggy shales (9 feet), with ribs of grey calcareous rocks. In certain zones these beds contain an abundance of *Dictyonema*, together with numerous fragments of Phyllopora, Lingulidæ, and Diplograptidæ.

The characteristic forms are *Dictyonema*, *Ganocladium*, *Lingula*.

(3) *Dionide*-beds.—Finally we have a thickness of about 6 feet of mudstones, containing such a large proportion of calcareous matter that in places they rather deserve the title of impure nodular limestones. They afford a large and varied association of fossils, some of which are beautifully preserved.

The commonest collected from these beds by Mrs. Gray or myself include :—

<i>Trinucleus seticornis</i> , <i>His.</i>	<i>Murchisonia</i> .
<i>Asaphus</i> , <i>sp.</i>	<i>Bellerophon</i> .
<i>Illænus Bowmanni</i> , <i>Salt.</i>	<i>Ctenodonta</i> .
<i>Agnostus perrugatus</i> , <i>Barr.</i>	<i>Orthonota</i> .

Before terminating the description of the Whitehouse-Bay beds at this locality, mention must be made of the section visible in the lower reaches of the Byne-Hill Burn, which empties itself into Myoch Bay a few yards to the south-west of the locality we have last noticed in detail. These beds are exposed in the stream-course near its mouth, and are of the same general character as those of the majority of the Whitehouse group, to which they unquestionably belong; but the absence of definite ribs of flagstone from among the soft blue shaly mudstones of which these Byne-Burn beds are made up, will not allow us to parallel the little group satisfactorily with any of the zones already described. In the Byne-Hill Burn they consist of about 100 feet of soft blue flaggy mudstones, arranged in thin beds, and striped with numerous seams of carbonaceous matter.

They contain some well-preserved Graptolites, viz. :—

<i>Leptograptus flaccidus</i> , <i>Hall.</i>	<i>Diplograptus quadrimucronatus</i> , <i>Hall.</i>
<i>Pleurograptus linearis</i> , <i>Carr.</i>	— <i>foliaceus</i> , <i>His.</i>
<i>Dicellograptus Morrisi</i> , <i>Hopk.</i>	<i>Climacograptus tubuliferus</i> , <i>Lapw.</i>

The Myoch-Bay and Byne-Hill-Burn exposures are the final exhibitions of the Whitehouse Beds in this locality, the strike of the strata carrying them inland beneath the cultivated flats of Shalloch and Ballochmyle.

3. *Barren Flagstones of Shalloch Mill.*—The band of purple and grey fossiliferous mudstones of the Whitehouse Beds last described is succeeded to the northward, throughout the whole extent of its range from Whitehouse to Myoch Bay, by a thick series of shales, flagstones, and greywackes of a dull greyish-green colour, generally destitute of all trace of unequivocal fossil remains (III., fig. 17). The breadth of this Barren-flagstone group upon the ground at its widest horizontal extension (as near Woodland Point) is about 200 yards. As the beds are nearly perpendicular, this would give the group an approximate thickness of about 500 feet.

For the first 50 feet of their thickness the Barren-flagstone strata
Q. J. G. S. No. 152.

consist of pale-green mudstones and very thin flags, having the same general dip and strike as the underlying Whitehouse Beds, out of which they graduate conformably. These shaly beds contain frequent examples of the enigmatical fossil *Nematolites Grayii*, a form that preeminently distinguishes this group throughout the Girvan region.

As we ascend in the succession, thick beds of flagstone gradually make their appearance among the mudstones, with which they agree exactly in their colour and composition, but are somewhat coarser and more compact in texture. At first these ribs of flagstone occur regularly at intervals of about 3 feet, and are usually not more than a foot in thickness. When we have overpassed the central line of the group, however, the ribs rapidly increase both in abundance and in individual thickness, so that finally they become, physically, much more important than the mass of soft shales and mudstones in which they are intercalated. Many of these flaggy beds attain here a thickness of from 3 to 4 feet, while the intermediary shales have dwindled down to a few inches. Near the summit of the group, however, as exhibited along the coast-line, the flags again become thinner and less conspicuous, and the shales regain their normal importance in the succession.

This band of Barren Flagstones forms a conspicuous feature on the surface of the coast-section, both eastward and westward from their typical exposure in Woodland Bay. They are well displayed in both sides of Port Cardloch, following immediately upon the fossiliferous zone of the Whitehouse Beds, their hard ribs standing up perpendicularly on the rugged coast-platform, divided from each other by the deep grooves from which the soft intercalary shales have been eroded. In Whitehouse Bay also they are shown in the same geological position; but only a few feet of their lowest zones are exposed, even at low water.

They form two small islands in Woodland Bay, in which their hard, thick-bedded central beds are prominently shown.

In the fine exposure formed by the rocky floor of Myoch Bay their basal beds of soft green mudstones are seen following at once upon the fossiliferous calcareous beds of the Whitehouse group. Here, too, they yield an abundance of the characteristic fossil *Nematolites Grayii*, Lapw., and an occasional example of *Dicellograptus*, as at Woodland Point.

Between Shalloch Mill and the rock of CraigsKelly the coast-line turns to the northward, crossing the line of strike of these beds. The central beds of the group are seen in one or two spots projecting from the sandy floor of the bay, and ranging thence into the interior of the country, where their geographical distribution will be described in subsequent paragraphs of this memoir.

It will be apparent from a study of the map (Pl. XXIV.), that we have now described all the strata visible along the coast-platform between Ardwell and Shalloch, with the exception of those occurring at the extreme point of Woodland promontory, the island of CraigsKelly and its neighbours, and the little point at Shalloch Forge. It

will be shown later on that these outer strata have no connexion with the Ardmillan Graptolitic series, but that they consist of massive boulder-beds and *Pentamerus*-limestones of much later geological age. They are separated from the Barren Flagstones by a gigantic strike-fault ranging from Shalloch Forge to Whitehouse Bay. The evidences of this dislocation will be given in the sequel.

In the Stinchar conglomeratic group, and the overlying Graptolitic Flagstone series, as developed along the coast-line between Kennedy's Pass and Craigs Kelly, we have therefore at this stage of our inquiry recognized the following succession in ascending order:—

(A) *Stinchar or Barr Series.*

Ac. Benan Conglomerate of Kennedy's Pass.

Ad. Balclatchie beds of Ardmillan Braes, 100 feet.

(B) *Graptolitic Flagstone or Ardmillan Group.*

Ba. Ardwell Beds, at least 1000 feet.

1'. Thin-bedded shales and mudstones, striped, carbonaceous, iron-stained, with *Diplograptus rugosus* and *Climacograptus bicornis*.

2'. Thicker-bedded shales and flagstones, striped, ironstained, with occasional gritty seams—*Diplograptus foliaceus* and *Diplograptus pristis*, *Corynoides calycularis*.

Bb. Whitehouse Beds, 300 feet.

1. Striped flags and shales with zones of cement-stone—*Leptana sericea* and *Dicellograptus Forchhammeri*.

2. Variegated mudstones and calcareous shales, with *Dionide*, *Trinucleus*, *Asaphus*, *Agnostus*, *Cyclopyge*, *Diplograptus flaccidus*, *Pleurograptus linearis*, *Diplograptus quadrimucronatus*.

Bc. Barren Flagstones, 500 feet.

1. Green shales with occasional zones of flagstones—*Nematolites Grayii*.

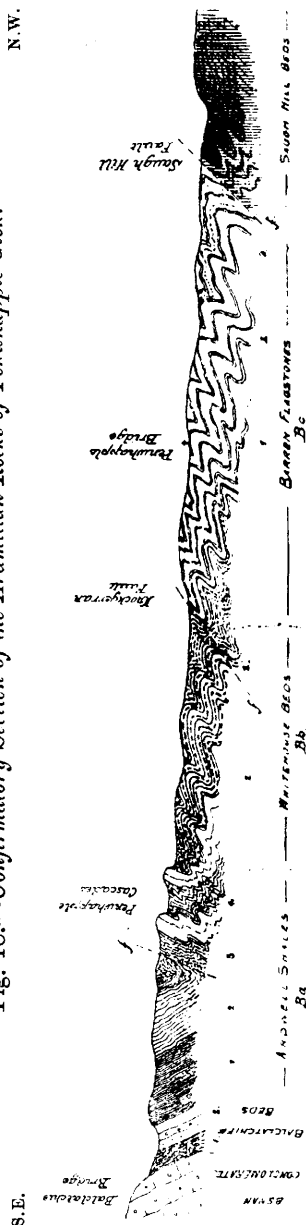
2. Thick-bedded green flagstones, with partings of dark green shale.

(c) *Description of the Confirmatory Section of the Graptolitic Flagstones visible in Penwhapple Glen.*

The thick series of Graptolitic and non-fossiliferous shales and flagstones which make up the Ardmillan group, attain their greatest geographical extension in the Girvan region in the moorland area to the east of Byne Hill, where they occupy a continuous tract of country from half a mile to one mile and a half in width, which stretches inland from the coast-platform of Ardwell and Shalloch (last described) to the hills of Knockgerran east of the gorge of Penwhapple.

The stream of Penwhapple, after leaving the conglomeratic area of Milljoan and Knockgerran, upon the intractable masses of which it spreads out in wide swampy flats, descends suddenly upon the softer Graptolitic series at a short distance below the bridge of Balclatchie. To the north of this point, aided by the more easily disintegrated nature of the strata over which it flows, it has excavated a profound gorge, three miles in length, and from 50 to 100 feet in depth. From end to end of this gorge a continuous and unbroken section of the rocky floor of the district is laid open to the inves-

Fig. 18.—Confirmatory Section of the Ardmillan Rocks of Penrhynpapple Glen.



(1) Soft banded shales and mudstones with frequent bands of cement-stone.—*Diplograptus quadrimucronatus*, *D. truncatus*, *Climacograptus tubuliferus*, *Leptograptus flaccidus*, &c.

2. *Asy* grains and occasional conglomerate.
 I. Calcareous nodular and fossiliferous mudstones.
 (Ac.) Benan Conglomerate.
 ff. Faults.

tigator (fig. 18); and the evidence it affords him of the arrangement of the component strata, and of the numerous folds and dislocations which have affected them, is invaluable.

(1) *Ba. Ardwell Flags and Shales*.—For the upper two miles of its course the glen has been excavated in the flaggy rocks of the Ardmillan group. We have here therefore an excellent opportunity of testing the accuracy of our interpretation of the sequence of these strata, as deduced from their exhibition along the shore-line of Shalloch and Ardwell.

The section of the Benan Conglomerate and the succeeding Balclatchie Beds, as displayed at the commencement of the Penwhapple gorge to the north-west, has been already described (p. 249 *et seq.*).

Lying immediately upon the ashy grits of the upper zone of the Balclatchie Beds, we find the basal strata (Ba 1 of fig. 18) of the Graptolitic series. They consist of masses of dark shales and thin-bedded flagstones. The shales are more or less carbonaceous, weather throughout to a rusty-iron colour, and are clearly identical in all essentials with the lower Ardwell beds that lie upon the conglomerate of Kennedy's Pass. Beds of the same general character extend down the glen, and are magnificently displayed in its rocky floor and steep cliffs, for a distance of about a quarter of a mile, until we reach the first of a series of massive green and more or less pebbly grits, over which the waters of the burn plunge in two fine cascades.

If the dips are to be relied upon, the first group of Ardwell strata between the Balclatchie Beds and the cascades are generally arranged in a broad synclinal form. Several distinct subdivisions are recognizable as at Ardwell. The lower division (Ba¹ of fig. 18) consists of thin-bedded, striped, iron-stained shales, containing many Graptolites in certain zones. The commonest forms are:—

<i>Diplograptus foliaceus</i> , <i>Murch.</i>		<i>Climacograptus calatus</i> , <i>Lapw.</i>
— <i>rugosus</i> , <i>Emm.</i>		<i>Corynoides calycularis</i> , <i>Nich.</i>
<i>Climacograptus Scharenbergi</i> , <i>Lapw.</i>		<i>Dicellograptus moffatense</i> ? <i>Carr</i>

Here, however, the shales contain several bands of *cement-stone*, which yield a few Brachiopoda. Nodules of calcareous matter, too, are frequent. These contain some fine examples of Orthoceratites, an occasional shell, and fragments of sponge-spicules.

From these beds have been procured at various times by former investigators, by Mrs. Gray, by Mr. M'Fie of the neighbouring estate of Knockgerran, or by myself, the following characteristic forms:—

<i>Orthoceras angulatum</i> , <i>Wahl.</i>		<i>Orthoceras politum</i> , <i>M'Coy.</i>
— <i>calamiteum</i> , <i>Münst.</i>		<i>Hyalonema girvanense</i> , <i>Nich.</i>

This basal (or Knockgerran) zone is overlain in the central parts of the exposure by a more flaggy series (Ba 2), answering to the more typical beds of the coast-section. Its beds consist of striped flags from 2 to 4 inches in thickness, relieved by occasional shale seams and a few insignificant bands of dark grey grit. Above follows a third subdivision (Ba 3) composed of ironstained shales, similar to

those of the basal zone. Its beds are much distorted and shattered; but Graptolites occur in the carbonaceous seams, chiefly—

Dicellograptus Morrisi, *Hopk.*
Diplograptus rugosus, *Emm.*

Clinacograptus bicornis, *Hall.*

Cascade-Beds (Ba 4).—At each of the two fine waterfalls above mentioned a mass of coarse green grits makes its appearance. In mineralogical aspect they are almost identical with those at the summit of the Balclatchie zone of the Benan-conglomeratic series, as displayed in the Doon Hill, Daldowie, and elsewhere. They occasionally become conglomeratic, being filled with zones and layers of small boulders of greywacke and quartz. They include between them a series of dark shales and mudstones, striped with lines of carbonaceous matter, and containing frequent bands and nodules of cement-stone. These calcareous seams, however, unlike those of the succeeding Whitehouse Beds, afford no examples of Brachiopoda, but are crowded with Graptolites in excellent preservation. In mineralogical aspect the beds remind us of those found on both margins of Ardwell Bay, at the summit of the Ardwell group; and their identity is placed beyond question by the fact that they contain all the peculiar fossils of that especial locality, viz. :—

Dicellograptus Forchhammeri, *Gein.*
Lasiograptus margaritatus, *Lapw.*
Diplograptus pristis, *His.*

Diplograptus foliaceus, *Murch.*
Clinacograptus caudatus, *Lapw.*
Dicranograptus ramosus, *Hall.*

(2) Bb. *Whitehouse Beds*.—Immediately we examine the floor of the glen below the second waterfall, it becomes evident that we have overpassed the limits of the Ardwell beds, and have reached the more varied overlying strata of Whitehouse Bay. The beds are faulted and folded even more intensely than upon our coast-section, the same strata coming to the surface again and again as we descend the course of the stream. From the lower cascade to the point in the glen where we meet with the terminal calcareous and variegated beds of this division, the distance, as measured upon these strata in the gorge itself, cannot be less than half a mile; yet, owing to the many repetitions and faults that have affected the strata, it is doubtful if their collective thickness is more than equal to that estimated in our typical locality upon the shore-line. All the beds have a southward inclination, as if passing below the Cascade-grits; but when the several recognizable zones are studied in detail, it becomes clearly evident that they are arranged in series of zigzag forms upon the ground, demonstrative of the presence of numerous broken and inverted arches, the axes of which cross the stream-course at a very acute angle. Thus, in spite of the prevalent southward dip, it may be regarded as certain that there is a general ascending sequence as we descend the stream. This conclusion is supported not only by the facts obtainable in the neighbouring areas, but by the circumstance that the variegated seams of the Upper Whitehouse Beds are found at the north end of the section, in a position answering to their place in the sequence of the corresponding strata upon the shore-line.

As at Whitehouse, the majority of the Lower Whitehouse beds consist of dark grey shales striped with dark lines of carbonaceous matter, and containing at intervals seams, flags, and ribs of hard calcareous grit or "cement-stone," with fragmentary Brachiopoda. Here, however, the shales are much looser and softer in texture, and are altogether much more fossiliferous than in the shore-section. They have, indeed, rather the character of the soft muddy beds of this group as developed in the lower part of the Byne-Hill Burn; and the fossils they contain place it beyond question that many of them actually appertain to that special zone. The majority of the shales weather to a rusty-red colour. They yield the following Byne-Hill-Burn Graptolithina in some profusion, and in a most perfect state of preservation:—

Pleurograptus linearis, Carr.

Leptograptus flaccidus, Hall.

Climacograptus tubuliferus, Lapw.

Diplograptus quadrimucronatus, Hall.

Diplograptus foliaceus, Murch.

— *truncatus*, Lapw.

Corynoides calycularis, Nich.

Upper Whitehouse Beds (Bb 2).—In the place where we should expect to find the ribbed mudstones that lead up into the purple shales of the upper zones of the Whitehouse Beds we find instead a thickness of nearly 100 feet of soft dark bluish-green mudstones devoid of ribs. They are well seen in the bed and bounding cliffs of the burn, forming a most distinctive band in the rocky succession. They break up under the hammer first into beds of 3 or 4 inches thickness, and afterwards into irregular-sided blocks, with a clearly marked conchoidal fracture. As a rule, no fossils whatever seem to be obtainable from these beds, though they look very promising for the palæontologist.

They are followed immediately by a very meagre representative of the purple and green mudstone group, of which only a few feet are visible in the bed of the stream; but these are clearly intercalated, as upon the shore-line, between the grey mudstones last referred to and the Barren Flagstones, which next form the cliffs for a long distance down the stream. These variegated mudstones, though wanting in their proper thickness, probably owing to the presence of faults, show us, nevertheless, a satisfactory quantity of their associated calcareous zones, which are here much harder and more flag-like than upon the shore.

Graptolites are difficult to procure; a few fragments of *Dictyonema*, *Ganocladium*, and *Climacograptus* are all that I have been able to identify from them. But Brachiopoda are abundant in the thick-bedded "cement-stones;" examples of *Leptaena tenuistriata*, *Orthis biforata*, *Orthis calligramma* and their usual associates are by no means rare.

(3) Bc. *Shalloch or Barren Flagstones*.—The seam of purple and green shales of the Upper Whitehouse-beds, last described, has a thickness of about 30 feet. It is succeeded immediately by a great mass of Barren Flagstones, which extend down the course of the stream for the next three quarters of a mile. As in our much more

restricted coast-section, the first division of this group consists (Bc 1) mainly of green mudstones, with distant ribs of flagstone. This division is most conspicuous in the floor of the glen between the line of the variegated mudstones and the foot of Laigh Assel Burn. The stream has worn away the soft shaly mudstones into deep hollows, between which rise the hard and conspicuous intercalary ribs. In one or two spots these mudstones are crowded with their characteristic organism, *Nematolites Grayii*, Lapw., of the corresponding beds of Shalloch Mill.

Continuing our progress down the stream, beyond the terminal strata of this essentially shaly division we encounter bed after bed of rock of the same general type, but in which the sandstone and flaggy ribs become rapidly more numerous and of greater thickness (Bc 2). These all dip invariably to the southward, as if passing below the Whitehouse Beds of the higher parts of the burn; but the rapid variation in strike and dip, and the frequent faults, show that it is impossible to suppose that we have here a true ascending section, but that, as in the former case, we are dealing with a rapid succession of inverted folds. Excellent sections of the beds are seen until we reach the termination of the group, a quarter of a mile to the north of Penwhapple bridge, where it is abruptly faulted against a series of black Graptolitic shales of the much newer *Pentamerus*-group of Saugh Hill.

Some hard grey gritty flags, with interbedded subcalcareous shales, visible in the broken sections near the northern termination of these beds, are different from any of the strata of this group recognizable upon the shore, and are probably higher in the series than any strata there displayed. They are, however, most distinctly to be placed in the same subformation of the Barren Flagstones, with which they agree in all essential particulars, and of which they undoubtedly form an integral portion in this locality, and a few others yet to be described.

They contain a few fragmentary Graptolites in the greyish brown shales seen in the land-slips near the great fault. The only form clearly recognizable is *Diplograptus truncatus*, Lapw.

Thus in this section in Penwhapple Glen we recognize, lying between the Benan Conglomerate and the Great Fault, a series of strata whose members are identical in geographical succession, in mineralogical characters, and in fossils, with those developed in our typical area of Ardmillan. This sequence, though repeatedly broken by numerous and important dislocations, bears evidence of having been originally identical with that of Ardmillan in every particular, many of the most characteristic petrological zones there exhibited being developed here in positions precisely correspondent. The apparent dip of the beds through a great part of the section is, it is true, different from that seen upon the shore-line; but, as we have shown, it may be regarded as certain that these inharmoniously-dipping beds are actually arranged in rapid and inverted folds.

It will next be shown that a corresponding arrangement obtains universally among the remaining exposures in the Girvan district.

(d) *Additional Exposures of the Graptolitic Flagstones south of the Girvan Valley.*

1. *Area of Pinnmore and Letterpin.*—The long strip of Ardmillan shales which stretches from Daldowie south-eastward to the valley of the Lendal, affords us by far the most satisfactory exposures of the Ardwell Shales considered in their fossiliferous character. The line of railway running from Girvan to Stranraer traverses the district almost at right angles to the strike of the beds; and its cuttings afford a magnificent and practically unbroken section from the bottom to the top of the series as there exhibited. The lowest strata exposed are certain green concretionary mudstones which are seen in the roadway underneath the great viaduct of Kinclaer. These probably belong to the transitional Balclatchie group, the main mass of whose beds are cut out by a small fault ranging along the strike of the rocks between that exposure and the great masses of Benan Conglomerate visible on the hills to the southward and in the stream-bed of the River Assel a few yards below.

Above these green mudstones follows a great thickness of very dark greyish-blue shales, beautifully shown in the railway-cutting, dipping steadily to the north-eastward at an angle of about 30°. They are fully as indurated as their counterparts in the lower portion of our typical section of Ardwell shore; but, in place of being practically barren, many of their laminæ are covered with easily identified examples of:—

Dicranograptus Nicholsoni, <i>Hopk.</i>	Climacograptus caudatus, <i>Lapw.</i>
Dicellograptus Forchhammeri, <i>Gerv.</i>	—— bicornis, <i>His.</i>
Diplograptus foliaceus, <i>Murch.</i>	Leptograptus flaccidus, var. <i>Hall.</i>
—— rugosus, <i>Emmons.</i>	Corynoides calycularis, <i>Nich.</i>
Cryptograptus tricornis, <i>Carr.</i>	&c.

Numerous scattered exposures in quarries and in the railway-cuttings enable us to complete the section as far as Letterpin fault. The beds remain essentially the same throughout. As we near the railway-station seams of cement-stone, grits with angular quartz-pebbles, and patches of coarse brown and more or less calcareous flagstones make their appearance at irregular intervals. Some of these probably belong to the underlying Balclatchie Beds. They contain many specimens of Brachiopoda, usually in a fragmentary but easily recognizable condition.

These Balclatchie and Ardmillan strata, a little further to the west, bear evidence of being arranged more or less in a synclinal form. The coarse yellow gritstones with fossils, seen in the numerous quarries around Mickle Letterpin and Chapelcroft, are probably identical with the Balclatchie zones of the railway-cutting, and are well exposed in many quarries and small natural sections over the fields in the neighbourhood of the Letterpin fault.

In these scattered exposures, more especially in one small quarry about one third of a mile north of Mickle Letterpin, certain grey and striped shales represent the transitional band at the base of the Ardwell group. From these I have procured, among others :—

Dicranograptus spinifer, *Lapw.*
Dicellograptus, sp.
Leptograptus flaccidus, var. β .
Diplograptus foliaceus, *Murch.*
Cryptograptus tricornis, *Carr.*

Climacograptus bicornis, *Hall.*
— *Scharenbergi*, *Lapw.*
Orthis Actoniae.
Leptaena tenuistriata.

Similar beds may be followed at intervals over the entire area of this district as marked upon the map (Pl. XXIV.). In the hollows between we see the typical dark blue or grey and more or less striped shales of Ardwell, weathering to their typical rusty-brown colour—here hardened and barren, there softer and affording a few Graptolites, always of the species of the shore. Along the line of the southern conglomerate many of the beds are inverted and highly indurated. The presence of the soft yellow sandy conglomerates of the Balclatchie Beds along the line of the fault to the north renders the west boundary of the beds in that direction more obscure.

