Chapter 3 General description of the Silurian rocks of the Southern Uplands of Scotland. I Stratigraphy. II Tectonic arrangement

In this chapter we propose to give a brief sketch of the geological history of the Silurian strata of the Southern Uplands, describing, first, the characters of the rocks and fossils in chronological order, and indicating the probable physical conditions which prevailed during each successive period; and second, the present tectonic arrangement of the strata as produced by the main elevation of the tableland at the close of Silurian time, and modified by subsequent denudation.

I. Stratigraphy

At the outset it is necessary to state clearly that, with the exception of certain areas where local unconformabilities prevail, the Silurian strata of the Southern Uplands point to continuous sedimentation from Arenig to Ludlow and Downtonian time; and further that, in the case of many of the great divisions of the system, there is a constant change in the nature of the sedimentation, as we pass from the Central Moffat region northwards and westwards by the Leadhills to the Girvan area. It is therefore essential to trace each successive rock-group, from the Moffat area towards the northern margin of the tableland, in order to understand the variation in the character of the strata, and the consequent changes in the nature of the fauna resulting from the altered physical conditions to which these variations point.

For the sake of convenience of description, the Silurian tableland has been divided into the following geographical belts, based on the geological relations of the strata (see (Index map)):

1. The Southern Belt, comprising the Wenlock and Ludlow Rocks along the southern margin of the tableland.
2. The Central Belt, from twenty to twenty-five miles in width, composed mainly of Llandovery and Tarannon Rocks (b^4), stretches from the Mull of Galloway north-eastwards by Castle-Douglas and Moffat to Melrose and thence to St. Abbs Head.
3. The Northern Belt, occupied by Arenig, Llandeilo, and Caradoc Rocks (b^1, b^2 b^3), extends from the northern slope of the Lammermuir Hills south-westwards, through the Moorfoot and Leadhills by Sanquhar to Loch Ryan and Portpatrick.
4. The Girvan area, comprising the districts in the neighbourhood of Girvan, Ballantrae, Blair and Straiton.

Lower Silurian

Arenig

Central Belt

Rocks. — The strata consist of cherts, mudstones, and grey shales, which at certain localities are associated with fine volcanic tuff.

Fossils. — The cherts are charged with radiolaria which, in this belt, have not been named; the best specimens for determination being obtained from the Northern Belt.

Conditions of Deposition. — The deposits imply the prevalence of oceanic conditions throughout the central area, with clear water, beyond the limit of sedimentation, save in some exceptional instances where fine terrigenous material was mingled with the radiolarian ooze. The fine tuffs likewise indicate volcanic activity, or at least the diffusion of volcanic material over the floor of the ocean in this portion of the Silurian region during the Arenig period.

Northern Belt

Rocks. — The lowest visible strata are of volcanic origin, comprising lavas of various types (diabase, "diabase-porphyrite", and mica-andesite), together with agglomerates and tuffs, of which perhaps the most interesting is

the augite-andesite tuff of Bail Hill, Sanquhar. These are traversed by intrusive igneous materials, including dolerites and gabbros.

Overlying the volcanic series comes an important development of cherts and mudstones, which, where typically developed in the Abington area, may be grouped in three sub-zones. The lowest of these is composed of red or chocolate-coloured cherts embedded in a fine ashy matrix, possibly of volcanic origin, which, when the matrix is exposed to weathering, bleaches to a white colour. The middle and upper sub-zones consist of green and grey cherts respectively, which occur as elongated flattened nodules from a few inches to a few feet across. Frequently they coalesce so as to form a more or less persistent bed. These banded cherts, the upper surfaces of which are often mammillated or botryoidal, vary in thickness from a few inches to a foot or more, and give rise to a remarkable ribbed contour which is a characteristic feature of the series. They are associated with green, grey, and red mudstones, sometimes several inches thick, which by the admixture of siliceous material pass laterally into alert. In one or two sections a thin seam or film of black shale is intercalated between the overlying mudstones and cherts and the underlying volcanic rocks.