The recurrence of similar mineralogical zones of strata in the series as developed in this extended area, though the group, as a whole, apparently dips steadily to the northward, makes it certain that the numerous inverted folds and accompanying faults, apparent on the flanks of Daldowie Hill, are prolonged into the Pinmore area; and to these are due the monotonous character and great apparent thickness of the beds.

2. *Exposures East and West of Penwhapple Glen*—The section we have described in Penwhapple Glen is typical of the structure of the entire area occupied by the Ardmillan group between the Benan Conglomerate and the great fault of Saugh Hill, south of a straight line ranging from the Dow Hill across the region into the faulted area of Dalarnford, on the terrace of Straiton and Garleffin. This entire district is floored with repetitions of the various subordinate members of the Ardwell Beds. The varying lines of strike are all clearly dependent upon the general outline of the mass of Benan Conglomerate, which everywhere underlies these rocks around the broad curve forming the southern and eastern limits of the area from Balclatchie to Piedmont. The strata are clearly more or less folded and faulted throughout: but the general similarity of the beds from bottom to top of the series, and the scanty exposures within the area, do not allow us to offer more than a general idea of the arrangement of the strata.

The finest sections to the southward are seen around the Barbae Hill near Tramitchell, where the fossiliferous Barbae Grit is seen to be surmounted by soft dark shales of the Lower Ardwell beds, containing a few shells and Graptolites in the intercalated cement-stones and conglomerate bands, and passing upwards into a great thickness of hard flaggy gritstones, separated by the usual rusty and striped carbonaceous shales. These shales and overlying flags sweep in a continuous curve, $2\frac{1}{2}$ miles in length, from Tra-

mittell through Barbae Hill into the heights of Trowier, parallel to the northern boundary of the Benan Conglomerate. The higher zones of these gritty beds become more sandy, and contain seams of small quartz pebbles here and there; and they are, I suspect, the equivalents of the Cascade-grits of the Penwhapple section. In the fields N.W. of Barbae they contain fragments of Encrinites and a few Brachiopods. The underlying softer shales are best seen on both sides of the roadway west of Barbae, and in the streams near Laggan, where they contain a few Graptolites.

In the great sheet of Ardwell flagstones displayed in the heights of Tralodden, Trowier, and Balgavarie, the strata are so broken and folded that no extended sections are visible. Nevertheless there is a sufficiency of evidence to show that the Benan Conglomerate rises again and again almost to the surface, while the various zones of the Ardmillan series are often recognizable in place upon the ground.

Ba, *Ardwell Beds*.—Excellent exposures of the Knockgerran or lower zones of the Ardwell Beds are afforded by the two small streams which unite at the farm of Tralodden. The beds show their usual striped appearance, contain the normal cement-stones, and are locally crowded with

Diplograptus pristis, *His.*
— *foliaceus*, *Murch.*

Climacograptus caudatus, *His.*
Corynoides calycularis, *Nich.*

A mass of similar beds is cut through by the lower reaches of the Piedmont Burn, near Glendoune. This is included between two divergent branches of the great bounding fault of the Girvan plateau. This fault, as will be evident from a study of the map, splits into two branches north of the summit of Saugh Hill; and in the included angle between them we find examples of the higher parts of the conglomerate or cascade group, together with some of the lower divisions of the Ardmillan series.

Fossils occur both on the flanks of Saugh Hill and in the depths of Piedmont Glen. At the latter locality I have collected

Diplograptus pristis, *His.*
— *foliaceus*, *Murch.*

Corynoides calycularis, *Nich.*

Diplograptus foliaceus and *Corynoides calycularis* occur also in the quarries on Fauldribban Hill.

In Piedmont Glen the middle zones of the Ardwell Shales are crowded with Graptolites at the foot of the small burn which descends from Laggan Loch. Here are found in excellent preservation :—

Diplograptus foliaceus, *Murch.*
— *pristis*, *His.*

Climacograptus caudatus, *Lapw.*
Corynoides calycularis, *Nich.*

At the foot of the glen itself occasional examples of *Lasiograptus margaritatus*, Lapw., and *Diplograptus foliaceus*, Murch., are met with in the contorted beds. They occur also in corresponding strata upon the low mound of Shalloch Hill.

A similar faulted patch of the Knockgerran zone of the Ardwell Beds occurs near the farm of Pinmacher, and is cut through by the

railway-line from Girvan to Stranraer. Excellent sections are visible in the railway itself near the tunnel and in several quarries near the farmsteading of Knockrochie. Graptolites are abundant in a few spots, especially *Diplograptus pristis*, His., and a form of *Climacograptus*.

The highest zone of the Ardwell Beds—the peculiar *Cascade Grits and Shales* of Penwhapple Glen, is recognizable at several localities. From the Cascades themselves its strata are prolonged to the eastward in a continuous band of small cliffs, which form a prominent feature upon the grassy slopes of Balgavarie Hill. In the stream which descends the slopes of the hill they afford a visibly ascending section, and yield their usual Graptolites in a state of excellent preservation. Here occur

Dicranograptus Nicholsoni, <i>Hopk.</i>		Climacograptus caudatus, <i>Lapw.</i>
— ramosus, <i>Hall.</i>		Diplograptus foliaceus, <i>Murch.</i>
Dicellograptus Forchhammeri, <i>Gein.</i>		Climacograptus bicornis, <i>Hall.</i>

The same zone is seen also upon the heights of Trowier Hill in the same stratigraphical position, and yielding precisely the same fossils.

A most interesting patch of the same band is found at the base of the north-western flank of Saugh Hill (see fig. 25, p. 299). Here it is caught up between two branches of the great Bargany dislocation; but its strata retain their normal characteristics, and afford the usual fossils, namely:—

Dicranograptus ramosus.		Dicellograptus Forchhammeri.
Climacograptus bicornis.		Diplograptus rugosus.

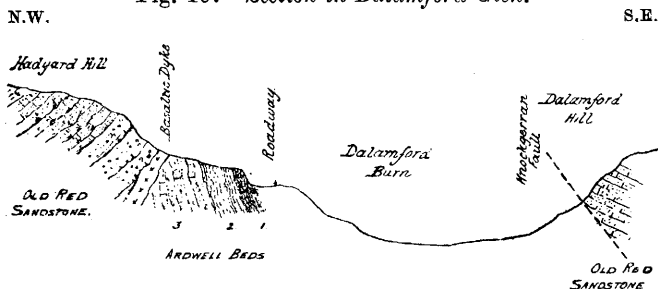
But the most remarkable exhibition of the beds of this zone is the section afforded by the narrow valley of Dalamford, about two miles east of the Penwhapple Glen. Here a strip of Lower Palæozoic strata several miles in length, but only about 100 yards in width, is bounded on both sides by rocks of Old Red Sandstone (see map, Pl. XXIV.). Along the roadway near Dalamford the visible Lower Palæozoic rocks are those of the Cascade-zone, and the transverse section of the valley is that given in the following section (fig. 19).

This narrow band owes its existence to the presence of the great Knockgerran fault, which is prolonged into this locality from the valley of the Penwhapple. The strata exposed along its course are not, however, confined to the Cascade-zone. The Stinchur Limestone is brought up in a shattered condition near the steading of Pentbeath, and is said to occur also in the south-eastern branches of Penwhapple Burn.

Bb, *The Whitehouse Beds*.—Only a very limited number of exposures of the beds of this group have been met with in this area. Beds unequivocally belonging to the Lower or Cement-stone-bearing division occur at the head of Piedmont Glen, where they follow in their proper position upon the grits of the Cascade-zone. In their shattered beds, as laid open in the stream-course, the usual fossils are procurable, chiefly:—

Diplograptus quadrimucronatus, <i>Hall.</i>		Dicellograptus Morrisi, <i>Hopk.</i>
— truncatus, <i>Lapw.</i>		Leptograptus flaccidus, <i>Hall.</i> &c.

Fig. 19.—Section in Dalarnford Glen.



Old Red Sandstone:—

Coarse red conglomerates and red and yellow flagstones.

Ardwell beds, Cascade-zone.

3. Calcareous grits, with partings of green and grey shales.
2. Green nodular sandstones, non-fossiliferous.
1. Black carbonaceous and ferruginous shales, with occasional hard arenaceous ribs—*Lingula*, *Dicellograptus Forchhammeri*, *Diplograptus rugosus*, *D. foliaceus*, *Climacograptus caudatus*, &c.

Strata belonging to the higher or Upper division have been detected only at a single locality between the two exposures of Myoch Bay and Penwhapple Glen, already described, namely, in the central parts of the gully formed by the north-east fork of Piedmont Burn. Here the purple and green mudstones of the Upper Whitehouse variegated beds form the bed and banks of the stream-course for some little distance, in their natural geological place between the Ardwell beds of Trowier Hill and the *Nematolites*-bearing flagstones of Doune Hill. They are much shattered, and have afforded no recognizable fossils. The boundaries of this zone, as given upon Plates XXIV. and XXV., west of Penwhapple Glen, are almost purely inferential, as hardly any sections are visible upon the ground.

B. Barren Flagstones.—The succeeding Barren-flagstone beds form a broad zone, about four miles in length and half a mile in width, which ranges from the summit of Doune Hill across the glen of Penwhapple into the moorland area north-west of Knockgerran. The central section of this zone in Penwhapple Glen, already described, is typical of the general arrangement of these strata from end to end of the band. The thin-bedded zones near the base of the group are well seen on the southern and south-western slopes of Doune Hill. The higher and flaggy beds are laid open at several spots upon the heights between Saugh Hill and Penwhapple; and by their disposition upon the ground enable us to mark out with some approach to certainty the line of the fault which bounds the band to the northward. In Saugh-Hill Burn itself they afford specimens of the characteristic fossil *Nematolites Grayii*; and in some quarries about a mile to the eastward, they yield examples of *Diplograptus pristis* and *D. truncatus*. There are many exposures of the same beds south and east of the farmstead of Littlelane; but no fossils have been obtained from them.

A patch of unfossiliferous strata, probably referable to the lower division of the Barren-flagstone beds occurs to the south-west of Brae Hill. It is cut off from all the neighbouring strata by faults of great magnitude; and it is therefore referred to this division with some doubt. Good exposures of its beds are seen in Cuddystone Glen and on the west side of Brae Hill. The strata are green and grey shales, with occasional beds and bands of flagstone, all totally barren of recognizable fossils, and altogether very similar to the highest zone of the Barren-flagstone group.

This completes our survey of the distribution of the Graptolitic-flagstone series *south* of the Girvan Valley. The remaining strata are very different in their characters, petrological and palæontological, from those we have studied hitherto; and their description is most conveniently deferred until we have made out the arrangement of the palæozoic strata which are exposed *north* of the Girvan Valley, on the heights of Craighead and Quarrel Hill, whose rocks unquestionably belonging to the Ardmillan-flagstone series are exposed in several localities, with clear relations to the overlying strata.

(C.) DESCRIPTION OF THE STRATA OF THE NORTHERN INLIER OF
CRAIGHEAD AND GLENSHALLOCH.

The Lower Palæozoic strata, whose interrelationships fall next to be described, occur in the prominent heights of Craighead, Quarrel Hill, and Glenshalloch, which together constitute the beautifully wooded ridge that forms such a conspicuous object to the north of the valley of Girvan, a few miles inland from the mouth of the river. These strata form a well-marked inlier, which is bounded on all sides by more recent beds of Old Red Sandstone and Carboniferous age; and, broadly speaking, it may be said that they are arranged in a dome-like or anticlinal form. The longitudinal axis of this anticlinal is not precisely coincident with the geographical axis of the ellipsoidal area occupied by the Lower Palæozoic strata, but lies a little to the southward. In consequence of this arrangement the strata forming the southern leg of the anticlinal have a short curve and a steep dip to the south-western margin of the area, where they are suddenly cut off by the grand boundary fault of Kilkerran and Craighead. Northwards, however, the beds have a gentle inclination, the angle of dip rarely exceeding 45° , and being sometimes as low as 10° or 12° .

The axis of the main anticlinal, instead of being approximately horizontal, is archlike, being depressed in both directions as we pass along it from its central point. The long elliptical dome thus originated has been truncated by denudation; and its component beds are now shown upon the ground as a series of concentric shells or zones of strata dipping everywhere outwards off the central parts of the dome. They admit of minute and almost complete examination in several localities. The general coating of wood and turf, however, hides some of the inferior beds from sight in the eastern and southern parts of the area; but towards the north-east a long and easily

interpreted ascending succession is displayed in the heights of Quarrel Hill, Mulloch Hill, and Glenshalloch.

(a) *Sections of the Inner Zones of Strata of the Quarrel-Hill Anticlinal.*

(i) *Barren Flagstone-series of Farden and Quarrel Hill.*

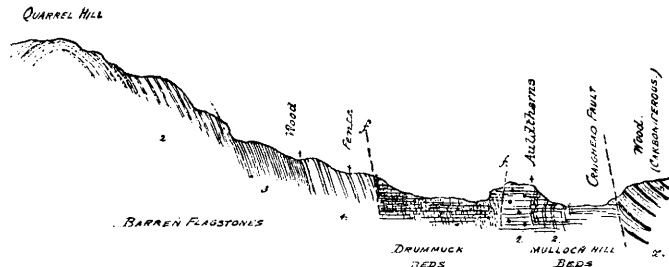
In the centre of this dome-like area, and consequently occupying the lowest horizon in the vertical succession of its rock-formations, we find a series of barren flagstones and shales, identical, both in their petrological characters and in the few organic remains they yield, with our Barren or Shalloch Flagstones of Shalloch and Penwhapple—thus presenting, at the very commencement of our study of the rocks of this area, a clear and definite horizon of reference for the surrounding and concentric zones of strata of which this northern inlier of Lower Palæozoic rocks is composed.

These flagstones occupy an ellipsoidal area about a mile in length, ranging from the loop-fault which bounds the igneous rocks of Craighead Hill, through the wooded grounds of Balweary, into the grassy slopes of Quarrel Hill. Over much of the area they occupy they are hidden from sight by superficial deposits; but excellent sections are laid bare in the burns which descend the ridge in the direction of Craighead fault, near Kildrummie. The most satisfactory of these exposures is that seen on the banks of the small stream to the west of Quarrel Hill, where the section figured below is displayed from end to end (fig. 20).

Fig. 20.—*Section of the Barren Flagstone Beds of Quarrel Hill.*

N.W.

S.E.



x. Carboniferous rocks, not exposed.

Ca. Mulloch-Hill Beds.

2. Calcareous flagstones, with *Brachiopoda*—*Meristella angustifrons*,
Atrypa scotica, &c.

1. Mulloch-Hill conglomerate.

Bd. Drummuck or *Trinucleus*-beds:—

Thin flags and shattered mudstones, with *Bellerophon bilobatus* &c.

Bc. Barren Flagstones.

(4). Grey flagstones and shales, weathering buff or yellow.

(3). Green shales and mudstones.

(2). Alternations of thin-bedded green flags and mudstones.

(1). Thin-bedded flaggy beds, with partings of green and grey mudstones—*Nematolites Grayii* and *Diplograptus truncatus*.

ff. Faults.

The lowest beds of the Flagstone series visible at this locality are seen at the head of the little burn, circling round the declining axis of the main anticlinal arch, and gradually acquiring a steep southward inclination as we descend the course of the stream. The oldest beds are greyish-green flagstones, from two to four inches in thickness, separated by the usual pale bluish-green seams of shaly sandstone, characteristic of the higher parts of the "*Barren Flagstones*" as seen near the Saugh-Hill fault in the gorge of Pen-whapple. They contain their peculiar fossil, *Nematolites Grayii*, Lapw., in some abundance, together with a few scattered examples of the equally characteristic Graptolite *Diplograptus truncatus*, Lapw.

Lower down the stream the flagstones and shales differentiate themselves in wider bands, and the strata put on an appearance identical with that of the most typical Barren Flagstones of Pen-whapple, showing the same regular alternation of a foot of hard grey grit with two or four feet of greenish flaky shales. Below the little wood the beds become steeper, and, as will be seen from the map (Pl. XXV. 4) and sections, begin to be much broken up by faults. Their highest beds as seen here are pale flagstones, with a light-blue interior, associated with similarly tinted mudstones, both weathering to the dull orange-buff colour affected by the beds of this formation wherever they have been long exposed to the action of the atmosphere.

A confirmatory section is visible in Farden Burn, about three fourths of a mile to the south-westward of Quarrel Hill. The oldest beds, ranging along the anticlinal line, occur in the banks of the stream at the back of the farmsteading of Farden, dipping in opposite directions at a small angle. As we descend the stream to the south the angle of inclination rapidly increases; and between the steading and the Craighhead fault we pass over a fairly continuous section of these beds, the majority of which are identical with the pale and buff-coloured flags and shales that terminate the exposure in Quarrel-Hill Burn, while they are similarly destitute of organic remains of any kind.

These Barren Flagstones are seen upon the opposite side of the anticlinal line in two localities only. One of these occurs in an old quarry a quarter of a mile to the west of Blair Farm, the other on the road-side at the farm-house itself. In both localities we find the barren buff-weathering shale and flagstones of the highest zone of the series, as usual, perfectly destitute of fossils.

The numerous faults and folds of the district do not allow an exact calculation of the vertical thickness of the portion of the Shalloch or Barren-flagstone group as here exposed. It may be roughly estimated at about 300 feet. The buff-tinted terminal band of flagstones and shales cannot be less than 100 feet in total thickness. This is apparently wanting in the Penwhapple exposure of these beds, and its thickness falls to be added to our estimate of the vertical extent of the Barren Flagstones of that area. This would give a collective thickness of about 800 feet to the entire formation of the Barren Flagstones as seen in the Girvan region.

(ii.) *Trinucleus-Mudstones of Drummuck.*

Round three fourths of the superficies of the anticlinal dome of Quarrel Hill the Barren Flagstones are succeeded by the highly fossiliferous group of dark mudstones which I term the Drummuck Beds. In mineral aspect and in fossils they remind us strongly of some of the zones of the Whitehouse shales (Bb) that immediately underlie the Barren-flagstone series; but they contain none of the brilliantly coloured mudstones of that group, nor any of the beautifully striped and banded shales which it possesses in common with the older Ardwell group. The physical relations of the Barren Flags and these overlying *Trinucleus*-mudstones are best displayed in the flanks of Quarrel Hill; but the finest and most prolific sections of the latter group are shown to the north, along the course of the Lady Burn, and in the neighbourhood of the farm of Drummuck, which gives its name to the subformation.

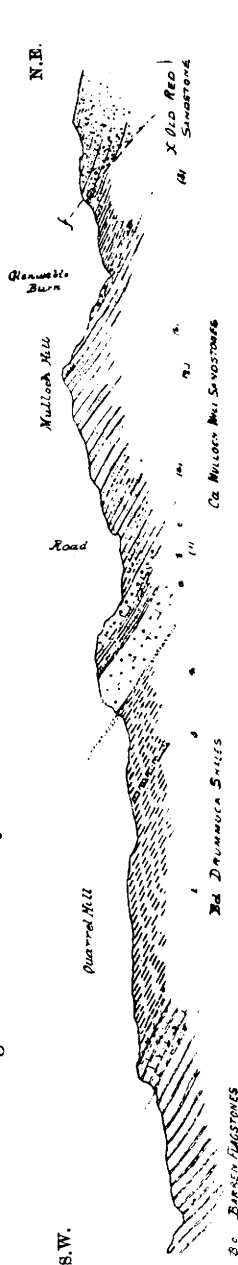
The superposition of these fossiliferous mudstones to the Barren-flagstone group will at once be understood from the following section (fig. 21, p. 618), which is carried in an easterly direction along the anticlinal axis from Balweary Wood to Mulloch Hill. Indeed the disposition of the several zones of strata which here cross over the anticlinal, as developed in the mapping of the area, make this so clear and unequivocal that no further proof of their relationship is necessary in this place.

1. *Quarrel Hill.*—The lowest strata I assign to the Drummuck Beds are a group of thick-bedded flagstones, filled with pebbles of quartz, and separated by seams of grey and green shales, both rocks containing a notable proportion of carbonate of lime. They are exposed in a steep escarpment at the summit of Quarrel Hill, dipping off the Barren Flagstones and plunging below the area occupied by the main mass of the Drummuck Beds. From this point, as will be seen from the map (Pl. XXV. 4), they may be followed foot by foot, occupying the same stratigraphical place in the succession, through the converging dislocations of Quarrel Hill, circling round parallel with the overlying and underlying zones, till they are finally cut out by a branch of the Craighead fault to the south-west of the old ruin of Auldthorns.

These pebbly flagstones have a collective thickness of about 50 or 60 feet, and abound in casts of fossils of the same general facies as those characteristic of the overlying mudstones. The commonest forms are *Leptaena sericea* and *Strophomena*.

The finer strata which succeed to these basal flagstones are well displayed in the numerous stream-courses that descend the eastern flanks of Quarrel Hill. Their upper boundary is strikingly defined by a mass of purple conglomerate, which forms the base of an overlying group, and ranges through the faulted areas strictly parallel with the basal flagstones last noticed. In the area thus limited, we find a great thickness of mudstones and shales of a greyish-blue colour, very rarely interrupted by thin seams of greenish-grey flagstone or greywacke. The lowest beds are hard shales, of tough texture, weathering down into conchoidal flakes. Higher up

Fig. 21.—Section through the Ardmillan and Newlands Beds of Mulloch Hill &c.



x. Coarse conglomerates and yellow grits of *Upper Old Red Sandstone*.

C. NEWLANDS SERIES.

- Ca. Mulloch-Hill Beds.
3. *Ptilograptus*-shales—yellow shales and mudstones, with *Ptilograptus* &c.
2. Mulloch-Hill sandstones (Brachiopod Sandstones).
(b) Rough-Neuk beds. Thick-bedded soft grey and green sandstones, with partings of calcareous shales—*Orthis mullochensis* &c.
(a) High-Mains beds. *Meristella angustifrons*, *Schrophomena expansa*, *Atrypa scotica*, &c.

1. Mulloch-Hill conglomerate.
(c) Upper conglomerate.
(b) Grey tilestones, with Brachiopods.
(a) Lower conglomerate.

B. ARDMILLAN SERIES.

- Bd. Drummuck or *Trinucleus*-mudstones.
4. Thrave beds, with *Ampyx*, *Dionide*, *Trinucleus*, and *Dicellograptus anceps*.
3. Starfish-bed. Grit band, with *Palæaster Wyville-Thomsoni* &c.
2. Quarrel-Hill mudstones and flags, with *Tellerophan acutus* &c.
1. Quarrel-Hill flags and conglomerates, with *Leptæna sericea* &c.
Bc. Barren Flagstones of Quarrel Hill and Balweary, with *Diplograptus truncatus* &c.

they deserve rather the title of bedded mudstones, occurring in distinct bands at least a foot in thickness. The terminal beds are soft sandy mudstones, weathering down into irregularly rounded fragments, coated exteriorly with oxide of iron.

Fossils are tolerably abundant throughout, more especially in the central beds, which afford, among others :—

<i>Trinucleus seticornis</i> , <i>His.</i>	<i>Bellerophon bilobatus</i> , <i>Sow.</i>
<i>Ampyx rostratus</i> , <i>Sars.</i>	— <i>perturbatus</i> , <i>Sow.</i>
<i>Illæus</i> , <i>sp.</i>	<i>Orthis calligramma</i> , <i>Dalm.</i>
<i>Dionide</i> , <i>sp.</i>	— <i>elegantula</i> , <i>Dalm.</i>
<i>Calymene Blumenbachii</i> , <i>Brongn.</i>	<i>Leptaena sericea</i> , <i>Sow.</i>

On the north-east side of Quarrel Hill no exposures are apparent ; but a short distance to the westward the stream of the Lady Burn has excavated a most interesting and instructive series of sections more than a mile in length through the higher zones of the group.

2. *Lady Burn*.—Near the head of the Lady Burn we find the purple Mulloch-Hill conglomerate crossing the little stream-valley almost at right angles to the course of the burn. Over this intractable rock the waters of the stream leap in a small waterfall, at the base of which the highest known strata of the *Trinucleus*- or Drum-muck-beds are seen, dipping steadily and conformably underneath the conglomerate at an angle of about 40°. They are soft, blue mudstones, homogeneous, thick-bedded, and more or less concretionary in structure, breaking up under the hammer into irregular and crumbling fragments. Exteriorly they are stained with rusty oxide of iron ; interiorly they are pierced by frequent inosculating worm-burrows, stained of a dingy red. Fossils are very rare ; only an occasional Brachiopod is discernible.

At their base, however, they contain a fossiliferous band, the abundant organic remains of which fully compensate for the barren nature of the beds above. Fragments of this fossiliferous band are exposed in an old quarry opened for procuring materials for the neighbouring stone walls, in which an occasional slab from the fossil seam may even yet be detected. The bed itself is a hard greenish-grey sandstone, a few inches in thickness, and highly calcareous. It is almost made up of fossil remains, many being in an excellent state of preservation.

Among others, I have collected from this bed :—

<i>Palæaster Wyville-Thomsoni</i> , <i>R. Eth.</i>	<i>Leptaena sericea</i> , <i>Sow.</i>
<i>Trinucleus Bucklandi</i> , <i>Barr.</i>	<i>Orthis calligramma</i> , <i>Dalm.</i>
<i>Illæus Bowmanni</i> , <i>Salt.</i>	<i>Conularia Sowerbyi</i> , <i>Defr.</i>
<i>Stauropcephalus globiceps</i> , <i>Portl.</i>	<i>Strophomena grandis</i> , <i>Sow.</i>
<i>Calymene Blumenbachii</i> , <i>Brongn.</i>	

together with forms of corals and Polyzoa of undeterminable specific characters.

The shales immediately below the Starfish-bed range down the remainder of the stream-course to the farm of Drummuck, and are shown in an abundance of natural sections. They have been frequently examined by Mrs. Gray and the officers of the Geological Survey, and have long been noted for the abundance and beauty of

the Trilobites they have afforded. They consist of pale-blue or greyish-green mudstones of the same general type as these at the summit of the subgroup; but they are harder, and often contain a notable proportion of sandy material.

In the section shown upon the burn-side opposite the farmsteading of South Thraive Mr. and Mrs. Gray have collected:—

<i>Trinucleus seticornis</i> , <i>His.</i>	<i>Dionide Lapworthi</i> , <i>R. Eth. jun.</i>
<i>Ampyx rostratus</i> , <i>Sars.</i>	<i>Bellerophon bilobatus</i> , <i>Sow.</i>
<i>Solenocaris solenoides</i> , <i>Young.</i>	<i>Dicellograptus anceps</i> , <i>Nich.</i>

Where the succeeding plantation comes upon the stream-course similar beds are seen containing numerous fossil forms. Here I have myself distinguished:—

<i>Diplograptus truncatus</i> , <i>Lapw.</i>	<i>Bellerophon bilobatus</i> , <i>Sow.</i>
<i>Trinucleus Bucklandi</i> , <i>Barr.</i>	— <i>trilobatus</i> , <i>Sow.</i>
<i>Illænus Bowmanni</i> , <i>Salt.</i>	<i>Holopella obsoleta</i> , <i>Sow.</i>

Midway between Thraive and Drummuck, beds a little lower in the succession are shown. These Mrs. Gray found to be prolific in beautifully preserved specimens of

<i>Ampyx rostratus</i> , <i>Sars.</i>	<i>Trinucleus seticornis</i> , <i>His.</i>
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At the farm of Drummuck itself the *Trinucleus*-beds are admirably shown in a small stream running parallel to the roadway to the south of the steading. Here fossils are not so numerous as in the former localities cited; but occasional Brachiopoda are found beautifully preserved.

The oldest strata of the Drummuck Beds seen in this locality are exhibited in a small stream crossing the roadway a quarter of a mile south of the farmhouse, and again in a small quarry near the head of Drummuck Burn itself. In both these localities we recognize the greenish thin-bedded lower shales of Quarrel Hill, and identify within them an occasional fossil.

Westward, the *Trinucleus*-strata are buried beneath recent accumulations and surface-soil; and, except in two small exposures, one at the little pond near the toll-bar at Trochraive, and another on the north-west corner of the enigmatical rock-area of Craighead Hill, nothing further is known of their extension in that direction.

This prolific subdivision of *Trinucleus*-mudstones and shales is denominated the Drummuck Beds, after the name of the farm in the neighbourhood of which its strata are most effectively displayed. The subdivision forms the highest member of the Graptolitic flagstone or Ardmillan group of our Girvan succession, being succeeded by the basal zone of a superior group of rocks, totally distinct both in lithological features and in organic remains. Before proceeding to notice these higher strata, it will be advisable to give a short summary of the several bands of rock that constitute our complete Ardmillan group as we now understand it, together with the names of the several localities where their strata are typically laid open for investigation:—

Generalized Section of the Ardmillan Series.

	feet.	{ Upper Mudstones.	Lady Burn.
		{ Starfish-band.	Quarrel Hill.
Cd. Drummuck Beds .	400	{ Lower Mudstones.	Drummuck.
		{ Basal Sandstones.	Auld Thorns.
		{ Upper zones.	Quarrel-Hill Burn.
Cc. Barren Flagstones	800	{ Middle zones.	Penwhapple.
		{ Lower zones.	Shalloch Mill.
		{ Variegated Mudstones.	Shalloch Mill.
Cb. Whitehouse Beds .	300	{ Lower Whitehouse-beds.	Penwhapple Glen.
		{ Cascade-beds.	Penwhapple.
Ca. Ardwell Beds	1200	{ Middle Flags and Shales.	Ardwell shore.
		{ Knockerran Shales.	Penwhapple.

(a) *Sections of the Outer Zones of Strata of the Quarrel-hill Anticlinal.*

(i.) *The Conglomerate and Shelly Sandstones of Mulloch Hill.*

Having determined the characteristics and sequence of the inner and older zones of strata of the Quarrel-Hill anticlinal, we now proceed to examine the sections which best display the corresponding relations of the outer and therefore newer zones of the dome. It will be seen from the map (Pl. XXV. 2) that the width of the Lower Palæozoic area of Quarrel Hill is not sufficient to allow these outer zones to range round the greater part of the mound-like saddle, as do the inner and inferior beds already described, but that they merely cross over the chief ridge of the declining anticlinal one by one, in successive and parallel bands, as we pass outwards to the north-east from the natural centre of Quarrel Hill, their outer edges being abruptly truncated by the Craighead and Glenshalloch faults.

The rapid convergence of these two dislocations towards the north-east progressively restricts the area individually occupied by each succeeding zone in the ascending series, until ultimately the two faults meet in the wooded heights of Glenshalloch, and the Lower Palæozoic rocks finally disappear from sight.

The older zones of the continually ascending succession of strata present in the triangular area thus limited, are most perfectly displayed in and around the central ridge of Quarrel Hill. To the northward of this central point no dislocation interferes with the sequence, and the regularly ascending series can be studied with ease and certainty; southward a plexus of faults, branches of the great Craighead dislocation, have shattered the strata into a host of irregular fragments, each one of which, however, falls naturally into its proper place after a careful mapping of the ground.

The natural arrangement of the lower divisions of these superior zones will be evident on an inspection of the foregoing section (fig. 21, p. 618), which is drawn from the central part of the Quarrel-Hill anticlinal of Ardmillan Beds, through the simple and unbroken area of Mulloch or Kirk Hill.

(Cal.) *Mulloch-Hill Conglomerate.*—The soft blue concretionary and highly fossiliferous *Trinucleus*-beds of the Drummuck mudstones

are succeeded abruptly by a mass of very coarse boulder-conglomerate, which forms a conspicuous scarp and ridge upon the highest points of Quarrel Hill, and ranges thence eastward and southward, round the curving anticlinal arch.

This peculiar conglomerate reminds us somewhat of the massive Benan Conglomerate of the south in the size and character of its included pebbles. These are of quartz, granite, felstone, and several varieties of igneous rock. The matrix, however, is of a dull purplish tinge, and is in truth a sandy gritstone. Its grains are usually well rounded; and when pebbles are rare the rock degenerates into a coarse sandy grit. In its aspect and composition the rock resembles the bands of conglomerate so abundant among the Old Red Sandstone rocks of Scotland, especially those of the lower division of that peculiar series. It is distinctly bedded throughout its entire thickness, which does not here exceed 75 feet, the planes of deposition being marked by seams of sandstone, lines of boulders, and zones of hard grey grit. Towards its summit it includes a thick zone of sandy flagstone, or tilestone, of a reddish grey tint, containing many casts of fossils, and indicative of the commencement of the conditions which resulted in the formation of the overlying masses of sandy flagstones of Mulloch Hill.

This conglomerate is traceable from the Craighead fault at Glenlochrie, through the faults of Quarrel Hill, into the valley of the Lady Burn, and thence in patches to the farmhouse of Drummuck, following in immediate and locally conformable succession to the Drummuck shales.

Scattered exposures of similar rock are seen to the south-west of this, as near Kipperly and Woodhead and, finally, in a wide area around the mansion of Trochraive. Here coarse conglomerates occur in detached quarries and in projecting bosses in the park and cultivated fields. These certainly belong to the Mulloch-Hill band; but they are flaggier and greyer, and have hardly the same characters either in their matrix or in their included pebbles.

The fossils afforded by the Mulloch-Hill conglomerate, in the type locality of Quarrel Hill, are principally Brachiopoda of the genera *Rhynchonella*, *Orthis*, *Leptæna*, and *Strophomena*, identical in species with those we shall find to be characteristic of the overlying Mulloch-Hill sandstones, and generally distinct, considered as a group, from those that mark the immediately subjacent Drummuck mudstones.

Indeed the distinction in physical features and in fossils between the soft Drummuck mudstones, with their abundant examples of *Trinucleus*, *Asaphus*, *Dionide*, *Ampyx*, and hosts of *Bellerophon* &c., and these overlying *Brachiopod*-sandstones is most striking; and we find here the grandest palæontological break in the entire Girvan succession. None of the genera enumerated above as characteristic of the Ardmillan group have ever yet been certainly met with above the base of this conglomerate; while the most characteristic species and genera of Trilobita, Brachiopoda, and Graptolithina of the overlying beds are equally absent from the Ardmillan series.

There is no actual proof of an unconformity between the Drum-muck mudstones and this conglomerate; but the change in mineralogical character from a soft laminated mudstone to massive boulder-beds and sandstones is proof of a complete modification of the physical features of the neighbouring sea-bed between the periods of deposition of these highly dissimilar sediments, and the great alteration in the aspect of the fauna, caused by the disappearance of many prominent genera and species, is sufficient proof that the intervening period was of great geological importance.

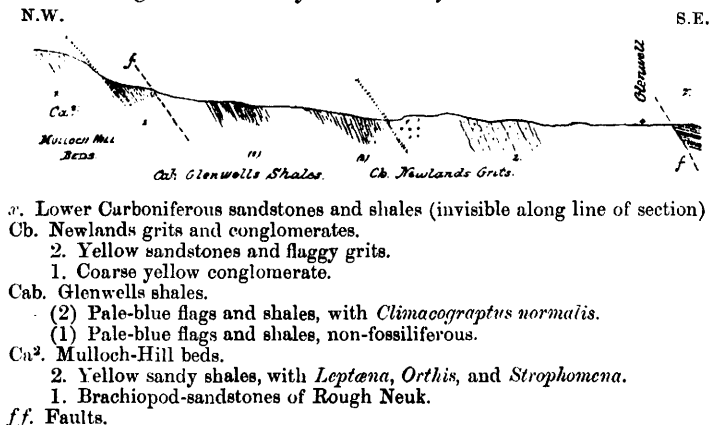
(Ca2) *Mulloch-Hill Sandstones*.—This purple conglomerate of Quarrel Hill graduates upwards into a mass of soft sandstones, at least 250 feet in thickness, which, because of their typical exhibition on the summit and flanks of Mulloch or Kirk Hill, I shall refer to as the Mulloch-Hill sandstones. They are shown in a large number of open quarries along the hill-road north-east of High Mains, and thence for some distance along the same road almost to the steading of High Newlands. A fine display of the same beds is seen in the old quarry at Rough Neuk; and they are easily studied *in situ* in the courses of the many burns that descend the flanks of Quarrel Hill. In all these localities they retain the same general facies of a thick-bedded series of sandstones separated by thin seams of sandy shales. The natural colour of the rock is a dark grey, with a slight greenish tinge; but when weathered it becomes gradually coated with an exterior tint of purple or yellowish red, which soon extends itself inwards till finally the entire rock becomes of a deep rusty or iron-shot colour.

These sandstones are soft and sectile, breaking up easily under the hammer. The more flaggy beds have usually a rough conchoidal fracture; the thicker sandstones split up much more evenly, and generally weather down into rough tilestones. The shaly alternations rarely show evidence of regular lamination, but fall away in rough and irregular flakes.

The whole mass of beds retains very much the same mineralogical character from base to summit; but in the lower zones sandstones are broadly preponderant. The highest zone of the group is actually a band of pale yellow sandstones. It passes upwards conformably into a superior group of yellow-weathering mudstones (Cb3), which, as seen on Mulloch Hill, are comparatively barren. A few Brachipoda and species of *Ptilograptus* occur in the exposures N.E. of Kirk Hill, near the cottage of High Newlands.

The Mulloch-Hill sandstones range southeastwards from the typical localities obliquely down the slopes of High Mains into the low-lying flat of the Quarrel Burn, below the ruins of Auldhorns. They are much cut up by the many loop-faults of that complicated area, and are finally inverted and pinched out, by the converging faults of Quarrel Hill and Craighead, near Kildrummie. In the streams and exposures of the area occupied by these beds below Auldhorns the strata are crowded with fossils. They are fully as abundant as upon Mulloch Hill, and are occasionally even more completely preserved.

Fig. 22. Section of the Strata of Glenwells Burn.



In the stream which descends from the north-east slope of Kirk Hill, and flows past Rough Neuk to the cottage of Glenwells, a tolerably complete section of the strata above the shelly sandstones of Mulloch Hill is laid open (fig. 22). Near the head of the stream, a short distance below the roadway, shell-bearing beds are discovered, dipping steadily to the S.E. off the sandstone group of Rough Neuk. Lower down these beds are followed, after an interval, by a series of blue and green mudstones with intercalated harder ribs. These strata have the same general inclination as the Rough-Neuk beds; but there is some doubt whether they succeed them in conformable sequence. They continue to occupy the bed of the stream for some distance, dipping at an average angle of about 50°, the beds becoming somewhat flaggier as we ascend in the succession. They appear to be generally barren of fossils, except in certain thin seams of striped shales, which have afforded me

Climacograptus scalaris, *His.* | ? *Monograptus tenuis*, *Portl.*
Dimorphograptus acuminatus, *Nich.*

At this point occurs another unfortunate break in the section, and no rock-exposures are seen for a distance of between 40 and 50 yards. These pale-blue mudstones and flags of Glenwells are thus completely isolated as regards their stratigraphical position. It is by no means improbable that they are separated from the true Mulloch-Hill beds by an important branch of the Craighead dislocation, which has cut out the basal zones of the Newlands series. They agree exactly, however, in dip and strike with the underlying Mulloch-Hill beds, while mineralogically they appear to be nothing more than the upward prolongation of the *Ptilograptus*-shales at the summit of that group. The strata next visible are so distinct in their lithological characters that they must be regarded as belonging to a new subformation. Hence it will be convenient provisionally to regard the Mulloch-Hill beds as terminated by these blue mudstones, below which the descending succession is tolerably continuous down into the basal conglomerate of High Mains and Craighens.

The Mulloch-Hill beds, as thus extended, consist therefore of the following members:—

- Cab. Glenwells Graptolitic Mudstones and Flags.
- Ca². Rough-Neuk or Mulloch-Hill Sandstones.
- Ca¹. Mulloch-Hill Conglomerate.

Generally speaking, it may be said that their lower beds are thicker and contain more of the purple and grey tilestones; the middle beds are alternations of thick-bedded sandy flags and sandy shales; and the upper beds show many zones of soft mudstones, pale-hearted and weathering to a golden yellow.

The entire sequence is exposed along the line of section already given (fig. 22). The thick-bedded sandstones are laid open in many spots to the left of that line in the broad hollow separating Quarrel Hill from the Mulloch Quarries. The flaggy central (or Rough-Neuk beds) occur in the quarries on the roads to the south of Mulloch, and the highest yellow pale-hearted flaggy mudstones near the house of High Newlands.

Fossils occur throughout the group, but they are comparatively rare in its highest division. In the exposures of the lower division, in the depression and roadway-quarries west of Mulloch Hill, they occur in incredible profusion, mainly, however, in the form of casts, the shell itself being weathered away and replaced by a soft ochreous matter of a beautiful orange-yellow colour. Here occur in abundance such characteristic forms as *Atrypa hemispherica*, *Orthis reversa*, *Meristella angustifrons*, and *Rhynchonella cuneata*, together with crowd of others, of which the most remarkable is the enigmatical *Nidulites favus*, which was first described from this locality.

In some of the lower beds the shells abound to such an extent that the rock deserves rather the title of an impure limestone than that of a true sandstone. This is the case also with the succeeding central and more flaggy group, of which a deep section is shown in the old quarry of Rough Neuk, one of the most prolific spots for fossils in the Girvan district. Corals are perhaps more abundant in this part of the subgroup than in the beds below; but even here, as throughout the whole series, Brachiopoda are overwhelmingly preponderant.

(ii.) *Pentamerus-Grits and Shales of Newlands.*

It will be apparent on a study of the map and sections (Pl. XXV. 4), that these Mulloch-Hill beds form a well-marked zone, which crosses the great inlier from side to side, reposing on the Ardmillan group of the central areas, and throwing off a fresh series of beds, which occur only in the north-easterly angle of the inlier in the neighbourhood of the farmstead of Newlands and the woods of Glen-shalloch. It will be evident also on further study, that the deposition of these new beds upon the ground is conclusive of their superiority to the Mulloch-Hill rocks; for they constitute a definite zone, having the same strike as the Mulloch-Hill beds themselves, and forming an exterior coating to the latter, as do the Mulloch-Hill beds to the underlying rocks of the Ardmillan group. In developing the interrelations of the subformations composing the

inner shells of the Quarrel-Hill dome, as already described, we have had the advantage of possessing easily interpreted sections of long extent and tolerably continuous throughout. Among these newer and outer beds, on the contrary, the sections are much broken, and some of the component zones of the series are represented in isolated exposures of very insignificant extent. It follows, therefore, that while the general disposition and broader features of the strata are easily made out, we are unable to construct a complete ascending tabulation of the beds, or say with absolute certainty what special thicknesses of rock are locally wanting.

The area occupied by these beds is the extreme north-easterly angle of the Lower Palaeozoic inlier, and is bounded on both its outer margins by faults of great magnitude, at the same time that it is more or less cut up by minor dislocations of dubious position. Nevertheless the component strata are exhibited in so many exposures that there can be no great question respecting their general arrangement, while they are of such a nature that they admit of very convenient subdivision in the field.

Broadly speaking, it may be said that the group is formed of two subdivisions—a lower subdivision of flaggy grits, sandstones, conglomerates, and calcareous flags, and a higher subdivision essentially composed of Graptolitic shales.

The *Lower Subdivision* forms a well-marked band about 200 yards in width, ranging parallel with the highest zone of the underlying Mulloch-Hill beds, from the cottage of Glenwells to the farmhouse of Newlands.

Its lowest beds are exposed at the little burn of Glenwells, to the southward of the Graptolitic mudstones we have referred to the Mulloch-Hill group, the intermediate beds being invisible for a distance of some 40 or 50 yards. These basal beds consist of thick-bedded sandstones and flags, with occasional zones of coarse conglomerate. The coarsest seams of conglomerate occur at the base of the section; but pebbly beds recur again and again in the succession. The matrix of the beds is sandy, and more or less calcareous. About 100 feet of these strata probably occur in the stream itself, between their first appearance above the Graptolitic mudstones and the neighbourhood of the cottage of Glenwells, where they are abruptly truncated by the great bounding fault of Kilkerran and Craighead.

The central and upper beds of this subdivision form several prominent ridges in the cultivated fields in their prolongation along the normal line of strike to the north-east, and in the wooded slopes between Glenwells and the farmhouse of Newlands. They afford, however, no serviceable exposures, except in the bed of the little stream which drains the hill-slopes west of the farmhouse, where the pebbly gritstones are seen in place close to the farmhouse itself, while a series of soft flaggy beds is found a short distance lower down the stream.

An old quarry, a few hundred yards north-east of the farm, has been excavated in the higher zones of this subdivision. No section,

however, is visible; and the quarry itself is filled with fragments of the coarse gritstones collected from off the surface of the fields.

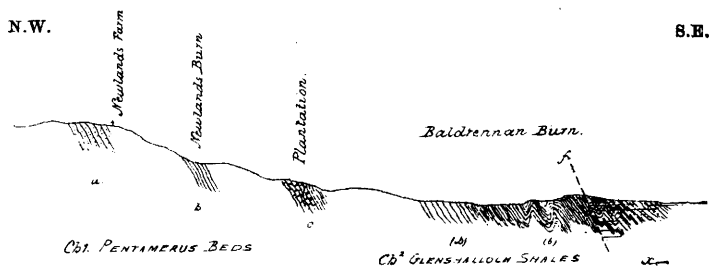
About twenty yards further, in the same direction, however, most valuable testimony is afforded us by a few limited sections in a small burn-course in a narrow strip of plantation. Here occur pale sandstones and calcareous flagstones, weathering of the same light yellow tint as the generality of the rocks of this subdivision. They split up under the hammer into angular fragments, and contain an abundance of casts of fossils. They yield examples of the characteristic Mulloch-Hill forms—*Atrypa hemisphærica*, Sow., *Nidulites fustus*, Salt., *Rhynchonella cuneata*, Dalm., *Ilcenus Thompsoni*, Salt.,—and, in addition, a host of new and very striking forms unknown in the underlying series, including *Pentamerus lens*, *Pentamerus oblongus*, *Atrypa imbricata*, *Phacops Stokesii*, *Proetus Stokesii*, *Encrinurus punctatus*, &c.

Of the strata which follow immediately upon these *Pentamerus*-flagstones, we know very little further from this locality. An exposure of a few of the beds of the same zone occurs in the same plantation a few hundred yards to the northward; and a limited section of shales weathering to a purple colour, in the ditches at the edge of Glenshalloch Wood.

(iii.) *The Graptolitic Shales of Glenshalloch.*

The yellow-weathering *Pentamerus*-conglomerates, grits, and flagstones of Newlands are succeeded to the eastward by a thick mass of soft shales and flags, of a dark greyish-green colour. They

Fig. 23. Section of the *Pentamerus* and Graptolitic Beds of Baldrennan Burn.



x. Lower Carboniferous sandstones, shales, and limestone.

Cb². Glenshalloch shales.

(b). Grey and striped Graptolitic shales and mudstones, with *Rastrites peregrinus*, *Monograptus fimbriatus*, &c.

(a). Pale flagstones, non-fossiliferous.

Cb¹. *Pentamerus*-beds of Newlands.

c. Yellow-weathering calcareous flagstone, with *Pentamerus oblongus*, *Atrypa reticularis*, *Encrinurus punctatus*.

b. Pale blue flagstone.

a. Coarse yellow conglomeratic gritstones.

occupy all the remaining portion of the Lower Palæozoic area, and

are well displayed in the branches of Baldrennan Burn, and in the smaller streams which drain the damp slopes of Glenshalloch Hill.

In the western branch of Baldrennan Burn the lowest visible strata of this higher subdivision consist of yellow-weathering pale-hearted flagstones, which are essentially identical with those of the underlying subgroup. These graduate upwards into a series of dark-grey Graptolitic shales, which extend downwards along the stream-course for a distance of about 150 yards, to the line of the great Craighead fault, where they are crushed against a series of flagstones, shales, and impure limestones, that possibly appertain to the Lower Carboniferous formations.

These Graptolitic shales dip at a steep angle, and appear to be more or less folded. Their united thickness may be estimated at about 200 feet.