Fossils. — The cherts are abundantly charged with radiolaria. From the researches of Dr. Hinde, in whose hands the collection of cherts made by the Geological Survey was placed for examination, it appears that, in thin sections of the unstained rock, the organic remains, when viewed under the microscope, look like larger and smaller circles filled with somewhat lighter material than the surrounding matrix. In this condition no structure is observed. In sections of the red or jaspery chert, the outlines of the radiolaria are more clearly defined, the radiating spines being sometimes seen. In the unstained and red cherts, the radiolaria are only represented by casts, their tests having been dissolved or otherwise rendered indistinguishable. Where, however, the rock has been stained by a dark or black substance, due to carbon, iron, or manganese, the tests have been preserved in the material which has replaced the original silica. In these stained portions fairly perfect specimens of radiolaria have been found by Dr. Hinde, showing one or more concentric spheres and spines projecting, from their surfaces.

From the collection of cherts Dr. Hinde has identified twenty-three new species of radiolaria, belonging to twelve genera, of which half are new, together with some spicules of hexactinellid sponges, and some minute toothed plates and detached denticles resembling the radulte of naked molluscs. He infers, as already stated, that the chert is due to the accumulation of the tests of radiolaria, and is thus a pure radiolarian rock, like the Tertiary beds of Barbadoes and the Nicobar Islands.

The thin seam of black shale overlying the Arenig lavas in the Abington district has yielded specimens of the following Arenig graptolites: *Tetragraptus fraticosus, T. quadribrachiatus,* together with a phyllopod crustacean, *Caryocaris Wrighti* (p. 286).

The mudstones, immediately overlying the foregoing. Arenig black shale, contain a profusion of hingeless brachiopods, similar to those which usually occur in graptolitic deposits, and belonging to the genera, *Acrothele,* 2 species; *Acrotreta*, 2; *Kutorgina*, 2; *Lingula*, 1; *Lingulella*, 3; *Linnairssonia*, 2; *Obolella*, 3; together with a glass-rope sponge *(Hyalostelia)* and Annelid jaws, referred to the genus *Arabellites.*

Conditions of Deposition. — The lavas, tuffs, and agglomerates prove that volcanic action was in full vigour in the northern area during the Arenig period, and in one instance, at Bail Hill, near Sanquhar, the augite-andesite agglomerate and tuff, which is there developed locally, seems to point to discharge from an adjacent centre. After the cessation of general volcanic activity, the waters remained clear, and allowed the accumulation of the radiolarian ooze. The Shelly mudstones and thin graptolitic shale no doubt suggest nearer proximity of land than is indicated by the cherts, but when viewed in connection with their fossil contents, they clearly indicate an oceanic phase of sedimentation.

Girvan area

Rocks. — Within the limits of the Girvan and Ballantrae region occurs the largest development of Arenig volcanic rocks in the Southern Uplands. They consist of a succession of diabase and "diabase-porphyrite" lavas with interbedded tuffs and agglomerates, the diabase-lavas being fine-grained and vesicular, while the diabase-porphyrites contain large phenocrysts of felspar. One of the most striking and characteristic features of the lavas is the pillow-shaped or sack-like

structure which they present in the field (Plate 1), the spaces between the spheroidal masses being sometimes filled with fine sediment such as black shale or limestone (Plate 2) From the distinctive petrographical types of the breccias and agglomerates near the top of the volcanic series, as, for example, the augite-andesite tuff of Mainshill, Ballantrae, and the diabase breccia of the conical hill, Knockdolian, it is clear that these pyroclastic materials must have been erupted from several independent vents.

The horizon of this succession of lavas and tuffs is clearly defined by the presence of fossiliferous flinty mudstones interleaved in the volcanic series, and by black graptolitic shales near the top, both of which yield graptolites of Middle Arenig age. Nowhere is the base of this volcanic series exposed within the limits of the Ballantrae and Girvan area, so that no estimate can be made of its total thickness, nor is it possible to fix the geological horizon of the earliest eruptions. Sir Archibald Geikie has, however, suggested that "possibly its visible portions represent merely the closing scenes of a long volcanic history which, over the area of the South of Scotland, extended into Cambrian time, like the contemporary series of Cader Idris".<ref>Ancient Volcanoes of Great Britain. Vol. 1., p. 196.</ref>

This volcanic series passes upwards into red, green, and grey cherts which are interstratified with tuffs and breccias that clearly overlie the Middle Arenig band of black shales. Indeed, the cliff sections leave no room for doubt that the radiolarian cherts were deposited contemporaneously with the volcanic eruptions, for not only are they intercalated with the breccias, but the latter likewise contain fragments of organic chert with radiolaria, which must have solidified on the sea-floor before its disruption by the explosions.