Fossils are rare; the only forms are Graptolithina. These occur in some striped seams near the termination of the visible section. The chief forms collected include:—

<i>Rastrites peregrinus</i> , Barr.	<i>Monograptus argutus</i> , Lapw.
<i>Monograptus crenularis</i> , Lapw.	<i>Diplograptus folium</i> , His.
— <i>leptotheca</i> , Lapw.	— <i>tamariscus</i> , Nich.
— <i>gregarius</i> , Lapw.	<i>Climacograptus scalaris</i> , His.
— <i>fimbriatus</i> , Nich.	<i>Retiolites</i> .

Similar strata are seen again in the normal line of strike in the Glenshalloch branch of the Baldrennan Burn, immediately to the north of the Craighead fault, extending up the stream for some distance. The beds have all the characteristics of those of the last-mentioned locality, and afford precisely the same fossils.

The same Graptolitiferous shales are laid open in many of the small gullies that drain Glenshalloch Wood, striking in various directions and affording presumptive evidence of the presence of several cross faults. Along the roadway west of the burn of Glenshalloch they are stained of a purple colour, and are twisted round to the north-west over the arch of the main anticlinal and its accompanying faults. The beds have much the appearance of those of the shaly zones of the Upper Palæozoic rocks of the neighbourhood, and appear to have been mapped as such by the officers of the Geological Survey. Their lithological character and the occasional Graptolites they contain, however, place it beyond question that they are simply a slightly discoloured portion of the Graptolitic strata. The following forms have been collected from them by myself:—

<i>Monograptus fimbriatus</i> , Nich.	<i>Monograptus leptotheca</i> , Lapw.
— <i>triangulatus</i> , Harkness.	<i>Climacograptus scalaris</i> , His.

These Graptolitiferous shales are the highest beds of Lower Palæozoic age exposed in this area. The remaining angle of country lying between Glenshalloch Cottage and the point of convergence of the Craighead and High Newlands faults is wholly covered by drift and brushwood.

Summary.—Our study of the fossiliferous strata of the Girvan succession exposed in the inlier of Craighead and Mulloch Hill has resulted in the detection of an easily interpreted ascending sequence

from the Barren Flagstones of Quarrel Hill into the Graptolitic flagstones and shales of Glenshalloch. The strata of the inlier belong to two distinct groups in the succession, each group being strikingly individualized by lithological characters and by peculiar organic remains. The strata of all except the highest formation of this sequence are exposed in unbroken succession; while there is sufficient evidence available to fix the true place of this final division, and to determine broadly the thickness and general characters and fossils of its natural members. We have, that is to say, in this northern inlier the following ascending sequence:—

- | | | |
|-------------------|---|--|
| Ardmillan Series. | { | <p>Bc. <i>Barren Flagstones</i> of Balweary and Quarrel Hill.</p> <p>Bd. <i>Trinucleus Shales</i> of Drummuck and Lady Burn, consisting of:—</p> <ol style="list-style-type: none"> 1. The fossiliferous basal grits of Auldthorns. 2. The <i>Trinucleus</i>-Mudstones of Lady Burn. 3. The Sandstones and Starfish-beds of Quarrel Hill. |
| Newlands Series. | { | <p>Ca. <i>The Mulloch-Hill Beds</i>, consisting of:—</p> <ol style="list-style-type: none"> 1. The Mulloch-Hill (High Mains) Conglomerate. 2. The Rough-Neuk Shelly Sandstones. 3. The Graptolitic Mudstones of Glenwells Burn. <p>Cb. <i>The Newlands Beds</i>, containing:—</p> <ol style="list-style-type: none"> 1. The <i>Pentamerus</i>-grits and Yellow Flags of Newlands. 2. The Graptolitic (<i>gregarius</i>) Shales of Baldrennan and Glenshalloch Wood. |

(D) STRATA BETWEEN THE SAUGH-HILL FAULT AND THE CAMREGAN LIMESTONE.

With the invaluable aid afforded us by the complete and highly satisfactory succession among the *Trinucleus*-, *Brachiopod*-, and *Pentamerus*-groups we have last determined in the Craighead area, we now return to the rocks of the main plateau, and resume our study of the Lower Palæozoic strata lying to the south of the Girvan Valley.

The strata of this important region which yet remain to be described, lie between the Saugh-Hill fault and the bounding dislocation of Bargany, which has depressed the Carboniferous and Old Red Sandstone rocks of the valley of the Girvan. The area they occupy extends inland from the sea-shore near Shalloch to the village of Straiton upon the upper course of the Girvan Water, a distance of 12 miles; but its greatest breadth rarely exceeds three fourths of a mile. Within the area thus defined, the rocks under notice, as will be apparent upon a study of the maps, are arranged in a series of well-marked petrological zones, which form a succession of very narrow parallel bands, ranging longitudinally through the area from the Braehill fault on the west across the gorge of Penwhapple, and thence into the steep slopes of Bargany and Dailly, till they finally plunge, one by one, below the gently inclined conglomerates, red sandstones, and traps which make up the Old Red Sandstone group of the Hadyard Hills.

At first glance it would seem that nothing could be more simpler than this arrangement. Rock-bands so distinctive in individual peculiarities, and so symmetrically disposed, are naturally expected

by the stratigraphist to be as easily and satisfactorily reduced to the natural order as were the regularly concentric and but slightly disturbed strata of the Craighead area. And, indeed, to a large extent, this expectation is justified by the event; for had the apparent inclination of the strata been trustworthy, there would have been no special difficulty in working out the entire sequence of the remaining rocks bed by bed; but, unfortunately, the repeated foldings and inversions, so palpable among the underlying Ard-millan strata of the Girvan plateau, are here continued and intensified; and the problem of the true sequence of the visible zones in the strata of the immediate neighbourhood of the Saugh-Hill fault, upon more extended examination, appears wellnigh unsolvable.

It will be seen from the map (Pl. XXV. 1) that a band of *Pentamerus*-grits and limestones (C c) forms what may conveniently be termed the longitudinal axis of the Lower Palæozoic region yet to be described. This band, which is traceable from end to end of its course, from the Braehill fault to the Hadyard Hills, forms a clear and easily recognizable horizon, or datum-line, to which to refer the less completely exposed strata of the region. North of this band, the strata, though inverted in inclination, present no special difficulties; but between it and the Saugh-Hill fault, the visible phenomena demand the most careful scrutiny.

This intermediate area is occupied by a series of hard gritstones and fine conglomerates, varied by occasional seams of flagstones, and thick bands of green, grey, and black Graptolitiferous shales. A kind of rude parallelism is evident among the beds; but the manner in which certain seams appear to thicken out in one locality, and to thin away in others, while elsewhere they seem at the first glance to be replaced by correspondent groups of wholly distinct petrographical characters, forces us to demand a much larger mass of testimony in favour of our conclusions than that which has satisfied us in the less disturbed areas already described.

(a) *Section of the Graptolitic Shales and Grits in Penwhapple Glen.*

The deep glen of Penwhapple affords by far the most-satisfactory and continuous section of these dubious gritstones and shales. They follow in immediate geographical succession to the Barren Flagstones of that gorge already described, from which they are divided by the important Saugh-Hill fault.

Northward from the line of this fault they occupy the bed and banks of the stream for about a quarter of a mile of its course, until we reach the datum-line of *Pentamerus*-limestone last mentioned.

The most cursory examination of the grits and shales by one who has already studied the strata of Newlands and Glenshalloch, described in the preceding section, is almost sufficient to convince him that these beds, as seen in Penwhapple Glen, are identical in their lithological features with the yellow grits and Graptolitic flagstones of the northern locality; and whatever doubts he may feel as to their general correspondence with the northern strata are soon dispelled if he take the trouble to collect the fossils from these Pen-

whapple beds, as he will recognize amongst them some of the most peculiar and characteristic Glenshalloch forms.

Hence, if no unconformability intervenes to cause a stratigraphical break in the succession we have already developed (and, as we have seen, there appears to be no evidence in the northern inlier in favour of such a break), it is clear at the outset that between these Graptolite-bearing shales of Penwhapple and the Barren Flagstones, with which the Saugh-Hill fault has placed them in physical contact to the south, there are actually missing the entire subformations of the *Drummuck Mudstones* and the *Mulloch-Hill Sandstones*, a vertical extent of rock at least 600 feet in collective thickness.

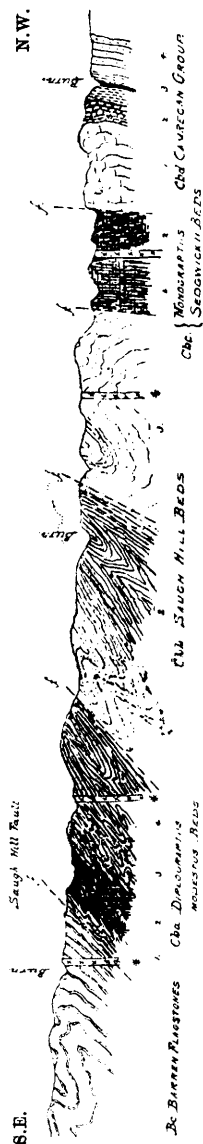
A more extended examination of these Graptolitic flagstones and grits, as here exhibited, while it will finally fix in the mind of the investigator the conviction of their general identity with the similar Glenshalloch series, will have the further result of showing him that some of the most conspicuous zones of rock apparent in that area are missing from this Penwhapple section, while other bands are here very conspicuous, which are apparently wanting in the Newlands and Glenshalloch area.

We have shown that, in spite of the innumerable inversions and dislocations determinable among the Ardmillan strata of the higher parts of Penwhapple Glen, there is nevertheless a generally ascending succession as we pass over the edges of the strata from south to north. As the strata now under examination are similarly affected by physical accidents, there is a strong *à priori* probability, amounting almost to certainty, that they will be found to be subject to the same general rule. We shall, indeed, show in the sequel that even the regularly disposed rock-bands on the northern side of the datum-line of the Camregan *Pentamerus*-limestone follow precisely the same rule of inverted succession.

Starting, therefore, from the line of the Saugh-Hill fault, let us study the Penwhapple section in detail, regarding the visible strata as inverted in position, and treating of the whole as a generally ascending sequence (fig. 24).

(Cba) *Diplograptus-modestus* Shales.—The strata which follow immediately upon the great dislocation form a thick zone of dark grey shales (Cba) with a few seams of flagstones. Its lowest beds are thick-bedded black mudstones, crowded with Graptolites in an excellent state of preservation. The basal beds of the group along the line of the fault itself are green flaggy rocks, concretionary and more or less calcareous. From these I have procured *Pentamerus* sp. The black mudstones themselves are crowded with *Diplograptus tamariscus*, Nich., *D. modestus*, Lapw., *Climacograptus normalis*, Lapw., *Monograptus tenuis*, Portl., *M. crenularis*, Lapw., *M. leptotheca*, Lapw., together with many fragments of Crustacea and Orthoceratites. These mudstones graduate upwards into the main mass of the grey shales through a small group of striped shales, containing an abundance of the same fossils with well-preserved Orthoceratites.

Fig. 24.—Section of the Newlands Rocks of Penwhapple Glen.



C. NEWLANDS SERIES:—

Cbd. Camregan beds.

- (4) Thick-bedded yellow gritstones, non-fossiliferous.
- (3) Purple mudstones, with zone of Graptolitic shale (*Rastrites-maximus* band), with *Rastrites maximus*, *Monograptus turriculatus*, &c.
- (2) Calcareous flagstones and shales (Camregan or Upper *Pentamerus*-limestone), with *Pentamerus oblongus*, *Sirophomena applanata*, &c.
- (1) Thick-bedded grey and yellow grits and sandstones, with *Rhynchonella cuneata* &c.

Cbc. *Monograptus-Sedgwickii* beds.

- (2) Black carbonaceous and pyritous shales and mudstones, with *Monograptus Sedgwickii*, *Rastrites peregrinus*, &c.
- (1) Grey and green mudstones, non-fossiliferous.

f.f. Faults.

Cbb. Saugh-Hill beds.

3. Thick-bedded grey grits, with small pebbles.
2. Flaggy shales, non-fossiliferous.
1. Coarse grits and flagstones, pale grey, with occasional pebbly seams.

Cba. *Diplograptus-modestus* shales.

4. Grey and green shales, generally unfossiliferous.
3. Striped shales, with Graptolites, Phyllopoets, and Orthoceratites.
2. Black carbonaceous and pyritous mudstones, with *Diplograptus modestus*, *Monograptus leptotheca*, &c.
1. Grey and green mudstones and shales, with *Pentamerus* sp.

B. ARDMILLAN SERIES:—

Bc. Barren flagstones.

- Upper zones with *Diplograptus truncatus*.

* Basaltic dykes.

In the grey shales themselves Graptolites are remarkably rare. The only forms collected by myself are *Diplograptus modestus*, Lapw., and *Diplograptus*, sp.

(Cbb.) *Grey Flays and Grits*.—The grey shales are followed by a similar thickness of hard grey gritstones (Cbb). Many of the beds are three or four feet in thickness, and are filled with small quartz pebbles about the size of a pea. They are associated with more thinly bedded flagstones without quartz pebbles. The beds are usually of a pale grey interiorly, and the majority weather exteriorly in the stream-course to an orange-yellow tinge. They are greatly twisted and broken; and no reliable estimate can be formed of their thickness. No fossils are known from this group.

This grit series is succeeded by a second zone of the grey shales so characteristic of the group. These are very similar to those of the first zone, but are more micaceous and iron-stained; but, to judge from the general disposition of the strata (see fig. 24), they are merely a repetition of the same beds. They contain no visible fossils in this locality.

A second grit band follows, resembling the first band in all essentials, but containing more of the thick-bedded pea-grits, some bands of which are at least six feet in thickness.

(Cbc.) *Monograptus-Sedgwickii Mudstones*.—Above follows the third and final shaly zone of the series. This is composed of a most conspicuous group of grey and black shales, apparently more than a hundred feet in thickness. The lower or southern half of the band is formed of greyish-green shales identical with those of the previous shaly zone, and like them wholly devoid of organic remains. The upper or northern half, however, is most unique in its lithological features.

It consists essentially of soft shaly mudstones, containing a large proportion of carbonaceous matter; and impregnated with sulphate of iron. The entire group is stained of a deep iron-shot colour, and is so excessively crushed and contorted that the bedding can only be made out with the utmost difficulty. Calcareous matter is occasionally present in notable quantity; and large nodular concretions are abundant in the steep cliffs of the rock which overhang the right bank of the stream.

Graptolites are abundant, but are most difficult of extraction, in consequence of the crushing to which these beds have been subjected; while fragments of Crustacea and Orthoceratites are occasionally seen.

The Graptolites as a whole are very distinct from those of the black shale near the Saugh-Hill fault at the base of our section. A few of the forms there obtainable are still present, viz. :—

Diplograptus tamariscus, *Nich.*
Monograptus tenuis, *Portl.*

| *Climacograptus normalis*, *Lapw.*
| *Monograptus attenuatus*, *Hopk.*

But they are accompanied by a host of other forms unknown in the basal beds, chiefly the familiar species :—

Rastrites peregrinus, <i>Barr.</i>	Monograptus intermedius, <i>Carr.</i>
— hybridus, <i>Lapw.</i>	— spiralis, <i>His.</i>
Monograptus Sedgwicki, <i>Portl.</i>	Diplograptus folium, <i>His.</i>
— Hisingeri, <i>Carr.</i>	— palmeus, <i>Barr.</i>
	— Hughesii, <i>Nich.</i>

The soft black mudstones terminate abruptly to the north against the series of grits and sandstones which form our datum-zone of the *Pentamerus*-beds of Camregan.

Our study of the Graptolitic shales and gritstones of Penwhapple have thus resulted in showing us that in this locality there are two distinct Graptolitiferosus zones, one at each end of the section—the earlier one characterized by *Diplograptus modestus*, Lapw., and a few other forms, and the later one by *Monograptus Sedgwickii*, Portl., and its usual associates. These two terminal zones are here divided from each other by an intermediate zone of barren pale-hearted and pebbly gritstone.

The *M. Sedgwickii* bed at the summit of the section is clearly absent from the Glenshalloch area; nor is there any thing in that district we can satisfactorily parallel with the central grits and shales of Penwhapple. The only strata, therefore, that we may regard as possibly common to our Glenshalloch and Penwhapple sections are the grey shales of the first zone; and even of these the black *D. modestus* mudstones at their base are unseen in the northern inlier.

If, therefore, the Newlands *Pentamerus*-grits which underlie the main mass of the Glenshalloch shales, conglomerates, and limestones are present in the southern area, we can only expect to find them in the immediate neighbourhood of the Saugh-Hill fault.

(b) Confirmatory Section of Saugh Hill.

Eastward of Penwhapple Glen no good sections of these strata are visible; but westward their beds are greatly developed and are fairly exhibited to the investigator.

Saugh-Hill area (Diplograptus-modestus Shales).—Excellent sections of the basal zone of grey shales are seen in the Tralorg Burn. The inverted beds dip with tolerable regularity towards the line of the Saugh-Hill fault; but we find evidence that the great dislocation crosses different horizons along its course, in the presence of soft white mudstones and shales which are unknown in the Penwhapple section; while occasional bosses of a coarse pebbly conglomerate are found along the same line.

As the line of grey shales is followed over the higher ground to the west, the section becomes obscured by vegetation, and we find no exposure of the *Diplograptus-modestus* band until we reach the head of Saughill Burn, more than a mile to the westward, where the many small drains afford a few insignificant exposures.

On the west side of Saughill Burn, at the precise point where the Saugh-Hill fault is cut off by a transverse dislocation, a good section of the Graptolite-bearing beds of a part of the grey-shale band is shown in the miniature cliffs by the side of the almost obliterated hill-road. Here dark carbonaceous shales dip into the Saugh-Hill fault at a

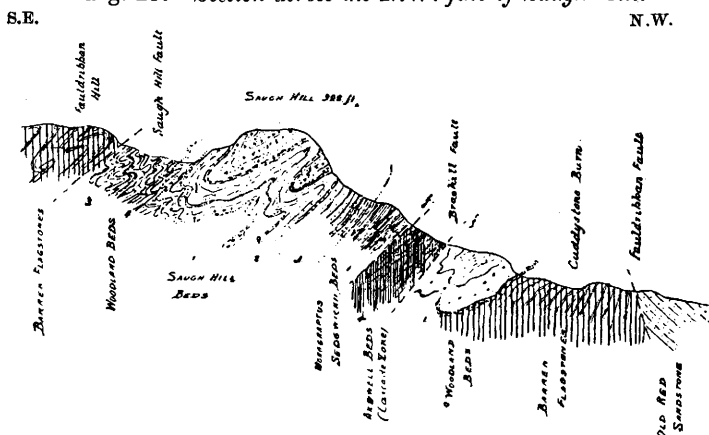
medium angle, and afford proofs of the extension of our lowest Penwhapple shale-band to this spot, both in their petrographical features, and the presence of

Diplograptus tamariscus, <i>Nich.</i>	Monograptus cyphus, <i>Lapw.</i>
— modestus, <i>Lapw.</i>	— gregarius, <i>Lapw.</i>
Climacograptus normalis, <i>Lapw.</i>	— tenuis, <i>Portl.</i>

and the generality of the Penwhapple forms (see fig. 25).

At this point the fault of Saugh-hill Burn brings the band to a sudden termination, the Ardmillan beds occupying the hill-slopes immediately to the westward.

Fig. 25.—Section across the N.W. face of Saugh Hill.



Ardmillan Series :—

Ba⁴. Ardwell Beds. Thin-bedded mudstones and conglomeratic grits of the Cascade-zone, with *Dicellograptus Forchhammeri*, *Dicranograptus Nicholsoni*, &c.

Bc. Barren Flagstones, with *Nematolites*.

(O) Newlands Series :—

Oba. Woodland beds.

(2) Craigs Kelly conglomerate?

(3) Striped shales, with *Diplograptus modestus*, *Monograptus leptotheca*, &c.

(4) Grey shales, non-fossiliferous.

Ocb. Saugh-Hill beds.

(1) Grits and flagstones and quartz conglomerate, grey, with *Climacograptus* &c.

(2) Calcareous band.

(3) Pale yellow sandstones, grits, and conglomerates.

Ocb. *Monograptus-Sedgwickii* beds.

1. Grey and green shales and thin-bedded flagstones, with *Rastrites peregrinus*, *Diplograptus palmeus*, &c.

Penwhapple Grits and Shales.—Returning therefore to our continuous section in Penwhapple Glen, we next proceed to define the distribution of the succeeding zones of pebbly grits which there

intervene to separate the grey-shale zone from the *M.-Sedgwickii* mudstones.

The yellow grits, imitating precisely in the gentle curvature of their strike the range of the grey shales to the south, sweep up from the banks of Penwhapple into the hill of Camregan, forming a broad and well-marked mound upon the surface of the ground. Thence they are followed continuously along the ridge into the summit of Saugh Hill, forming a broad mound-like ridge, from 700 to 900 feet in height and more than two miles in length, which looks down upon Girvan and the cultivated slopes of the Brae. At its eastern extremity the extent of surface floored with this band of coarse grits is not more than 300 feet in width; but as it proceeds to the eastwards, it rapidly enlarges its diameter, till finally, upon the summit of Saugh Hill (fig. 25), it cannot be less than 600 feet wide; and the group attains here a geographical importance which has suggested to me the title of *Saugh-Hill Group* as the collective name for the entire Gritstone and Graptoliferous series.

The coarse grits are exposed in a host of quarries and natural sections along the ridge; and much additional knowledge of the physical characteristics of the group is obtainable. In addition to the coarse and more or less flaggy gritstones of Penwhapple Glen, we have here actual beds of conglomerates with pebbles an inch or two in diameter and peculiar breccias made up of angular fragments of quartz, gritstones and shales, imbedded in a strange matrix of a greyish-white colour. Some of the associated grits are of great thickness, but are generally separable into large parallel flags. The entire group is very sandy in character; the majority of the beds weather to an orange-yellow, and occasionally even to a faint pink colour. Fossils are said to have been procured from these beds; but I have never yet been able to detect a single fragment of anything organic within them.

The great width of the band upon Saugh Hill is undoubtedly due to the fact that the beds are repeatedly folded. A peculiar rock, having the general character of a bastard limestone, makes its appearance again and again as we cross the band transversely, and affords a good idea of the number of hidden folds.

The narrow diameter of the same zone near Penwhapple is in all probability due to faulting, as there are certainly several strata upon Saugh Hill that are wanting in our Penwhapple section.

Monograptus-Sedgwickii Mudstones.—Between the summit of the Saugh-Hill ridge, which is occupied by the yellow grits and sandstones described, and the general datum-line of the axial Camregan limestone group, few sections are visible; but all the evidences they afford us concur to prove that this interesting band of country is mainly occupied by the final or *M.-Sedgwickii* band of the Saugh-Hill group. The second grit of Penwhapple cannot be traced for any great distance westwards; and its place is occupied by dark shales, apparently of the *M.-Sedgwickii* zone, within a quarter of a mile of the glen. Grey flaggy shales similar to those in contact with these grits are traceable bounding the Saugh-Hill sandstones along the northern

slopes of its prominent ridge until we reach the north and south fence which separates the properties of Killochan and Bargany. A little to the west of this fence the *M.-Sedgwickii* beds are seen *in situ*, retaining all the characteristics they exhibited in Penwhapple glen, and affording :—

<i>Rastrites hybridus</i> , <i>Lapw.</i>		<i>Diplograptus palmeus</i> , <i>Barr.</i>
<i>Monograptus Sedgwickii</i> , <i>Portl.</i>		— <i>tamariscus</i> , <i>Nich.</i>
— <i>spiralis</i> , <i>Gemm.</i>		<i>Climacograptus normalis</i> , <i>Lapw.</i>
— <i>lobiferus</i> , <i>M^cCoy.</i>		

The northern slopes of Saugh Hill are occupied by grey shales and flags probably a little lower in the series. These are well exposed in many sections on the hill-face, very conspicuous from the valley below. They contain few fossils, the chief forms I have been able to procure from them being *Monograptus gregarius*, *Lapw.*, and *Rastrites peregrinus*, *Barr.*

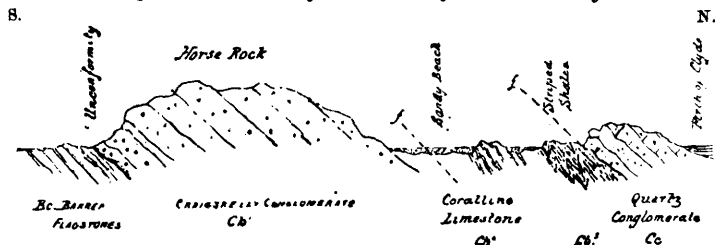
(c) *Coast-area of Shalloch and Woodland.*

The broad band of yellow gritstone and grey Graptolitiferous shales we have traced from the gorge of Penwhapple into the heights overlooking the seaport of Girvan is abruptly truncated, where it attains its widest geographical extension at the western extremity of Saugh Hill, by the transverse fault of Saugh-Hill Burn. The area through which its strata would naturally be prolonged is occupied by the older and very distinct Ardmillan Shales, which strike almost at right angles to the Saugh-Hill band. These Ardmillan strata, after gaining their normal strike in Piedmont Glen, are continued to the west in the coast-platform of Shalloch and Ardwell as far as the distant headland of Woodland and Kennedy's Pass, between which, as we have shown, they attain their most typical development in the Girvan region.