The interbedded lavas, tuffs, and agglomerates are associated with intrusive igneous materials of various petrographical types, comprising serpentine, olivine-enstatite rock, and gabbros, &c. At certain localities foliated gabbro, garnetiferous hornblende-schist, and chlorite schist appear among the intrusive masses, together with certain remarkable granulitic rocks which frequently show a banded structure. These basic masses have been subsequently invaded by dykes and lenticular bosses of dolerite which present chilled margins along their lines of contact with the surrounding rocks.

Fossils. — The organic remains found in the various sediments associated with the volcanic series underlying the radiolarian cherts consist mainly of graptolites of Middle Arenig facies; the following genera being represented: *Tetragraptus,* 6 species; *Dichograptus*, 4; *Didymograptus*, 4; *Trigomograptus*, 1; *Phyllograptus*, 1; *Dendrograptus*, 1; *Climacograptus*, 1; and *Dictyonema,* 1. The phyllopod crustacean *Caryocaris Wrighti* is likewise recorded from these horizons. The genera of hingeless brachiopods hitherto met with in these sediments are not so numerous as those in the Shelly mudstones of the same age in the Northern Belt, viz.: *Acrotreta,* 2 species; *Discina*, 1; *Lingula*, 1; *Obolella,* 2. Sponges are represented merely by their mooring rods (Plate 26)

Though radiolaria have not been specifically described from the Girvan area, they occur in profusion in the various bands of chert, as may be readily seen by an ordinary lens.

Conditions of Deposition. — The succession of lavas and tuffs points to submarine volcanic eruptions which have been continued for a considerable lapse of time, the spheroidal masses of lava being surrounded by fine sediment transported from the existing land surface. During pauses in the eruptions fine sand and mud were accumulated on the sea-floor, in which were entombed the remains of hydrozoa, phyllopod crustaceans, and brachiopods. It is probable that as the volcanic episode advanced the sea-floor was slowly subsiding, for the land-born sediment disappears near the top of the series, and is replaced by radiolarian ooze, which must have been laid down in clear water. That the volcanic agencies had not become quiescent, however, but continued at intervals to break out anew, is proved by the fragments of lava and pieces of the already consolidated chert, which were evidently derived from the disruption of the sea-floor, and were buried in a fresh accumulation of radiolarian ooze.

Llandeilo

Central Belt

Rocks. — The lower division of the Llandeilo Rocks throughout this region is represented by radiolarian cherts and mudstones which immediately overlie the Arenig band just described.

The upper division (Glenkiln Shales) is composed partly of black shales alternating with thin black cherts or flinty ribs, from one to three or four inches thick, and partly of grey and orange-coloured ashy mudstones, with bands of grey radiolarian chert, the latter being indistinguishable in hand-specimens from the chert which immediately overlies the Arenig volcanic rocks. These cherts are succeeded by a few feet of black shales, passing upwards into the overlying Hartfell black shales.

Volcanic rocks, consisting of fine tuffs, associated with radiolarian chert, occur at certain localities. The fine tuffs at Trowdale, near Castle-Douglas, may belong to Lower Llandeilo time, and the (ashy) mudstones found in Craigmichan Scaurs seem to be composed partly of volcanic materials.

Fossils. — The cherts of Lower Llandeilo age, as well as those interbedded with the Glenkiln black shales, are abundantly charged with radiolaria.

The Upper Llandeilo Rocks (Glenkiln Shales) possess a characteristic assemblage of graptolites which differs in a marked degree from that recorded from the Arenig Rocks of the region. Indeed, only two of the Scottish genera *(Didymograptus* and *Climacograptus)* pass upwards from the Arenig to the Upper Llandeilo horizon. It is a remarkable fact that *Didymograptus Murchisoni,* which is the zonal form of the Lower Llandeilo Rocks of Wales and other regions, has not been detected throughout the length and breadth of the Southern Uplands. Its absence, however, may be accounted for on the supposition that the Lower Llandeilo Rocks are, in the South of Scotland, represented by the upper part of the zone of radiolarian chert, which intervenes between the Middle Arenig black shales and the Glenkiln black shales.