The great fault of Braehill and Dailly, which forms the southern boundary of the Carboniferous and Old Red beds of the Girvan valley, and which crosses the front of Saugh Hill at the head of Cuddystone Burn, comes upon the shore at Shalloch Forge and is prolonged south-westwards down the entire length of the coast-platform. It runs in a straight line parallel with the edge of the shore, and throws down against the flaggy Ardmillan series a very different set of beds of a most peculiar petrological character. They consist of massive boulder-conglomerates, pebbly grits, and striped shales. The hard and intractable nature of these peculiar strata, as contrasted with the more easily eroded Ardmillan beds with which they are in contact, has resulted in their being preserved as a line of conspicuous reefs, which rise up boldly out of deep water, and form a protecting fringe along the seaward edge of the platform. At high water they compose a line of long and narrow islands, against which the waves dash their fiercest, while the interior parts of the platform, occupied by the Ardmillan series, are covered from sight by the less agitated waters which force their way through the many openings in this natural breakwater.

1. *Shalloch Forge*.—At the back of the blacksmith's shop of Shalloch, where the Braehill fault comes upon the sea-shore, we find excellent exposures of the strata of this conspicuous protecting series. The general succession there apparent is given in the following section (fig. 26).

Fig. 26.—Section of the Rocks of Shalloch Forge.



B. Ardmillan Series:—

Bc. Barren flagstones.

C. Newlands Series:—

Cba. Woodland beds.

Cba¹. Coarse green boulder-conglomerate of Craigskeilly.

Cba². Coralline limestone, with *Pentamerus oblongus* &c.

Cba³. Striped shales, with *Diplograptus modestus*, *Monograptus leptotheca*, &c.

Cc. Saugh-Hill beds.

Cc¹. Quartz conglomerate of Shalloch Forge.

f f. Faults.

The beds which have the appearance of being lowest in the succession are certain green flagstones and shales (Bc), lithologically similar to those of the Barren Flagstones of the Ardmillan group and the green flagstones occasionally found in the Graptolitifera zones of the Saugh-Hill beds. They are only seen at low water, immediately to the south of the rugged boss of the Horse Rock, which at high tide forms the most northerly of the protecting fringe of islands already referred to. Of these green flagstones only about 30 feet are seen, and they dip at an angle of about 45 degrees to the northward, and are succeeded, with a slight unconformity, by the remarkable mass of boulder conglomerate of which the Horse Rock itself is made up. This conglomerate is from 50 to 60 feet in total thickness, and contains many interbedded seams of gritstones, which show that the general inclination of the rock is almost identical with that of the flagstones below. The main mass of the conglomerate is made up of well-rounded boulders varying from one inch to a foot and a half in diameter. They consist of pieces of granite, porphyry, felstone, greywacke, shale, Lydian stone, quartz, and jasper, imbedded in a coarse sandy matrix of a dark green colour and excessively indurated. In its general aspect the rock reminds us of the Benan Conglomerate, and also in the special association of its enclosed boulders, but it is altogether harder and much more firmly compacted than is generally the case with that deposit.

Above this Horse-Rock conglomerate there is a break in the

section of some 30 or 40 feet, and the next strata seen are very different in their mineralogical characters. They protrude in little bosses from the sand of the small beach immediately north of the Horse Rock itself, and consist of a few feet of highly calcareous flagstone, or "bastard limestone," much altered and disturbed, but abounding in casts of *Pentamerus oblongus* and other Brachiopoda, together with well-preserved examples of *Alveolites Labechei*, *Favosites gothlandica*, and other corals.

After a second hiatus of less geographical importance than the former, these Coralline Limestones are succeeded by a thin group of Graptolitiforous shales, which are traceable from the back of the smithy, parallel to the two zones already noticed, for about 60 yards out to sea. They consist of dark greyish-blue and somewhat flaggy beds veined by seams of carbonaceous matter. They are thrown into innumerable wrinkles and contortions, which are beautifully exhibited on the wave-washed shore at the back of the Forge.

These shales contain an abundance of fairly preserved Graptolites of the species *Diplograptus modestus*, Lapw., *Climacograptus normalis*, Lapw., *Monograptus tenuis*, Portl., and *M. cyphus*, Lapw., together with forms of *Dictyonema* and *Orthoceras*.

The Graptolitic shales are followed abruptly by a conspicuous group of conglomeratic sandstones. They form a broad band lying to the north of the shales, and ranging outwards from the roadway into the deep water beyond the Horse Rock. These superior beds are emphatically bedded sandstones, much softer and looser in texture than the generality of the Lower Palæozoic rocks; they contain an abundance of white quartz pebbles, often rounded, but occasionally angular, scattered confusedly through the main body of the rock. The basal beds are filled with patches and angular fragments of the underlying shales, and the two formations are dovetailed into each other in a most intricate manner, rendering the detection of their natural relationship more a matter of speculation than of absolute certainty.

The base of these conglomeratic sandstones must originally have been unconformable with the Graptolitiforous shales with which they are in contact. Although the two strikingly distinct rock-groups are greatly crumpled and intermixed along the line of junction, a cautious study of the phenomena apparent places the fact of their original discordance almost beyond question.

Abundant small fragments and many large slabs of the neighbouring grey shales occur in the heart of the sandstones, sometimes lying parallel with the plane of bedding, sometimes inclined at a wide angle thereto. Again, the lowest visible zone of the sandstone conglomerate is filled with pieces of the same striped shales, which are surrounded and buried up by the coarser pebbly rock, as if they had projected from the sea-floor at the time of the formation of the sandstone, and had been enveloped and buried by the latter being deposited around and above them. Thus it is highly probable that the conglomeratic sandstones which now dip generally with the underlying beds were originally somewhat discordant with them,

and that their present steep dip is owing to the intercalary fault we have referred to. This fault, however, while it has permitted these overlying beds to be crushed into a general correspondence in inclination with the underlying strata, has not actually allowed of their removal far from their original position, the angular fragments included in the sandstones being primarily derived from the striped shales with which they are still in contact.

This quartz conglomerate is, in all likelihood, identical with a similar band which is found at the base of the Saugh-Hill rocks, running from the head of Saugh-Hill Burn to the eastern slopes of Camregan Hill. It is there divided from the striped and grey shales of the *Diplograptus-modestus* beds by a narrow strip of flaggy greywackes with *Climacograptus normalis*. (See Map, Pl. XXV. 1, and Section, fig. 25.)

Turning next to the neighbouring Graptolitic shales and associated strata of Shalloch Forge, and bearing in mind the fact of the fault and possible unconformity between them and the conglomeratic sandstones, we find that they present us with no further difficulty. The observer who has made himself familiar with the section of the Saugh-Hill shales and gritstones in Penwhapple Glen will at once refer the striped shales here exhibited to the zone of striped shales in the immediate neighbourhood of the great fault of Penwhapple; for not only are the strata lithologically similar in the two localities, but their fossils are absolutely identical species for species.

The underlying Penwhapple zone of black mudstone should here be found in the blank which intervenes between the striped shales and the Coralline limestone with *Pentamerus*, which latter affords an additional link of correspondence with the Penwhapple section, where we find the merest fragment of the Coralline seam in the lowest concretionary rock with *Pentamerus* and Corals.

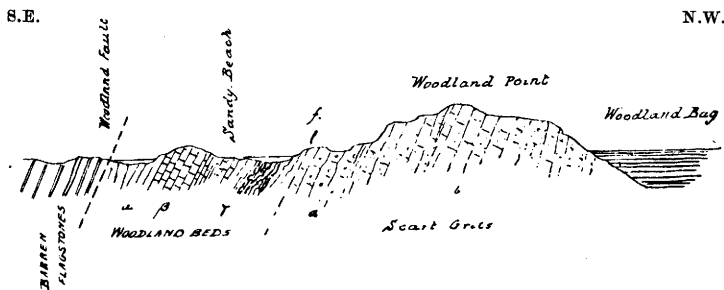
In the Saugh-Hill section of Penwhapple this Coralline seam is the lowest rock exposed; but if no hidden fault intervene between the bed, as here exhibited, and the coarse Horse-Rock conglomerate, we are here enabled to descend much lower in the succession, and to provisionally locate the boulder-beds of the Horse Rock immediately below the base of the Penwhapple and Saugh-Hill sections, and immediately subjacent to the Coralline or *Pentamerus*-band.

2. *Craigskelly*.—The boulder-bed of the Horse Rock is prolonged south-westward into the long mound-like boss of Craigskelly. This forms a low rugged island at high water, but is connected with the shore by a sandy beach at low states of the tide. The coarse strata of the Horse Rock are here perpendicular in attitude, and have a transverse diameter at least double that they possess in the former locality. The boulder-beds already described occupy the south-eastern half of the island; while all the western half is formed of hard-bedded gritstones several feet in thickness, plunging suddenly downwards into deep water. These gritstones weather to a yellowish tint, and a few have the peculiar pink tinge which marks many of the rocks of Saugh Hill, with which also they agree in the pale grey

tint of their unweathered interior. In spite of their forbidding aspect, they contain many fragments of well-marked fossils, principally *Strophomena grandis*, *Atrypa reticularis*, *A. hemisphærica*, *Dictyonema*.

3. *Woodland Point*.—The line of reefs formed by these Saugh-Hill strata is broken beyond the boss of Craigs Kelly by the wide opening of Shalloch Bay. Near the centre of this bay, however, a similar band of hard yellow gritstones rises again into view, forming the two small islands of the Scart rocks, which are isolated from the shore even at lowest tides. At the succeeding headland of Woodland Point, the band comes for the last time upon the shore-line, and we are here presented with the most fossiliferous exposure of the Lower Saugh-Hill strata in the Girvan region.

Fig. 27.—Section of the Strata at Woodland Point.



C. Newlands Series:—

Scart grits (? Saugh-Hill beds).

(b) Thick-bedded pale-hearted gritstones, with occasional flags.

(a) Quartz conglomerate and pebble-beds.

Woodland beds.

γ. Thin-bedded soft shales and mudstones, with carbonaceous seams: *Monograptus leptotheca*, *Climacograptus normalis*, &c., *Orthoceras*, *Encrinurus*, *Atrypa*.

β. Calcareous flagstones (Woodland or Lower *Pentamerus*-limestone), crowded with *Stricklandinia lens*, *Pentamerus oblongus*, *Strophomena grandis*, &c.

α. Calcareous flags and shales, with few fossils.

B. Ardmillan Series:—Barren Flagstones.

f. Faults.

The headland itself is composed of a long reef of gritstone, which at low water is united to the main shore-line by a sandy beach, but at high water forms a rugged island of the type of Craigs Kelly. The above section (fig. 27) affords a general idea of the disposition of the strata at this interesting locality.

The main body of the reef is formed of a series of yellow-weathering gritstones (b), in beds varying from 2 to 4 feet in thickness. They are pale-hearted and very intractable under the hammer; but the matrix is not coarser than that of the average gritstones of Saugh Hill and Penwhapple. The breadth of the reef occupied by these massive gritstones cannot be less than 100 feet; but the beds, through varying but little from the perpendicular, afford indications

of folding and dislocation. The inner edges of the reef are formed by coarser beds (*a*), which are filled with abundant fragments of quartz, gritstone, and igneous rocks, and deserve rather the title of coarse pebbly conglomerates.

Between these conglomerates and the beds next to be described, the phenomena visible upon the ground give rise to the suspicion that a fault is present; but of its magnitude and effect in interrupting the natural sequence no evidence is forthcoming.

The low and partly sand-covered area lying between these conglomerates and the great Braehill fault, which brings up the Barren Flagstones of the much older Ardmillan series, is occupied by a series of calcareous strata most prolific in fossils. These are exposed in some insignificant bosses of rock that are accessible only at low water, and in occasional patches of strata which project here and there through the floor of the sandy beach.

Next to the intermittent conglomeratic bands last noticed follow certain green flaggy shales (γ), striped with lines of carbon and seams of calcareous matter. Only a few feet of these beds are exposed, but they are most prolific in beautifully preserved Graptolites, especially *Diplograptus modestus*, Lapw., *Climacograptus normalis*, Lapw., *Monograptus tenuis*, Portl., *M. gregarius*, Lapw., *M. leptotheca*, Lapw., together with fairly preserved Brachiopoda and forms of *Orthoceras*.

These beds are followed to the south-east by soft green shales, highly calcareous, and abounding with most exquisitely preserved examples of *Strophomena grandis*, *Atrypa reticularis*, *A. imbricata*, *Orthis elegantula*, and *Leptaena quinquecostata*.

They are succeeded by a thickness of about 30 feet of highly calcareous flagstones or limestones (β), which form prominent ridges on both sides of the peninsula. These limestone flags are arranged in beds which vary from a foot to an inch in thickness, and are almost made up of organic remains. Some of the beds are a compacted mass of *Stricklandinia lens*; others are crowded with *Strophomena grandis*; but all are indeed most astonishingly prolific. Here I have collected *Stricklandinia lens*, *Pentamerus oblongus*, *Atrypa reticularis*, *A. imbricata*, *Bronteus*, *Encrinurus punctatus*, *Holopella*, and a host of Corals, Eocrinites, and *Orthocera*.

About 30 or 40 feet of these *Pentamerus*-limestones are here exposed, dipping at an apparent angle of about 60° to the south-west, that is to say into the line of the great longitudinal fault which here intervenes to separate them from the ancient barren flagstones of the Ardmillan series.

That these *Pentamerus*-limestones, Graptolitic shales, and massive gritstones belong to the same special group as the rocks forming the more easterly portions of this rock-reef as exposed in Craigs Kelly and its neighbourhood is absolutely certain. The rocks of this reef have a special character of their own, easily recognizable upon the ground, which distinguishes them at sight from the flaggy Ardmillan strata with which they are in unnatural contact, while the fossils are the same along the entire extent of the reef.

If the Graptolitiferous striped shales of Shalloch Forge are, as I have already argued, the highest visible beds of these Craigs Kelly rocks, the analogy furnished by the structure of the area already studied would lead us to infer that the band of Woodland limestone which lies upon the opposite margin of the band along the line of the great fault must be the lowest visible zone of the series as here exhibited.

It is not wholly impossible, however, that the rocks of this reef are actually arranged in the anticlinal form suggested by the diverging dips upon the opposite margins. If so, the Woodland limestone would form part of the Coralline lime-band of the Horse Rock and the Woodland grits, being lost in the fault at the base of that limestone, a part of them only being seen upon the north-western flanks of Craigs Kelly, while the boulder-band of the Horse Rock would then form the lowest bed of the series. But the presence of the soft Graptolitic mudstones between the Woodland limestone and the Scart grits, the similarity of the basement-beds of the latter to the quartz conglomerate of Shalloch Forge, together with the general correspondence in petrological characters of the Scart grits and those of Saugh Hill, all concur to favour the theory of the general identity of the Woodland limestone and the Coralline band. In this case the sequence of the Newlands Series along the shore-line will stand as follows :—

Cbb. Saugh-Hill beds.	{ 2. Scart Grits and Flagstones. 1. Quartz conglomerate.
Oba. Woodland beds.	{ 4. Grey non-fossiliferous shales of Penwhapple. 3. Striped and black Graptolite-shales and mudstones. 2. Woodland Limestone. 1. Craigs Kelly Boulder-conglomerate.

On this view we are able to reconcile several important physical facts obtainable within the Girvan region.

(1) At the south-eastern extremity of the Horse Rock, where the Craigs Kelly boulder-bed is seen in contact with the underlying green flagstones and shales, there is a distinct appearance of unconformability, the coarse boulder-beds resting upon the slightly eroded faces of the older beds.

(2) On the north-western flank of Saugh Hill a boulder-conglomerate, probably identical with that of Craigs Kelly, rests at once upon the Barren Flagstones of Cuddystone Burn (see fig. 25).

(3) The united thickness of the Woodland and Saugh-Hill sub-formations, thus arranged, agrees closely with that of their representatives, the coarse conglomerates and yellow flagstones of Newlands and Craigs Kelly, in the northern inlier.

(4) An unconformability at the base of the Craigs Kelly conglomerate rids us of the necessity for assuming the presence of the Drummuck and Mulloch-Hill formations south of the Girvan valley, and thus reduces the theoretical downthrow of the Saugh-Hill and Woodland faults to comparative insignificance.

It is interesting to notice also that this special stratigraphical break occurs at precisely the same palæontological horizon as that which divides the so-called Lower and Upper Silurian of Southern Britain.

If these conclusions are accepted, we have in the strata belonging to the same general group as the Newlands and Glenshalloch beds of the northern inlier the following zones south of the datum-line of the Camregan limestone :—

- | | |
|--|---|
| Cbc. <i>Monograptus Sedgwickii</i> beds. 100 feet. | { 2. Thick zone of Graptolitic shales, aluminiferous and concretionary, with <i>Monograptus Sedgwickii</i> .
1. Grey and green, non-fossiliferous shales and mudstones. |
| Cbb. Saugh-Hill Grits and Shales. 200 ft. | { 3. Coarse yellow sandstones, flags, and grits, with pebbles.
2. Pale yellow grits and flags, with a zone of impure calcareous rock.
1. Quartz conglomerate and grits. |
| Cba. Woodland beds. 200 feet. | { 4. Green, non-fossiliferous shales.
3. Black and striped Graptolitic shales.
2. Woodland or Lower <i>Pentamerus</i> -limestone.
1. Craigs Kelly conglomerate. |

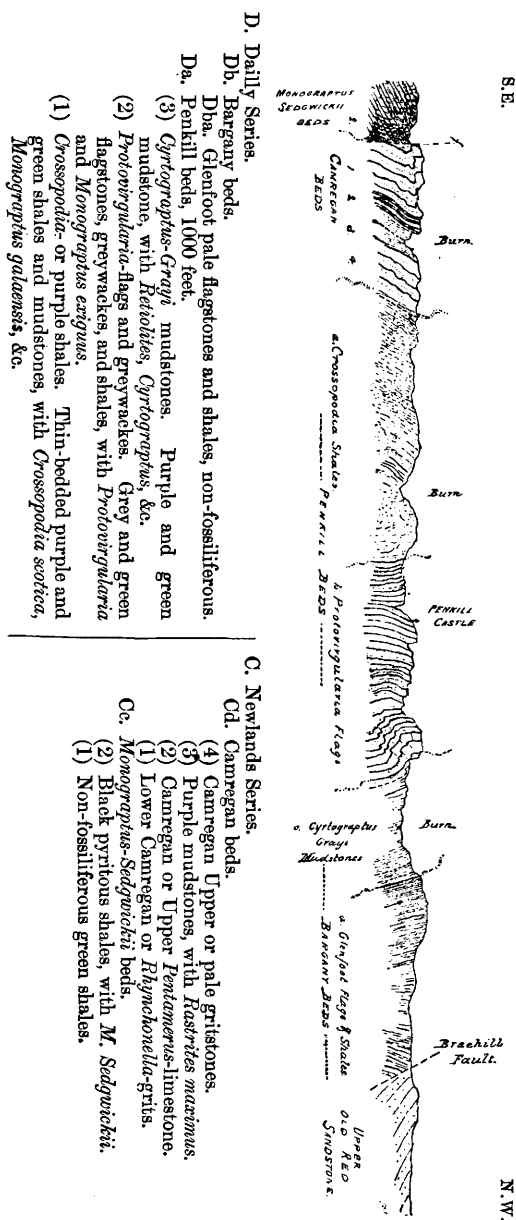
(E) STRATA NORTH OF THE CAMREGAN LIMESTONE.

(a) *The Camregan Limestone and its associated Strata.*

Having completed our examination of the shattered and more or less incomplete sections of the wide band of Saugh-Hill rocks, we now enter upon the study of those found in the area lying immediately to the northward. This new area is, by contrast, one of great geological simplicity, where, as a consequence, our task of determining the order of succession is comparatively easy and satisfactory (Plate XXV. 1).

It is formed of a narrow belt of Lower Palæozoic strata, about 12 miles in length, lying between the band of dark mudstone with *Monograptus Sedgwickii*, which forms the terminal member of the Saugh-Hill Group, and a line drawn parallel with this zone about half a mile to the northward. The belt of country thus defined, as we have more than once pointed out, is occupied by several parallel zones of rock, individualized by well-marked petrographical and palæontological peculiarities, and traceable longitudinally through the area from the Braehill fault on the west to the Old Red Sandstone of the Hadyard Hills on the east.

In the complete transverse section of these strata afforded by the gorge of Penwhapple to the south of the old castle of Penkill (fig. 28) we find the beds of the soft crumpled mudstones of the *M.-Sedgwickii* zone crushed suddenly against a group of massive gritstones and flags to the north. The first beds of this new group weather of a yellow tinge, and vary from 2 to 4 feet in thickness. Interiorly they are of a pale bluish-white colour, agreeing in this respect precisely with the thick-bedded gritstones of Saugh Hill. The massive grits immediately above the *M.-Sedgwickii* zone are almost perpendicular, and the line of contact, in which the crushed and contorted mudstones and shales of the latter are sud-



denly succeeded by the gritstones, has all the appearance of a fault. The gritstone zone extends down the burn for a distance of about 60 or 70 yards. Its beds are all much convulsed and disturbed, so that no reliable estimate can be formed of their thickness. They are quite barren in their central portions; but in their lower beds, in the neighbourhood of the *M.-Sedgwickii* band, their weathered edges are crowded with casts of *Rhynchonella*, associated with rarer examples of *Orthis* and *Strophomena*.

These thick-bedded yellow *Rhynchonella*-grits are followed by a group of calcareous flagstones which have an apparent thickness of about 50 feet. Their more southerly beds are much shattered, but the terminal zones dip steadily to the southward at an angle of from 60° to 70°. A beautifully complete section of these beds is afforded by the cliffs on the right side of the gorge.

The lower or southerly beds are nodular, but they contain no fossils; but the upper beds, which are so highly calcareous that they may be regarded as impure limestones, are many of them a mass of corals and shells.

The genus *Lindstræmia* or *Petraia* occurs in myriads, in association with *Pentamerus*, *Atrypa*, and *Strophomena*, buried in a rock of extraordinary toughness and compactness under the hammer.

The terminal seams are blue shales, strongly calcareous, the irregular laminæ of which are covered with trails and markings of Annelida. In these shales fossils are less plentiful than in the limestone flags, but they are more easily extracted and more completely preserved.

Here we find the usual Upper Girvan fossils:—

<i>Enrinurus punctatus.</i>	<i>Halysites catenulatus.</i>
— <i>variolaris.</i>	<i>Atrypa hemispharica.</i>
<i>Bronteus Brongniarti.</i>	— <i>reticularis.</i>
<i>Illænus Thomsoni, &c.</i>	<i>Pentamerus oblongus.</i>

This highly fossiliferous zone I denominate the Penkill or Camregan limestone, after the localities where its fossils have been most carefully studied, and which will be presently noticed more particularly.

In this typical locality in Penwhapple Glen, this Camregan limestone is succeeded to the northward by a zone of purple and green mudstones of about the same thickness as the limestone zone below it. These mudstones contain merely a few Annelid-markings throughout their entire vertical extent, except in one thin seam of dark carbonaceous shales near their centre, about a foot and a half in total thickness.

This carbonaceous seam may be followed by the eye across the stream from the east to the west bank of the gorge, and thence up the course of a small runnel descending the steep slope to the left, where its laminæ are laid open and may be studied *in situ*. It here contains an abundance of fairly preserved Graptolithina, together with occasional examples of Phyllopodous Crustacea. From these beds I have collected, among other forms:—

Rastrites maximus, Carr.
Monograptus turriculatus, Barr.
— *crassus*, Lapw.
— *Hisingeri*, Carr.

Monograptus runcinatus, Lapw.
Diplograptus palmeus, Barr.
Peltocaris aptychoides, Salt.

These *Rastrites-maximus* mudstones pass upwards into a group of massive yellow gritstones very similar, in their petrological characters, to those which succeed to the *M.-Sedgwickii* zone. They resemble these beds most especially in their pale blue matrix, and in containing a notable proportion of calcareous matter, but differ from them in the absence of the fine seams of pebbles and in the total want of organic remains. About 60 feet of these pale yellow gritstones are here exposed, and form the final member of this first or Camregan group, the purple sandstones and shales which follow belonging more naturally to the overlying and succeeding *Crosso-podia*- or Purple Shale formation.

Extension of Camregan Beds to the East of Penuhapple Glen.— This marked group of fossiliferous gritstones, calcareous flagstones, and Graptolitiferous shales is traceable up the left side of the stream into the wood of Camregan, where the shell-bearing gritstones are laid open in several quarries near the northern edge of the wood. Here these grits are softer and looser in texture than in the burn itself, and their fossils are procurable with comparative ease. They are crowded with casts of Brachiopoda, which are so abundant in certain seams as irresistibly to recall to mind the wonderfully prolific shelly sandstones of Mulloch Hill, on the north of the Girvan valley. The beds, too, have the same coarse sandy texture, calcareous and gritty composition, and more or less flaggy fracture.

It is this locality which gives its name to the band, as it is the only spot upon its entire course through the Girvan district where it is possible to find a local name geographically significant of the group, and at the same time sufficiently definite in its application to prevent ambiguity. The commonest fossils I have collected here are:—

Rhynchonella llandoveriana.
Atrypa hemisphærica.

Tentaculites ornatus.
Encrinurus punctatus.

I am not able to refer these beds to their exact horizon in the section of the Camregan group as exhibited in the gorge of Penuhapple; but I suspect that they belong generally to the gritty flags with *Rhynchonella*, found in contact with the *Monograptus-Sedgwickii* zone.

In the continuation of the same line of strike to the eastward beyond the limits of the wood we find a small section of the Camregan beds at the head of a small burn running down the hill-slope to the west of the fence. Here only a few flaggy grits and shales are seen; but they contain the usual types of the Camregan limestone, such as:—

Encrinurus punctatus.
Atrypa hemisphærica.

Rhynchonella.
Pentamerus oblongus.

The beds are much shattered, and their relations to the purple mudstones of the succeeding zone to the southward are somewhat obscure, and are in all probability indicative of the presence of a line of fault at the point.

For the next half-mile the beds of the calcareous Camregan zone are obscured by drift and vegetation; but a few yards to the west of the boundary-line between the Killochan and Bargany estates they are exhibited in several small excavations at the head of Cuddystone Burn. These hollows show only the more shaly beds of the series, but these are abundantly fossiliferous. They contain the usual forms of *Rhynchonella*, *Atrypa*, and *Encrinurus*, frequently in an excellent state of preservation.

In the burn-course below, and amid the surrounding patches of heather and long grass, evidences of the presence of the remaining fossiliferous beds of the Camregan group are found in the form of angular blocks of yellow gritstone and fine conglomerate, filled with *Pentamerus oblongus*, and the characteristic hard calcareous flaggy beds, crowded with *Petraia* or *Lindstroemia*.

This is the final exposure of strata of the Camregan band in this direction, for a few yards to the west it must be cut out by the great Braehill fault; but blocks of the coralline flags and *Pentamerus*-gritstone are found at intervals in the drift down the entire course of Cuddystone Burn, and are frequent in the débris collected off the neighbouring fields.

Sections West of Penwhapple Glen.—From our typical section in Penwhapple Glen the strata of the Camregan grits mount the east cliffs of the glen, and, crossing the Tralorg road, are shown again in the course of the southern arm of the Penkill Burn. Here only a few feet of the calcareous zone and the overlying yellow grits are exposed; but the limestone beds are so convenient of access that they have been long and successfully worked by collectors, and have afforded, especially to the extended and enthusiastic researches of Mrs. Gray, a large suite of fossils of all groups.

In addition to the usual *Pentameri*, *Rhynchonellidæ*, &c., we find:—

Bronteus Brongniarti, Barr.
Cheirurus trispinosus, Wyv.-Th.
Encrinurus variolaris, Brongn.

Strophomena applanata.
—— *antiquata*.
Phragmoceras compressum.

and a host of other well-known and typical Silurian forms. Indeed this little spot may well be defined as the typical fossil-bearing exposure of the Camregan Limestone.

For the next two miles the strata of this zone are hidden below the grass-clad surface of the hills; but in the exact continuation of the line of strike we find an excellent exposure of its fossil-bearing shaly beds in a branch of the Bargany Burn, near the western base of the Hadyard Hills. At this spot we discover the shaly strata which occur at the junction of the Camregan Limestone and the fossiliferous zone of purple mudstones.

The grey flaggy shales to the south afford an abundance of casts

of shells of *Atrypa reticularis* and *Strophomena*, and the dark-striped shales to the north well-preserved specimens of

Rastrites maximus, Carr.
Monograptus crassus, Lapw.
— *turriculatus*, Barr.

Monograptus Hisingeri, Barr.
Diplograptus palmeus, Barr.
Peltocaris aptychoides, Salt.

Here the strata of this zone make their final appearance in the Girvan region, being buried from sight a few yards to the eastward by the unconformably overlying Old Red Sandstone of Maxwellston Hill.

I regard this Camregan zone, which has formed our chief horizon of reference among the complicated group of Graptolitic shales and flags, conglomerates, gritstones, and calcareous rocks developed in Penwhapple Glen, Saugh Hill, and upon the outer edges of the coast-platform near Woodland, as forming the final member of the *Third Series* of rock-formations into which the Girvan succession is most naturally divided. This series, which commences with the Mulloch-Hill conglomerate, and terminates with the upper grit bands of these Camregan beds, is nowhere completely exhibited from base to summit in continuous section in the Girvan region; and the order of its sediments is only *approximately* determined by the careful piecing together of the disjointed fragments of the sequence found in several scattered localities. Nevertheless I trust that I have shown that, even from the physical point of view, a sufficiency of evidence is at our command to make it clear that the order of succession here adopted is in all probability generally identical with that which obtained among these beds previous to their disruption.

The irregularly scattered distribution of the rocks of this division makes it difficult to suggest a collective title for the whole group that shall be sufficiently comprehensive, and at the same time of definite local value. In the northern inlier in the neighbourhood of the farm of Newlands, the lower half only of the group is exposed. The basal beds, again, are wholly missing from the South Girvan plateau. But the relation of the group as a whole to the underlying formations is best displayed in the Newlands area, within which are also developed all the different lithological varieties of its strata, together with several distinct groups of its fossils. Hence it will be most convenient to distinguish it by the title of the *Newlands Series*.

The strata of this Newlands Series consist of massive beds of shelly sandstones or barren gritstones, occasionally passing into coarse conglomerates and boulder-beds, and alternating with thick zones of grey, green, and black Graptolitic shales.

A striking peculiarity of the coarse beds of this group is their property of weathering to a buff or yellow colour under the action of the weather. In the matter of fossils this group is altogether the most prolific in the Girvan succession.

The order of sequence of the Newlands Series is given in the following scheme, in ascending order:—

Generalized Section of the Newlands Series.

(a) <i>Mulloch-Hill Group</i>	375	{	1. Mulloch-Hill Conglomerate.
			2. Rough-Neuk Grits.
			3. Glenwells Shales.
(b) <i>Saugh-Hill Group</i>	200	{	(a) Woodland Limestone, Conglomerate, and Shales.
			(b) Saugh-Hill Grits and Flags.
			M.-Sedgwickii Beds.
(c) <i>Camregan Group</i>	200	{	1. Grey Shales, barren of fossils.
			2. Black Mudstones with Graptolites.
			1. <i>Rhynchonella</i> -Grits.
			2. Upper <i>Pentamerus</i> -Limestone and Shales.
			3. Yellow Gritstones and Flags.

(b) Flagstones and Shales of Bargany and Straiton.

The Lower Palæozoic strata of the Girvan region which yet remain to be described form a narrow strip of country about ten miles in length, stretching from the banks of Penwhapple Burn, between Penkill and Old Dailly, past the village of New Dailly and the heights of Kilkerran, to the village of Straiton upon the Water of Girvan to the south of Maybole.

Along this line the northern edge of the continuous upland plateau of Saugh Hill and the Hadyard Hills plunges suddenly downwards into the lowlying district of the Girvan valley in a long straight slope of singular steepness. To the west of Penwhapple Glen this steep slope forms a most prominent feature in the landscape, its upper margin presenting a series of rocky points, several exceeding 1000 feet in elevation, which mark the outer edge of the Old Red Sandstone terrace of Garleffin, and its lower portions merging imperceptibly into the maze of parks and woodlands that give such a forest-like aspect to the fertile valley of the Girvan.

The prime cause of this abrupt physical feature is undoubtedly the presence of the great Braehill fault, which runs along the edge of the slope from end to end, throwing down the Carboniferous of the Girvan valley against the Silurian rocks to the south. Throughout the whole of its range this is actually a downthrow to the northward. It is essentially a strike-fault, running almost parallel with the average trend of the Palæozoic rocks, but by no means confined to a single horizon either in the Silurian or the Carboniferous, but truncating the strata of both at a very acute angle.

At its eastern end, within the present district, near Penwhapple, this fault is situated at the base of the steep slope already referred to, and brings into abrupt collocation some of the highest rocks of the Silurian of the Penwhapple, and a zone comparatively high in the Upper Old Red Sandstone. The overlying zones of the Lower Carboniferous emerge one by one till, finally, near the head of Lady Burn, above Kilkerran, the base of the Carboniferous is exposed, and the unconformably underlying Silurian rocks begin

to appear on the northern side of the fault, and they retain this position till we reach the point where the fault passes to the eastward beyond the limits of the region under description. These underlying Silurian strata, being less susceptible of erosion than the neighbouring Carboniferous beds, form the outer edge of the bounding slope of the plateau; and the Braehill fault gradually mounts higher and higher upon the slope as we pass to the eastward till, finally, for the last four miles of its course, near Straiton, it runs almost along the summit.

The band of Silurian rocks found in this district between the Old Red Sandstone of the Hadyard Hills and the Carboniferous of the Girvan valley rarely exceeds half a mile in width; and throughout much of its extent is even less than one fourth of a mile in breadth, while in some spots it seems to vanish altogether. It attains its greatest diameter to the west, along the line of Penwhapple Glen, where its strata are seen following in unbroken sequence upon the yellow *Pentamerus*-gritstones of Camregan and Penkill.

The strata which floor the whole of this narrow band of country consist of thin-bedded flagstones and shales, with seams of hard, but essentially flag-like grits distributed irregularly throughout the succession. If we make exception of the local development of certain brilliant-coloured bands, it may be said that the more prominent petrological characters of these strata are essentially the same everywhere throughout the area; and even upon a first examination the stratigraphist instinctively assigns them all to a single and connected series. From the three rock-series already defined this new series is distinguishable, not only by its petrological characters, but also by the general absence of organic remains, the few fossils it has afforded being restricted to half a dozen widely separated seams, each of a few inches in thickness.

The geographical distribution of this series of grey flagstones and shales admits of being most satisfactorily described, as they present themselves in :—

- (1) The lower portion of the gorge of Penwhapple Glen above Old Dailly;
- (2) The steep north slope of the Hadyard Hills above New Dailly;
- (3) The eastern or Straiton area north of the Bargany fault;

and the entire series is most naturally and conveniently designated by the general title of the *Dailly Series*, after the name of the parish in which its strata are most fully laid open for study, and where they attain their widest geographical extension in the Girvan region.

1. *Section of Lower Portion of Penwhapple Glen* (see fig. 28, p. 645).—The third zone of yellow gritstone, which forms the summit of the *Pentamerus*-bearing Camregan beds of Penwhapple Glen, is at once succeeded by a group of strata altogether more unique in their petrological features than any we have hitherto studied on the banks of the glen. They consist of beds of purple and green shale of great

thickness, the purple strata distinctly predominating, occasionally passing on the one hand into soft mudstones almost destitute of definite lamination, and on the other into flagstones of great thickness. They continue down the stream from the line of *Pentamerus-gritstone* to the final crook of the burn below the farmhouse of Penkill, where they are succeeded by a very distinct group of pale grey flagstones.

The strata lying between these limits must be assigned on petrological grounds to one and the same group or subordinate formation, and will be referred to as the *Penkill Beds*. The section of these beds here displayed appears to be continuous. It is about 500 yards in length, and the total thickness of the strata exposed may be estimated at about 1000 feet.

(Da¹) *Crossopodia Beds or Purple Shales*.—For the first 150 yards the strata of the Penkill Beds consist of finely laminated shales of a deep purple colour, only occasionally interrupted by narrow seams of green or grey. On a few horizons, however, the purple and green shales are arranged in alternating bands of colour of an inch or two in thickness, forming a peculiar striped rock of remarkable appearance. These purple shales are magnificently exposed at this locality, and not only in the bed of the stream itself, but in the steep wooded cliffs on both sides of the gorge; and there is little appearance of contortion or repetition among them.

They are crowded along many horizons with multitudes of worm-tracks and so-called Annelid-trails; in some spots near the southern end of the exposure every lamina is a perfect maze of these imperfectly studied markings. The commonest and most characteristic is M'Coy's *Crossopodia scotica*; and the less conspicuous species are:—

Nemertites tenuis, M'Coy.
Nereites Sedgwickii, M'Coy.

Nereites cambrensis, M'Coy.

Graptolites occur also in the greatest variety in a few seams of slightly carbonaceous shales, discernible with difficulty on several horizons in the succession; they are mere laminae, and the Graptolites themselves are poorly preserved. The forms collected by myself include:—

Monograptus exiguus, Nich.
— *Beckii*, Barr.
— *galaensis*, Lapw.

Rastrites distans, Lapw.
Diplograptus, sp.
Retiolites obesus, Lapw.

(Da²) *Protovirgularia Flags and Grits*.—These purple shales are succeeded in the section by an equal thickness of flaggy beds of a greyish-green colour, about two inches in thickness, which alternate with green and purple shales, identical with those of the preceding subgroup, and forming a well-marked division of this formation, exactly intermediate in petrological features and geographical position between the purple shales below and the division next to be described. They contain a few of the usual Annelids, together with rare examples of the characteristic *Monograptus exiguus*, Nich., found in a small stream near the northern extremity of the section of these beds.

These flaggy or ribbed shales are followed to the northward by a mass of well-bedded greywackes, which are seen to perfection at the foot of Penkill Burn, below the old castle. Their most southerly beds consist of greywackes from two to three feet in thickness. All the middle and main mass of the zone are flagstones or flaggy greywackes, frequently less than a foot in thickness, with an occasional seam of shale. The final band is a pale grey calcareous greywacke, forming a solid mass several feet in thickness. Fossils are rare. Those known are of the same species of Graptolites as those enumerated from the preceding division; they occur in an insignificant, highly carbonaceous seam overlying the highest greywacke bed.

(Da³) *Cyrtograptus-Grayi Mudstones*.—The fourth and final division of the Penkill Beds is a mass of soft purple and green mudstones. They are very imperfectly seen in their more southerly beds, between the foot of Penkill Burn and the crook of Penwhapple; but their terminal zone is well exhibited at the latter locality. The purple mudstones are here capped by thin seams of graptolitic and more or less calcareous shales, which are easily studied in the south bank, at the right angle of the burn at this spot, and in the bed of the stream itself at the western angle. The fossils they afford occur in a most exquisite state of preservation, the Graptolites being frequently preserved with their full relief. Here occur

Retiolites Geinitzianus, Barr.
Monograptus priodon, Bronn.
— var. Flemingii, Salt.

Cyrtograptus Grayi, Lapw.
Cardiola fibrosa, Sow.
Acidaspis Brightii, &c., Murch.

together with a few examples of Brachiopoda and Crustacea.

The remaining rocks of this locality belong to the distinct Bargany beds, and will be noticed in detail when we come to speak of the strata to the eastward.

This completes the description of the Purple-shale and Flagstone group as seen in Penwhapple Glen. The section here must be regarded as typical. The old castle of Penkill, the seat of the Boyd family, is built upon these rocks, above the cliffs of Penwhapple, about the centre of the group. It is therefore entitled the Penkill group, and is regarded as being composed of the following divisions:—

- | | | | |
|--|---|--|---------------------------------|
| Penkill
(<i>Crossopodia</i> -)
Group. | { | (4) Penkill mudstones or <i>Priodon</i> (<i>Grayi</i>)-beds. | } <i>Protovirgularia</i> -beds. |
| | | (3) Penkill greywackes. | |
| | | (2) Penkill flags. | |
| | | (1) Penkill or Purple shales (<i>Crossopodia</i> -beds). | |

Geographical Extension of the Penkill Beds.—The broad band of purple and grey strata formed by the beds of the Penkill group is traceable for some distance both east and west of the typical section in Penwhapple Glen. A tolerably continuous section across many of the beds of the group is seen in the course of the small burns which descend the northern slope of Camregan Hill, immediately west of the plantation, while scattered exposures are seen in occasional quarries in the wood itself. In all these localities we find an abundance of the characteristic Annelid-trails &c.

On the east of the glen, the little stream which crosses the line of the Camregan limestone upon the Assel road, and falls into the Penwhapple below Penkill Castle, affords an excellent confirmatory section of the *Crossopodia*-shales. Some of the beds of the higher greywacke zone are laid open in quarries about half a mile north-east of the Castle, where those beds present identical characters with their counterparts in Penwhapple, and afford a few examples of Annelid-trails and the enigmatical fossil *Protovirgularia*.

The Burn of Bargany, yet further to the east, crosses the band almost at right angles to its course; but only a few poor sections are exposed along it. Such as these are, however, they are sufficient to prove that the group retains the same sequence and thickness as in our typical section.

A few yards west of this burn these strata are unconformably overlain by the Old Red Sandstone beds of the Maxwellston Hills.

2. *Sections south of Bargany*.—The sections we have next to notice are found in the steep slopes which overlook the beautifully wooded lands of Bargany House, and occur at scattered intervals in that long strip of Silurian lying between Penwhapple Glen and the Burn of Lindsay's town, about four miles to the eastward. The rocks which occupy this subarea are all very similar in their external features, consisting of (a) grey and green flagstones and occasional greywackes, with dividing seams of shales, and (b) thick zones of ribbed shales, arranged in alternating hard and soft bands of an inch or two in thickness. They all dip, as a rule, at a steep angle to the southward, as if passing below the zone of the Penkill shales last described; but here, as in Penwhapple Glen, this apparent dip is delusive, the strata being inverted in geological position.

Near the foot of Penwhapple Glen the most southerly beds of the Bargany flagstones are seen in the bed and banks of the stream, succeeding and apparently overlying the fossiliferous "*Cyrtograptus-Grayi* band" with perfect regularity. They consist of grey flags varying from six inches to a foot and half in thickness, and are divided from each other by similar thicknesses of grey and green shales. When split open, the matrix of the generality of the beds is seen to be finely levigated and of a peculiar palish blue or greyish-green tint, a feature which distinguishes more or less all the beds seen in the Bargany area. The harder flags are frequently filled with closely approximately transverse fractures and joints, which allows of their weathering into a multitude of long angular prisms, the outer ends of which are coincident with the base and summit of the flaggy bed out of which they are formed. These beds fill up the final 300 yards of space which intervene between the *C.-Grayi* band and the great Bargany fault to the north, where the Lower Palæozoic rocks are brought into contact with the greenish-grey sandstones of the Old Red Sandstone of the Girvan valley. These Bargany flags are here totally barren; their visible thickness may be estimated at 300 feet.

A tolerably continuous section of the same flaggy series is seen in the course of Bargany Burn, about a mile and half to the eastward

of this spot. The purple mudstones of the "*C.-Grayi* bed" which caps the Penkill-shale group of that locality are succeeded to the northward by scattered exposures of pale jointed flagstone with shale-partings, identical with the flagstones of Penwhapple Glenfoot. These Glenfoot flags extend down the stream for a distance of about 200 yards, and agree therefore in collective thickness with their counterparts of the glen.

Between them and the great Bargany fault to the northward, which is shown in a section of great interest in Blackwood Head coppice, is found an equal thickness of grey, flaggy shales or muddy flagstones. Many of these have the same pale-coloured interior as the Glenfoot beds; but they are altogether a more finely laminated group, showing no actual greywacke zones at this spot, but only occasional harder ribs. They are beautifully shown in the cliffs of the little glen dug out by the burn, at the waterfall near the Bargany fault, where they are seen in contact with the Carboniferous of the Girvan valley. They are frequently striped with faint lines of carbonaceous matter, suggestive of the presence of Graptolites, a few of which are obtainable at this spot, such as

Monograptus acus, *Lapw.*

| *Monograptus priodon*, *Bronn.*

The next stream-course to the eastward, which excavates a small gorge on the opposite side of the wood, presents us with a section of parts of the Glenfoot flags and these shalier Blackwood-Head beds. The Glenfoot beds exposed are especially interesting, as they are higher in the group than the majority of those we have studied in Penwhapple Glen. The final band is seen to contain several seams of sandy greywacke of a pale purplish colour, while the intermediate shales have a peculiar greyish-green or, as it were, washed-out tint, and a dull flaky surface, which is new among the beds hitherto met with in the Girvan succession.

The lowest ribbed shales of the Blackwood-Head beds are shown in two fine quarries, and form a most conspicuous assemblage of about 150 feet of dull greyish-brown rocks in beds of about 2 inches in thickness.

A few feet of the higher striped shales are seen to the northward, close to the line of fault.

In the small hollow of the Lime Glen, three fourths of a mile further to the eastward, the pale-hearted finely levigated sandstone flags of Blackwood-Head occur in a broken section in the neighbourhood of the Bargany fault. So far as can be made out upon the ground, they here consist of three distinct lithological seams, viz.

- (c) Yellow-weathering mudstone flags, pale-hearted, white or bluish grey.
- (b) Yellow-weathering mudstone flags with stripes of carbonaceous matter.
- (a) Pale-green ribbed shales and mudstones.

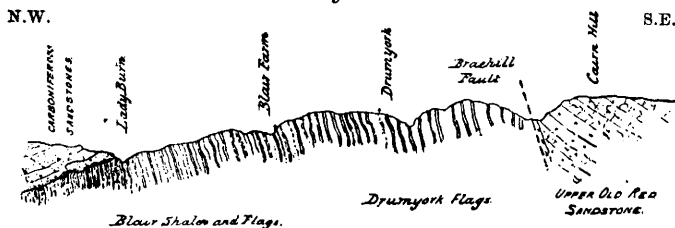
The white-hearted mudstone flags (c) are seen also in Currah Glen. In some neglected quarries below the rugged cliff to the south-west

of the farm-house of Craig, fine greenish-grey shales are exposed, not unlike those of the quarries east of Blackwood Head; but the latter lie at the northern limits of the Blackwood beds, while these Craig shales, if the strike of the beds is to be trusted, lie on the opposite or southern side of the band.

No further exposure of any moment is seen in this direction till we cross the supposed line of the Braehill fault on the Bargany Hill, and enter upon the Straiton band of Silurian strata, which, near Blair Farm, emerges from below the Carboniferous rocks of that district.

3. *Blair Farm and Drumyork*.—The Silurian strata are laid open in many sections in the course of the Lady Burn above Kilkerran House, near Drumyork, and in the grassy mounds around the farm-house of Blair. The disposition of the strata at this locality will be evident on a study of the accompanying section (fig. 29).