The zonal graptolite of the Glenkiln Shales is *Caenograptus gracilis*, which is associated with the following genera: *Didymograptus*, 2 species; *Thamnograptus*, 2; *Clathrograptus*, 1; *Dicranograptus,* 7; *Dicellograptus,* 6; *Leptograptus*, 1; *Diplograptus,* 6; *Cryptograptus*, 1; *Glossograptus*,1; *Lasiograptus*, 2; *Climacograptus*, 3; *Corynoides,* 2. (Plate 24)

The number of genera and species of hingeless brachiopods is limited, compared with those occurring in the mudstones which immediately overlie the Arenig volcanic rocks. They are restricted to the genera *Acrotreta, Acrothele, Siphonotreta,* and *Discina.* The glass-rope sponge *(Hyalostelia) is* also recorded from this horizon.

Conditions of Deposition. — In Lower Llandeilo time, oceanic conditions prevailed during the accumulation of the radiolarian ooze in the central region, save at certain localities where, owing probably to the elevation of the sea-floor, the area of deposition was brought within the limit of terri-genous sedimentation. In Upper Llandeilo time, the sea-floor must have remained for a long interval sufficiently deep and far from land to permit the fine sediment to accumulate, in which the graptolites and hingeless brachiopods were entombed.; The zone of orange-coloured mudstones and radiolarian cherts indicates a recurrence of oceanic conditions with clear water, followed by the deposition of fine dark mud which now forms the few feet of black shale at the base of the Hartfell shales.

Northern Belt

Rocks. — The Lower Llandeilo Rocks are here represented, as in the central area, by the upper portion of the zone of radiolarian chert, which intervenes between the Arenig volcanic rocks and the Glenkiln Shales (Upper Llandeilo). In a few exceptional localities (Tannylaggie, Glen Trool, Waterhead) the cherts are apparently intercalated with greywackes in such a way as to preclude the supposition that the relationship is due to faulting.

In the case of the Upper Llandeilo group there is conclusive evidence of the gradual change in the character of the sedimentation as we pass towards the northern margin of the tableland and westwards towards Girvan. Over much of the area, however, the Upper Llandeilo Rocks are represented by black shales of the normal Glenkiln type in the Moffat region. Indeed, throughout the various anticlines of the Moffat series, which are traceable along the southern portion of the Northern Belt, as, for example, from Morroch Bay, south of Portpatrick, north-eastwards by Glen Trool, Carsphairn, and Sanquhar, thence by the Lead Hills and Abington to the Moorfoot Hills and the northern slopes of the Lammermuirs, there is little variation in the lithological characters of the Upper Llandeilo Rocks. They consist of a mass of black shales with thin black siliceous ribs or flinty bands from one to several inches thick. But to the north of this limit a marked change is observable. For instance, in Cowie's Linn Burn, north of Eddleston, in the county of Peebles, the strata yielding the

Glenkiln fauna (Upper Llandeilo) no longer consist of a solid mass of black shales, but are composed either of dark sandy micaceous shales interleaved in grey shales, or of dark rusty bands embedded in green and grey mudstones.

Similar modifications are observable along the margin of the tableland from Leadburn to the valley of the Clyde north of Abington, where, in some instances, the black shales disappear altogether and sediments of a different type rest directly on the radiolarian cherts. One example may be quoted to show how rapidly the change takes place within a short horizontal distance. In the Wandel Water, north-east of Abington, below Birnock shepherd's house, black shales of the normal Moffat type appear, with the characteristic Glenkiln fauna, while about two miles across the strike, in the River Clyde near Wandel Mill, the same fossils occur in dark films in sandy shales and greywackes. Again, in the Fingland Burn — a tributary of the Spango Water, north-east of the Sanquhar coal-field — the Glenkiln fauna appears in dark seams, from one-tenth of an inch to an inch thick, interleaved in sandy shales.

Crossing the Nith and proceeding along the northern border of the tableland, we find similar phenomena, as, for instance, at Craiglure Lodge, near the head waters of the River Girvan, where the characteristic Glenkiln fossils can be obtained from minute dark seams in sandy shales, embedded in massive greywackes and grits.

In the south-western portion of the Northern Belt, in the neighbourhood of New Luce and Loch Ryan, the change in the character of the sedimentation of the Upper Llandeilo Rocks extends much further south than in the districts just referred to. Indeed, it is clearly recognisable in the Main Water of Luce, about two miles north of New Luce, where, at the south end of an important section, the Glenkiln fossils occur in massive, flaggy black shales, while at the north end of the same section they appear in minute streaks of blue-black shales embedded in grey shales. Still further north, in the Cairn Ryan slate quarries, on the east side of Loch Ryan, at the mouth of Glen App, and in the neighbourhood of Barrhill, a characteristic assemblage of Glenkiln fossils has been collected from thin dark carbonaceous seams or films, interleaved in grey and blue shales and slates, the latter being associated with greywackes.

It is obvious, therefore, that some of the coarser sediments (shales, flagstones, greywackes, and grits) which replace the Glenkiln black shales in the Northern Belt must be of Upper Llandeilo age. Indeed, one of the difficulties resulting from the lateral variation in the phase of sedimentation in this northern area is that of fixing the upper limit of the coarser sediments of Llandeilo age, for many of these unfossiliferous Llandeilo grits are lithologically indistinguishable from certain grits which are believed to be Caradoc.

Some of the pebbly grits along the northern margin of the tableland are probably Upper Llandeilo, and the coarse conglomerate of Corsewall Point west of Loch Ryan, which is believed to be on the horizon of the Benan conglomerate of the Girvan district, may belong to the close of Upper Llandeilo time.

Some of the volcanic rocks in the Bail Hill area, near Sanquhar, may be of Upper Llandeilo age.

Fossils. — All the characteristic graptolites of the Glenkiln Shales (Upper Llandeilo) of the Moffat region have been recorded from the black shales occupying a similar horizon in the Northern Belt. And even where these strata are replaced by coarser sediments, many, if not most, of the characteristic Glenkiln forms occur in the thin films interleaved in the grey shales and greywackes. It is interesting to observe that in addition to these forms, *Loganograptus Logani,* a graptolite which elsewhere occurs in Arenig Rocks, together with *Dendrograptus,* appears in the Abington and Leadhills region in black shales of Upper Llandeilo age. The graptolites are associated with some of the genera of hingeless brachiopods found in the Glenkiln Shales of the Central Belt.

Conditions of Deposition. — The black shales point to conditions of deposition near the verge of sedimentation, but the gradual replacement of these fine sediments by coarser deposits as we proceed northwards clearly indicates that the land surface from which these materials were derived lay to the north-west of the Silurian sea.

Girvan area

Rocks. — As in other districts of the Southern Uplands, the Lower Llandeilo Rocks are here represented by radiolarian cherts and mudstones, being the upper portion of the zone which overlies the black shales of Middle Arenig age. In one important section on the shore near Port-Currarie, between the River Stinchar and Glen App, the radiolarian cherts and

mudstones are overlain by volcanic agglomerate and tuff, the latter being immediately followed by mudstones yielding a characteristic assemblage of Glenkiln fossils (Upper Llandeilo). It is obvious, therefore, that volcanic action must have here continued locally into Lower Llandeilo time.

In dealing with the Upper Llandeilo Rocks of the Girvan area, we must clearly distinguish between the district lying to the south of the River Stinchar, where there is a perfect passage from the Arenig lavas and tuffs to certain mudstones and other sediments which yield many of the characteristic Glenkiln fossils (Upper Llandeilo), and the district to the north of the Stinchar, where there is a marked unconformability, separating the Arenig volcanic rocks and radiolarian cherts from the overlying sedimentary series of Girvan. From a consideration of the palaeontological evidence it is highly probable that this break in the continuity of the geological record north of the Stinchar valley took place in Upper Llandeilo time.

Taking first the Upper Llandeilo sediments south of the Stinchar valley, we find them to consist of green, grey, and blue-black fossiliferous mudstones (Currarie, Portandea) followed by green and grey mudstones, shales, _and friable greywackes, the latter being largely derived from Me disintegration of volcanic and plutonic rocks (the Tappins group). In the pebbly grits associated with the "Tappins beds", there are small fragments of radiolarian chert and volcanic rocks. In like manner the Glen App conglomerate, which appears to be intercalated in the higher part of the same series, presents an assemblage of pebbles, almost identical with those met with in the Benan conglomerate to be referred to presently. Indeed, these coarse boulder-beds of Corsewall Point, Glen App, and Benan, north of the Stinchar, are all believed to occupy much the same horizon.