Fig. 29.—Section of the Grey Flags and Shales of Blair and Drumyork.



D. Daily Series.

Db. Straiton beds.

- (b) Blair shales and flags, with *Cardiola*, *Ceratiocaris*, *Retiolites*, and *Monograptus vomerinus*.
- (a) Drumyork flags, olive-green, non-fossiliferous.

What are considered to be the lowest beds are seen in the stream-course close to the Bargany fault above Drumyork. They consist of olive-green flags and shales, much jointed and contorted, crushed abruptly against the Old Red Sandstone rocks to the south.

These beds are succeeded by flaggy shales with occasional ribs of flagstone, weathering often of a dull yellowish tint, some striped with lines of carbonaceous shales, others of a cold olive-green colour, more or less calcareous, and with rough harsh flaky surface. These are exhibited in many natural and artificial openings on the south side of the hill-road between Drumyork and Blair Farm. In a quarry about a hundred yards east of the farmsteading they afford in great abundance the characteristic fossil *Monograptus vomerinus*, Nich., and less commonly the following species:—

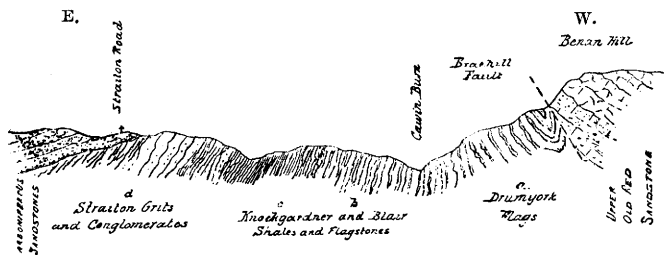
<i>Beyrichia Klødeni</i> , M'Coy.	<i>Cardiola fibrosa</i> , Sow.
<i>Orthoceras subundulatum</i> , Portl.	<i>Bellerophon wenlockensis</i> , Sow.
<i>Retiolites Geinitzianus</i> , Barr.	<i>Cyrtograptus</i> , sp.

Between these beds and the southern margin of the overlapping strata of the Lower Carboniferous to the north, beds of flagstone, varying from a foot to a few inches in thickness, and separated by seams of striped blue and grey shales, are seen at several spots in the Lady Burn; they are occasionally fossiliferous, affording

Cyrtoceras, sp. | *Monograptus vomerinus*, *Nich.*
Orthoceras subundulatum, *Portl.* | — *Flemingii*, *Salt.*

It is doubtful if any of these beds actually belong to the Bargany group of the area last described, though they greatly remind us of the strata of that group in their general features. They clearly belong both physically and geologically, however, to the same general series as the Bargany beds, possibly following them in the natural order of succession.

Fig. 30.—General Section of the Silurian beds of Knockgardner and Straiton.



D. Daily Series.

Db. Straiton beds.

- (d) Straiton purplish conglomerate, grits, and flags.
- (c) Thin-bedded shaly flags, with *Beyrichia Klædeni* (Knockgardner beds).
- (b) Grey flags and shales (Blair beds).
- (a) Olive-coloured, non-fossiliferous flags and shales (Drumyork flags).

4. *Knockgardner and Straiton* (fig. 30).—The flaggy strata of the three subzones of the Blair beds range from this point eastward to the village of Straiton, a distance of at least $3\frac{1}{2}$ miles, running strictly parallel with the Bargany fault to the southward. In the course of a small stream descending the north slope of Benan Hill, a mile south-west of Straiton, the cold olive-green flags of Drumyork are again seen in contact with the Old Red Sandstone. The more finely laminated strata of Blair Farm are exposed in quarries at the farmstead of Knockgardner, where they are crowded with *Beyrichia Klædeni*, M'Coy, and yield a few scattered examples of characteristic Blair fossils, *Pterinea pleuroptera*, *Conr.*, *Orthonota truncata*, *Conr.*, &c., and indeterminate species of *Cyrtograptus* and *Monograptus*.

The same beds are seen further east in the banks of the Cawin Burn. Of the most northerly or highest (?) zone of the Blair beds, only a short section is seen in the streams running down the peaty region north of Shaw's Knowes.

West of the village of Straiton the terminal beds of this flaggy zone are succeeded in the hillocks south of the roadside by a most peculiar set of strata, consisting of purple and grey conglomeratic greywacke and flagstone, of great hardness and toughness. The matrix of the chief grit or conglomerate band is purple, and is more or less sandy in character, reminding us of the red conglomerate at the base of the Mulloch-Hill Sandstone. It is interbedded with blue mudstones and olive-green flaggy shales. These beds are all wholly destitute of fossils, but form together a most distinctive physical assemblage.

The same zone of purple flagstone and conglomerate is found in precisely the same stratigraphical position along the line of strike two miles to the westward, where it is shown in some old quarries near the roadway between Knockgarnor and Kirkbride.

At both these localities this Straiton gritstone band is followed unconformably by the overlying Carboniferous rocks of the Girvan valley, thus forming the outer and final member of the entire Lower Palæozoic series of this region. To the west of Straiton itself the southern margin of the Carboniferous rocks creeps down upon the Bargany fault, and the Silurian is finally buried from sight by the unconformably overlying strata of Upper Palæozoic age.

It is evident from the foregoing descriptions that the whole of the strata found in the long strip of Silurian country extending from the Brachill near Girvan to the village of Straiton, and forming the northern slope of the plateau lying to the south of Girvan valley, belong to one and the same general physical series. To this series, which we term the Dailly Series, after the parish in which its strata are most perfectly developed in this region, must clearly be assigned the highest place among the four natural divisions of the Girvan succession, for it follows the third or Newlands division in the geographical order of the deposits of the region, and graduates therefrom in its lithological characters. Its strata dip either perpendicularly or at steep angles to the southward, as if to pass under this third or Newlands series. But not only is their superiority in stratigraphical position to be inferred from the fact already demonstrated that the strata north of the Knockgerran fault are generally inverted, but it is placed wholly beyond question by the evidence of the fossils. This inversion, then, being admitted for the series as a whole, it is to be expected that there is actually to be found an ascending order among the beds as we depart northward from the Camregan grits, which form the highest band of the Saugh-Hill series in the direction of the Bargany fault and the unconformably overlying Carboniferous. We have seen that there can be no dislocation of importance in any of the sections capable of study, the beds following each other with great regularity in parallel zones, which graduate almost insensibly the one into the other. Reserving therefore the palæontological arguments in support of these views to the succeeding part of this memoir, we are justified in the presumption that the Dailly Series consists of the following groups in descending order :—

Generalized Section of the Dailly Series.

Dailly Series, 2600 feet.	Upper Dailly.	Straiton beds, 900 ft.	{ Straiton Grits and Conglomerate. Blair Shales (<i>Vomerinus</i> -beds). Drumyork olive-coloured Flags.
		Bargany beds, 700 ft.	{ Blackwood Flags. Glenfoot Flags and Shales.
	Lower Dailly.	Penkill beds, 1000 ft.	{ <i>Cyrtograptus-Grayi</i> mudstones. Penkill Greywackes. <i>Protovirgularia</i> -flags. <i>Crossopodia</i> - or Purple Shales.

(F) SUMMARY OF THE FOREGOING EVIDENCES AND CONCLUSIONS
RESPECTING THE STRATIGRAPHY OF THE GIRVAN SUCCESSION.

(1) In the foregoing pages I have laid before the reader all the more important data obtainable in the geographical area under examination which bear upon the main question of the natural order of the Lower Palæozoic rocks of the Girvan region. The original arrangement of the beds themselves has been so frequently interrupted by profound dislocations, and has been rendered so dubious locally by perplexing folds and inversions, that the task of reducing them to their natural order has been one of far more than ordinary difficulty. But so well are the several subformations in the collective series individualized by distinct petrological features, that the field-geologist has generally little hesitation in recognizing their entangled or dislocated fragments at a glance. At the same time also the foldings and inversions of the strata prevail only in certain definite geographical subareas, where they can usually be ultimately detected and allowed for. Finally, the greater faults are, as a rule, by no means difficult of localization, owing to the fact that they bring into abrupt and unnatural collocation upon the ground strata very distinct in their lithological and palæontological features.

Nevertheless the complexities and difficulties of the stratigraphy of the fossiliferous rocks of the Girvan region are so great that the solution of the problem of their natural sequence has been only arrived at by the accumulation of an excessive amount of evidence collected in the field. This evidence, however, is now so full, and so conclusive, that there can be no longer any doubt of the natural petrological subdivisions of the strata of the Girvan rocks, or of their true positions in the ascending succession.

(2) The physical evidence, as developed in the preceding pages, in support of our conclusions may be summarized as follows:—

(i) Selecting the remarkable Benan-Hill Conglomerate as our primary horizon of reference, we discover 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. This series exhibits proofs of the most perfect conformity from base to summit, and its various members admit of minute and

Fig. 31.—*Detailed Vertical Section of the Strata of the Girvan Succession.*

(Scale 1 inch=480 feet.)

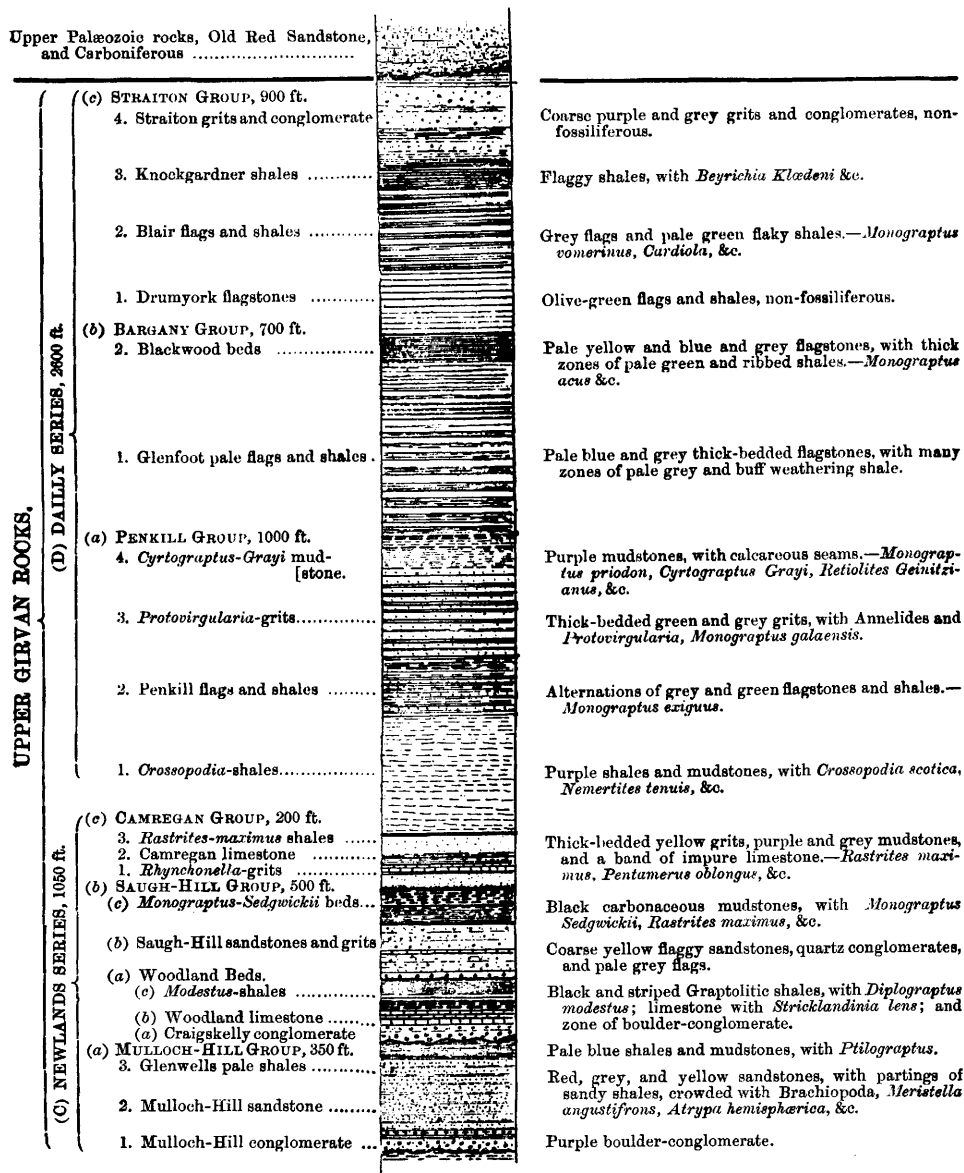
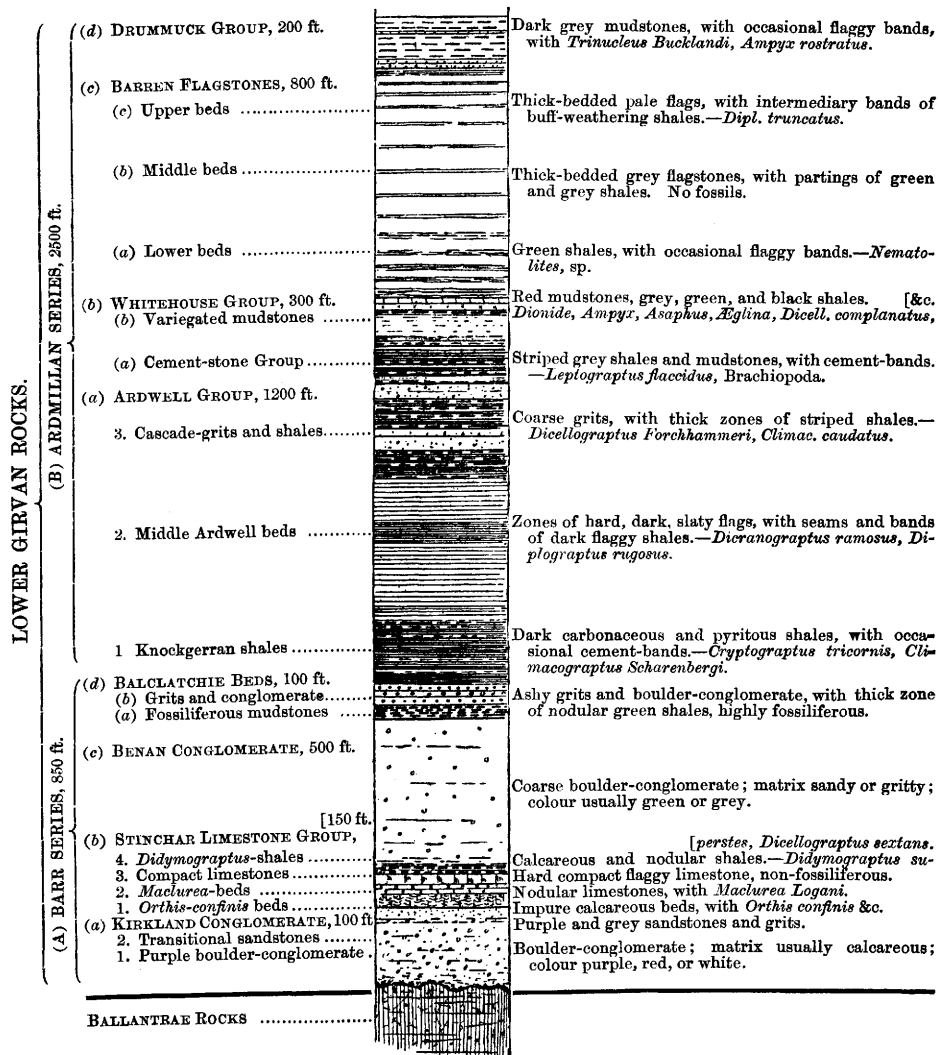


Fig. 31 (continued).



complete investigation in the field. This Barr Series includes the well-known Craighead or Stinchur 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.

(ii) The tumultuous Barr Series is everywhere conformably surmounted, in the sections of the Girvan region, by a second series (the *Ardmillan Series*), composed throughout of Graptolitic flagstones and shales, which nevertheless arrange themselves naturally in several distinct subformations of well-marked petrological characters. The higher and lower divisions of this great series (the Ardwell, Barren Flagstone, and Drummuck Beds) have their respective systematic positions fixed by incontestible stratigraphical evidences. 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.

(iii) The Graptolitic series of Ardmillan visibly underlies a third series (the *Newlands Series*), consisting of *Brachiopod*-sandstones, *Pentamerus*-grits, and *Monograptus*-shales. The natural place of the first (Mulloch-Hill beds) division of this series is fixed beyond dispute by its relation to the terminal beds of the older Ardmillan series, and that of the highest division (the *Camvegan* group) by its relation to the newer *Dailly Series*. The systematic position of the central division (the Saugh-Hill group) is deduced with equal certainty from its intermediary place in the series; but the sequence of the component strata of this central division is rendered so dubious by inversion, faulting, and local unconformities, that we are unable to give more than a provisional classification of its minor zones.

(iv) Finally, we discern a fourth petrological series (the *Dailly Series*), at once the thickest and most homogeneous series in the Girvan succession. Its place at the summit of the whole is established by the circumstances that it forms a single series of similar strata, which is wholly distinct from either of the series below, while it lies on the southern (or upper) side of the Newlands Series, from the highest zones of which its strata appear to graduate in conformable sequence.

(3) In place of an enigmatical group of Lower Palæozoic rocks of no great vertical thickness, varying locally in their petrological characters to an extraordinary extent, and containing an admixture of fossils elsewhere characteristic of formations of several distinct geological epochs, as believed by some of the earlier students of these beds, we find an orderly arranged sequence of strata several thousands of feet in vertical thickness, grouped very naturally in successive formations of distinct petrological features, each formation retaining even in its subordinate zones the same characters over the entire area, and, as we shall show in the second part of this memoir, invariably affording the same special group of fossils.

(4) In brief, our study of the stratigraphical relations of the rocks of the Girvan succession has fully established the following propositions :—

i. The Girvan succession of Lower Palæozoic rocks consists of a generally continuous series of more or less fossiliferous strata of a collective thickness of 7000 feet.

ii. It is divisible into four main rock-formations, each of which is individualized by special petrological and palæontological characteristics.

iii. Each of these formations is, again, made up of several subordinate members, whose relations to the subformations above and below are beyond dispute, and which retain their special characteristics both in rocks and fossils wherever they are laid open for investigation within the district.

The detailed classification of these Lower Palæozoic strata of Girvan, as developed in the preceding pages, is given in the Table, fig. 31, pp. 660, 661.

(5) These Girvan rocks appear to repose, at their base, upon the generally older igneous and altered rocks of Ballantrae. The Ballantrae rocks have, as yet, been too imperfectly studied to allow us to hazard any conclusion respecting their true geological age. That many of the rocks grouped together under this title are of far greater antiquity than the basement-beds of the Girvan succession may be regarded as established by the fact that fragments of the Ballantrae rocks occur in the Kirkland or Purple Conglomerate at the base of the Girvan sequence. These pre-Girvan traps 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, as at Shalloch Hill, Laggan Hill, and elsewhere, almost certainly include some greatly altered Girvan rocks.

(6) The sequence among the Girvan fossiliferous rocks is broken by at least one fairly distinct unconformability, viz. that at the base of the Craigs Kelly conglomerate; but the presence of boulder-beds at the base of the Mulloch-Hill group, at the base of the Saugh-Hill Grits, and elsewhere, renders it exceedingly probable that other local stratigraphical breaks may eventually be detected.

These local unconformities, however, can be of no great systematic importance; for the general gradation, both in sediments and fossils, from the base to the summit of the Girvan succession is practically complete. Each distinct petrological formation in the vertical series is connected with its neighbours, both above and below, by a group of beds intermediate both in physical and in zoological features. Thus the very distinct formations of the Stinchur Limestone and the Benan Conglomerate graduate into each other through the transitional zone of the *Didymograptus*-beds (Ab⁴), the Benan and Ardwell series through the transitional Balclatchie group, the Ardwell and Whitehouse beds through the intermediary Cascade beds, and so on. Even the two grand divisions of the succession, the Upper and Lower divisions of the Girvan rocks, are united by the intermediary formation of the Mulloch-Hill beds.

The geographical distribution of the various members of the Girvan succession within the region we have described is given in the accompanying Maps and Plates, &c.

The detailed description of the physical structure of the region, and of the lithology and palæontology of the several members of the Girvan succession, together with the discussion of their resemblances, physical and zoological, to their extra-Girvan equivalents, are points deferred to the second part of this memoir.

EXPLANATION OF THE PLATES.

PLATE XXIV.

General Map of the Girvan District.

PLATE XXV.

Maps of the more important subareas of the Girvan District.

- Map 1. The Saugh-Hill and Penwhapple district.
2. The Stinchar and Benan-Hill district.
3. The coast-line from Ardwell to Shalloch Forge.
4. The Quarrel-Hill and Newlands district.

DISCUSSION.

Dr. DAVIDSON said that though he had not visited the locality, Mrs. Gray's fine collection of Girvan fossils had lately passed through his hands, and Prof. Lapworth had supplied him with his classification of the rocks. He had examined the fossils carefully, and compared them with the table of strata made from Prof. Lapworth's notes, and found them to coincide in every particular.

After about four months of assiduous research he was able to recognize, from the Llandovery, Caradoc, and Upper Llandeilo of that district, some 115 species, an enormous number from so restricted a locality. Some of the forms are quite new, and have not been hitherto discovered either in England or in Ireland.

It was astonishing to find so very large a number of species in rocks attributed to the Upper Llandeilo in Scotland; for whilst in England and in Ireland the total number of recorded species of Brachiopoda from the whole of the Llandeilo would not exceed some 28, the Upper Llandeilo of Ayrshire alone has furnished us with nearly 60. Of this number about 18 would be common to the Llandeilo of England (including Ireland) and Girvan; so that, with the exception of about 10 species, all the others would be, in the present state of our knowledge, peculiar to Scotland. Of course these numbers are provisional, as Dr. Davidson had not finally completed his investigations, but the general results will not be materially modified. On the other hand, whilst some 75 species have been recorded from the Caradoc of England and Ireland, only about 28 have been collected from the Middle and Upper Caradoc of Girvan. Nearly all the Caradoc species found in Ayrshire occur

CENERAL MAP of the GIRVAN REGION

Scale 1 mile

Reference

Downloaded from <http://www.lyellcollection.org/> at Orla Doyle on January 12, 2016

NEWLANDS SERIES

- Cc. Upper Pentamerus Limest.
- Cb. Lower Pentamerus Limest.
- Ca. Mulloch Hill Group
- Bd. Mulloch Hill Conglomerate
- Bc. Drumuck Beds
- Bh. Barren Flagstone
- Ba. Whitehouse Beds
- Ba. Ardwell Beds
- Ba. Cascade Grits
- Ba. Middle Flags

ARMILLAR SERIES

- Ad. Balclatchie Beds
- Ac. Benan Conglomerate
- Ab. Stinchur Limestone
- Aa. Orthus Confins Beds
- Aa. Purple Conglomerate

BARR SERIES

- Ad. Ballantrae Rocks

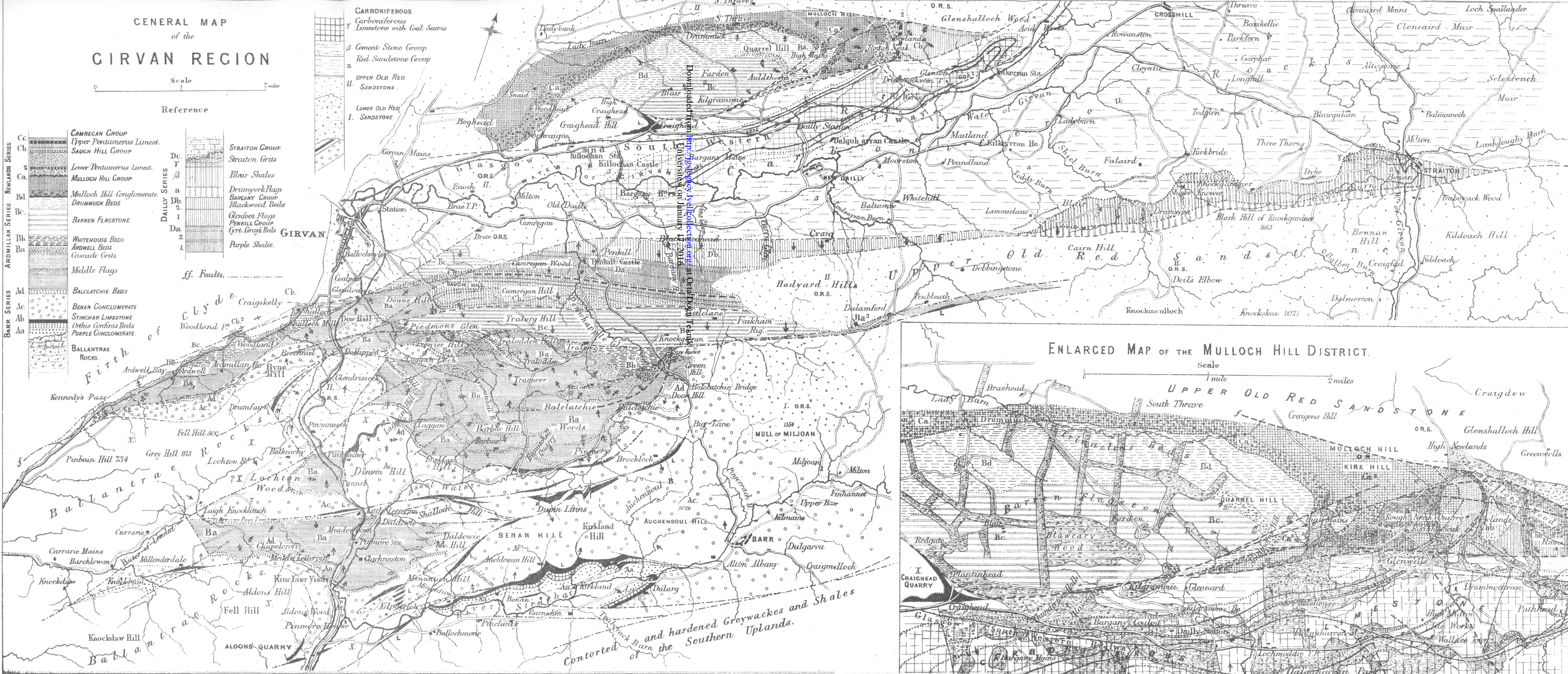
DAILY SERIES

- Dc. Straiton Grits
- β. Blair Shales
- a. Dranyork Flags
- Db. BARGANY GROUP
- 2. Blackwood Beds
- 1. Glenfoot Flags
- Da. PENKILL GROUP
- 2. Grit. Gray's Beds
- 1. Purple Shales.

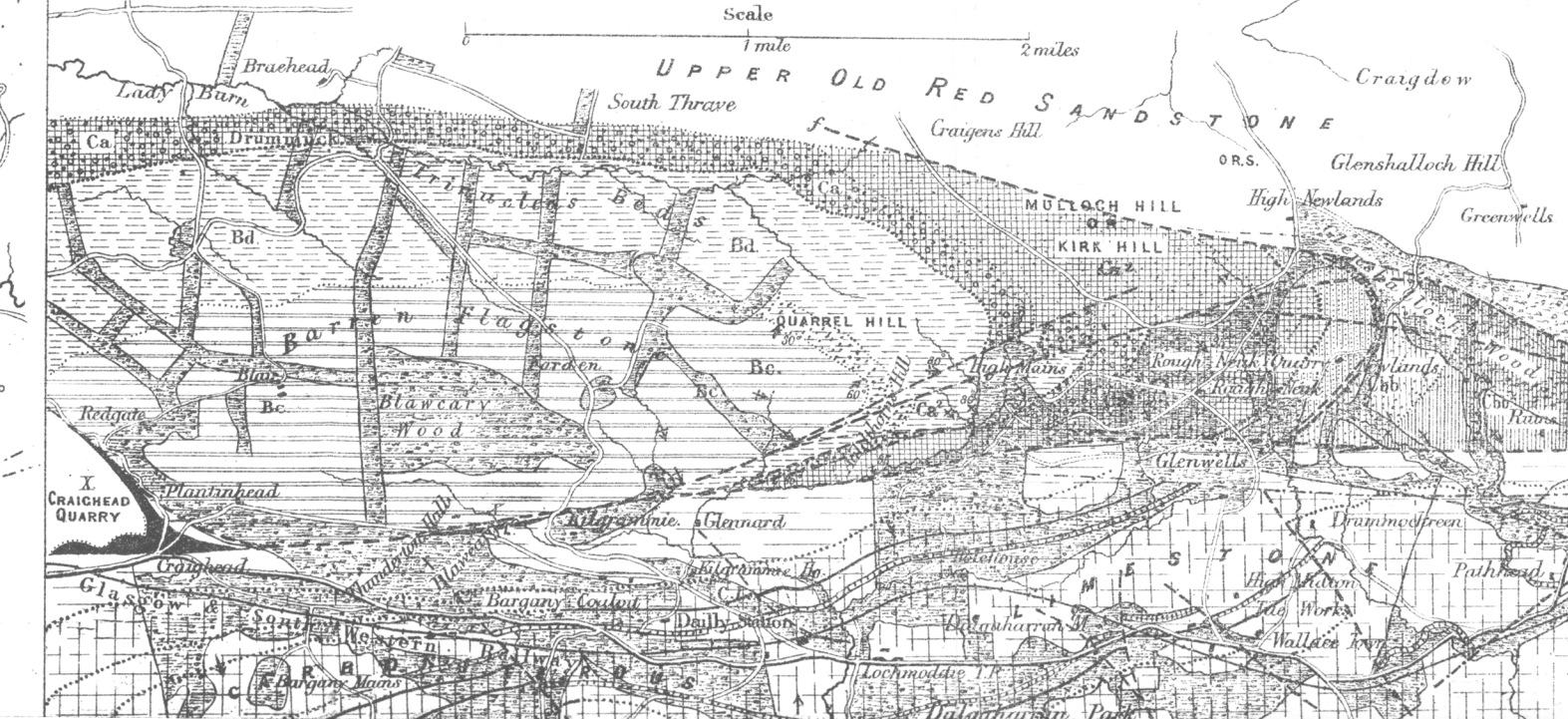
CARBONIFEROUS

- Carboniferous Limestone with Coal Seams
- 3. Cement Stone Group
- 2. Red Sandstone Group
- 1. UPPER OLD RED SANDSTONE
- 2. LOWER OLD RED SANDSTONE
- 1. I. SANDSTONE

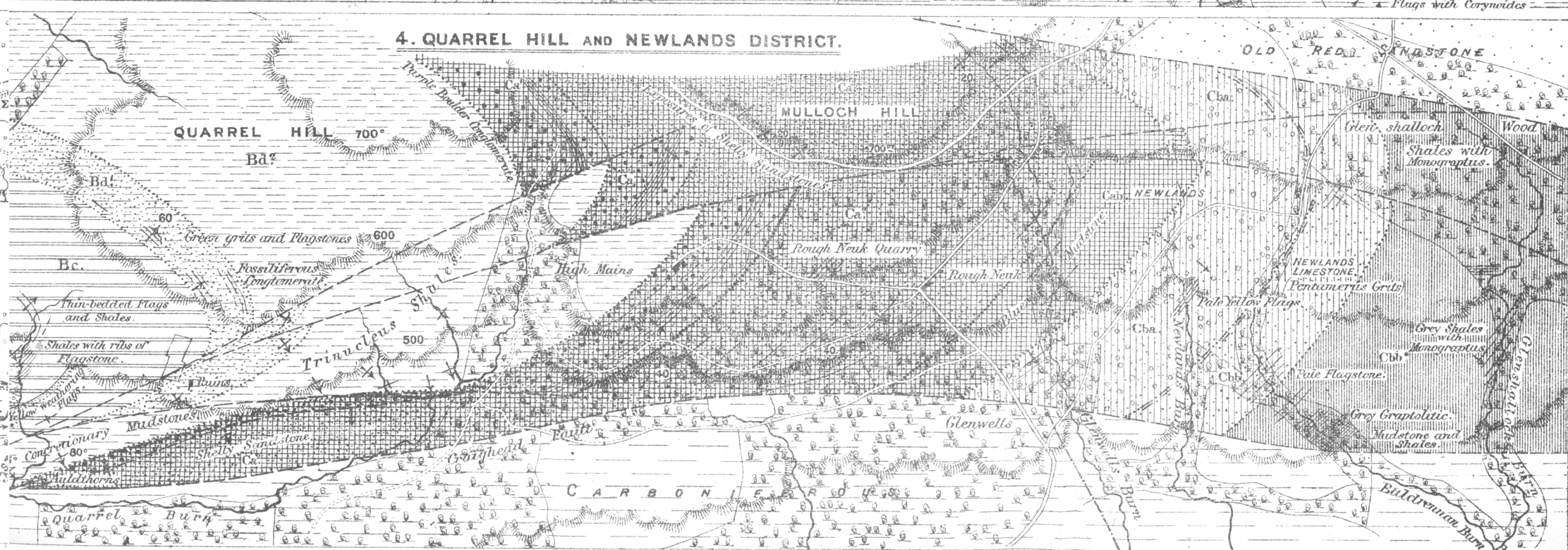
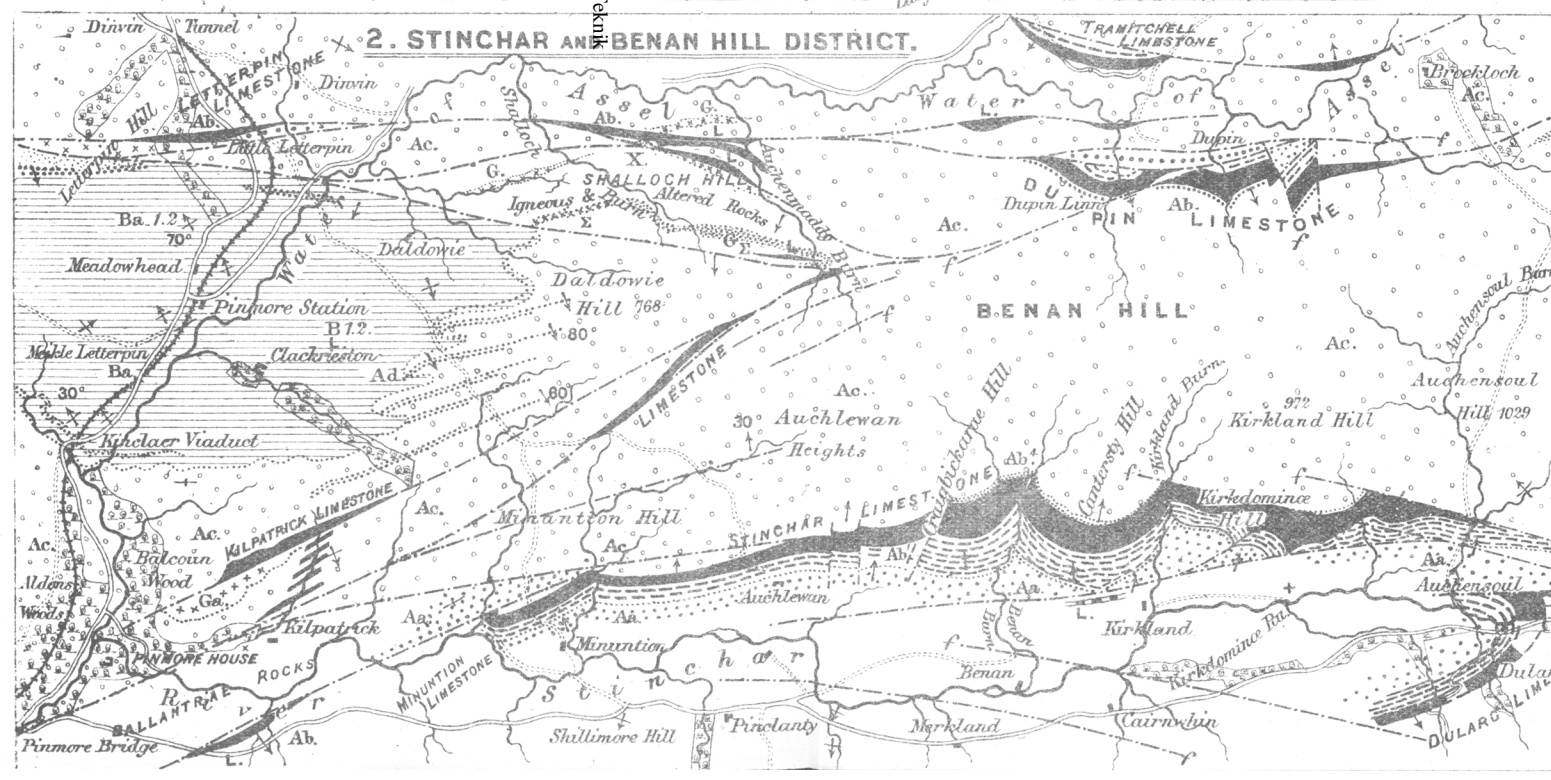
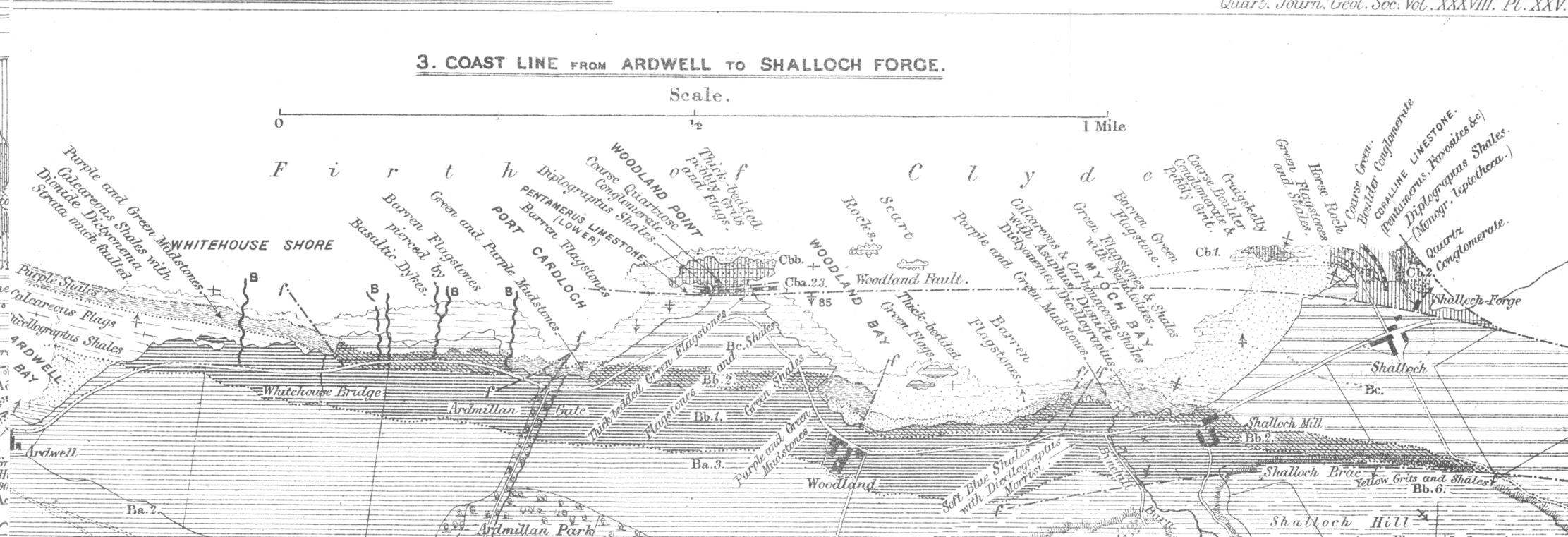
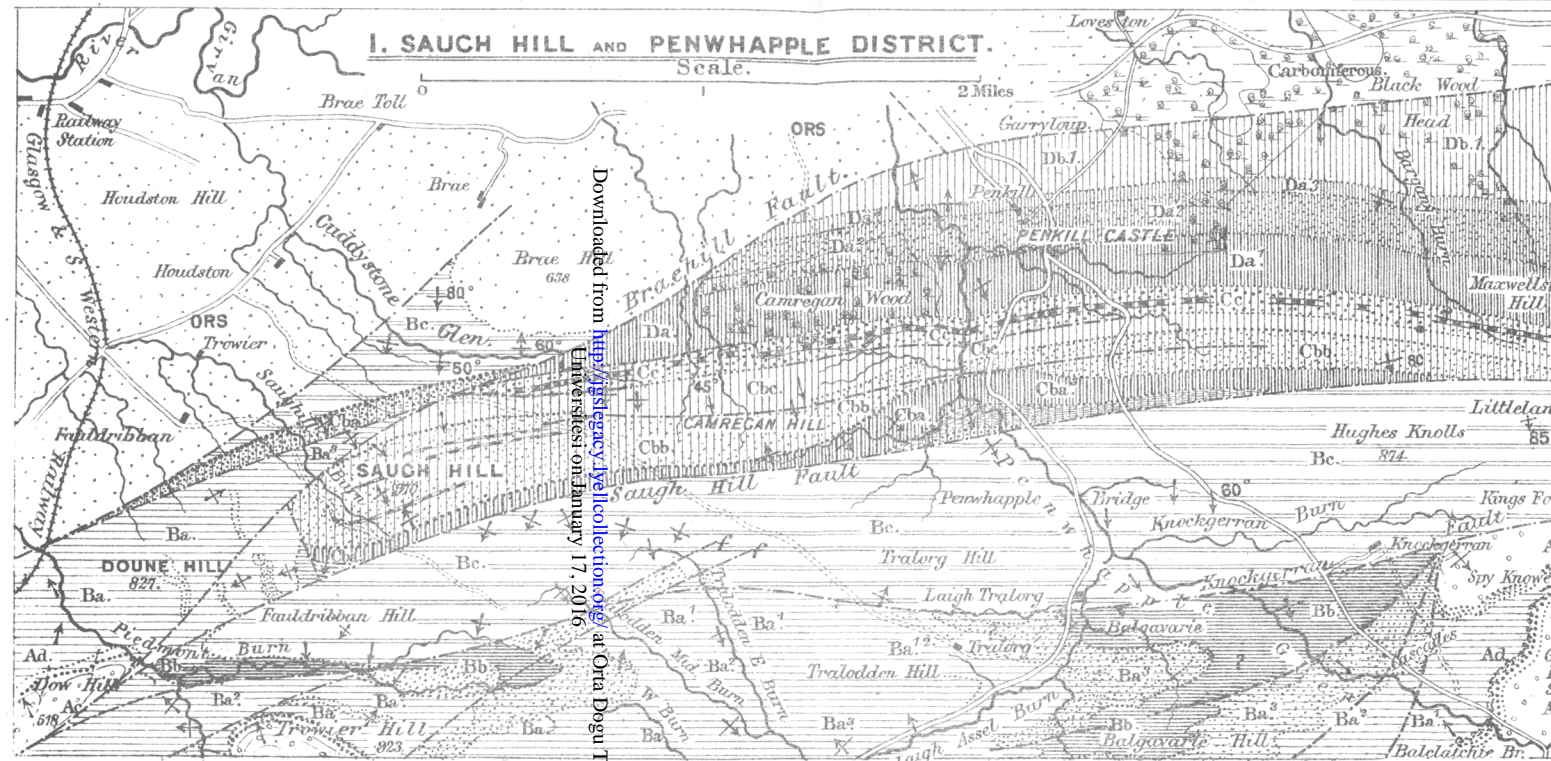
ff. Faults.



ENLARGED MAP OF THE MULLOCH HILL DISTRICT.



Contorted of and hardened Greywackes and Shales
the Southern Uplands.



also in our English rocks of that age; and some more have been found in Peeblesshire, the Lead-Hill district, and in some other places in Scotland, which will swell out the list of Scottish Caradoc forms. Endeavouring to ascertain, as nearly as possible, how many species of Caradoc Brachiopoda occur in the Upper Llandeilo of Scotland, Dr. Davidson found that about 30, or a little more than half, of the Upper Llandeilo species passed upwards into the Caradoc, or were common to both periods.

With respect to the Llandovery, which Prof. Lapworth divides into Lower, Middle, and Upper, he found 15 species in the lower division, 29 in the middle, and 34 in the upper. Of these, 6 are common to the three divisions, 14 to the middle and upper divisions, 10 pass from the Caradoc into the Llandovery, and 4 species only seem to have passed upwards through the whole Girvan series, viz. *Orthis calligramma*, *O. elegantula*, *Strophomena rhomboidalis*, and *S. corrugatella*. Thirty of the Llandovery species occur likewise in the Wenlock and Ludlow rocks. There is therefore a very marked difference between the species of Brachiopoda that characterize the Upper and Lower Silurian rocks of Great Britain.

Dr. Hicks said the paper showed how we were gradually being able to correlate the various districts of the Lower Palæozoic rocks, and arriving at a tolerably universal order in the succession. It was impossible to touch upon all the important questions raised by this paper. Among them he would, however, notice one or two. The paper showed that in one direction there were shore-lines, and in another there were deeper waters—a point of great importance in physical geology. He also noticed in Prof. Lapworth's map, in one corner, an area of metamorphic rocks overlain by conglomerates, and probably of Precambrian age. This would have an important bearing on the question of the age of the beds in the north of a similar character, but supposed by Murchison and the Survey to be of Silurian age. Here also we find the newer beds, as there, frequently faulted down among the older ones. We were greatly indebted to Prof. Lapworth for the admirable work he had done.

Prof. HUGHES agreed with the conclusions of Prof. Lapworth, and pointed out that in Wales and England we had the same order of succession of the life-zones so far as they had been worked out. In North Wales the Llandeilo beds were not well defined, being near the volcanic centre; in South Wales they were more fossiliferous, but were soon overlapped. The great difficulty in correlation was in the May-Hill series (Upper and Lower Llandovery), in which we had variable basement beds, indicating the submergence of an irregular land surface. At Llandovery there was a great thickness of both Upper and Lower divisions, with the zone of *Stricklandinia lens* and *Meristella crassa* in the Lower, and of *Pentamerus oblongus* in the Upper. On the west flanks of the Malvern range, within the area mapped as Hollybush Sandstone, he had found May-Hill beds below the zone of *P. oblongus*. In North Wales and the Lake-district there is no clear equivalent of the Upper May-Hill; but a variable basement series can be traced having palæontological affinities with

the Lower May-Hill. On either side of the Lake-district (at Rebecca Hill, Ireleth, and at the west end of the Craven district) a conglomeratic base marks the horizon of a break corresponding to that described by Prof. Lapworth at the base of his Upper series.

Mr. ETHERIDGE expressed his high opinion of the work done by Prof. Lapworth. It was most satisfactory to thus see how important palæontological evidence became in unravelling a difficult country. The mistake of not paying sufficient attention to palæontology had, he thought, been made in mapping the northern part of Britain. He believed that Prof. Lapworth had successfully unravelled this difficult region; and we should be thankful to him for the unwearied labour and the patience and knowledge he had brought to bear upon it.

Prof. LAPWORTH, in reply, thanked the Meeting for the reception it had given him. In the present part of his paper he had dwelt mainly on stratigraphical arguments; but, as regards the second part, he must express his gratitude to Dr. Davidson for what he had done in aiding him. He had also said little about Mrs. Gray's collection, as that was in process of being described, and would be treated in detail in the succeeding portion of the memoir. As regards the older rocks mentioned by Dr. Hicks he said little, as it was foreign to his paper; but the Ballantrae rocks were certainly older than the Girvan beds, as fragments of them occurred in conglomerates at the base of the Girvan rocks, and the latter overlie them. With regard to the basement beds of the Llandovery in North Wales, he had examined them and believed there were three series, as in Scotland,—one only near Birmingham, two as you approached the Stiper Stones, and a third in the Welshpool area; so that he was in favour of putting all the Llandovery beds into the Silurian. He thanked Mr. Etheridge for his support, and would call attention to the valuable work done by Mr. Etheridge, Jun., on the fossils from this locality. He called attention to the way in which his own work bore out Dr. Smith's dictum of "strata identified by superposition and organic remains."