North of the Stinchar valley there is a vast difference in the character of the Upper Llandeilo Rocks, owing to the presence of the prominent discordance to which allusion has just been made. Beneath the unconformable series no fossiliferous representatives of the Glenkiln Shales have as yet been detected. It is true that near Bennane Head certain green and grey mudstones and greywackes overlie the radiolarian cherts (Arenig and Lower Llandeilo), but they have hitherto proved unfossiliferous.

Those members of the unconformable series which are here regarded as of Upper Llandeilo age are, in ascending order, (a) Kirkland conglomerate and sandstones, (b) Stinchar limestone, (c) Graptolitic mudstones, (d) Benan conglomerate; which not only rest unconformably on the folded and highly denuded surfaces of the Arenig volcanic and plutonic rocks, the Arenig black shales and radiolarian cherts, but likewise contain well-rounded pebbles and fragments of these very materials.

Fossils. — The fossils occurring in the mudstones, of Upper Llandeilo age, which overlie the Arenig volcanic rocks and cherts south of the valley of they Stinchar (Portandea, Currarie) consist mainly of graptolites, with a marked Glenkiln facies, such as *Didymograptus superstes, Caenograptus pertenuis, Dicranograptus minimus, Climacograptus caelatus.* Special interest, however, attaches to this horizon from the abundance of specimens of *Dendrograptus gracilis* in the section 600 yards north of Port-Currarie (see page 429), where, in addition to the characteristic Glenkiln forms, this species is associated with a *Callograptus*-like *C. Salteri* and a *Didymograptus* like *D. extensus.* Hingeless brachiopods, including the forms in the Glenkiln shales of the Central Belt, together with the genera *Siphonotreta* and *Kutorgina,* are likewise found in these mudstones.

In the Upper Llandeilo Rocks on the north side of the Stinchar valley the marked change in the lithology of the strata is accompanied by a no less conspicuous change in the facies of the fossils. Here for the first time we find, as in the case of the Stinchar Limestone, a prolific assemblage of calcareous organisms, indicating an entire difference in the character of the sedimentation.

A conspicuous feature of the limestone is the abundance of those organisms forming irregular nodules, with concentric structure, named *Girvanella,* which are now believed to have affinities with the calcareous Algae. In certain bands *Foraminifera* enter largely into the composition of the limestone, the forms all belonging to one species, viz.: *Saccamina Carteri,* which is likewise found in abundance in some of the Scottish Carboniferous limestones. Corals are in great profusion in some of the limestone exposures, as at Craighead. No fewer than seventeen genera have been recorded from all the outcrops of this band in the Girvan region, including *Chaetetes, Favosites, Halysites, Lindströmia, Streptelasma, Stenopora, Tetradium,* &c.

In the Monograph on the Silurian Fossils of Girvan (page 94), Professor Nicholson states that "*Lyopora favosa, Tetradium Peachi, Prasopora Grayae, Streptelasma Craigense, S. Europaeum, S. aggregatum,* and *Lindströmia subduplicata* are the common forms of the Craighead Limestone, and, with the exception of the last, they are not known to occur elsewhere in Britain". Since the publication of this work, *Lyopora favosa* has been recorded from the Kilbucho grit and *Lindströmia subduplicata* from the beds at Wallace's Cast and Kilbucho. Judging only from the corals, Professor Nicholson inferred that the Craighead Limestone "occupies a tolerably low position in the Lower Silurian series, corresponding perhaps with the upper part of the Trenton Limestone, or the base of the Cincinnati and Hudson River formations of North America".

The echinoderms are poorly developed in these Upper Llandeilo limestones, the only prominent form being *Glyptocrinus.* The arthropods, on the other hand, are found in abundance; the cirripedes being represented by *Turrilepas,* the ostracods by the genera *Cythere* and *Primitia,* while no fewer than fourteen genera of trilobites have been obtained from this horizon, including *Ampyx,* 1 species; *Calymene*, 1; *Asaphus*, 2; *Cheirurus*, 2; *Illaenus*, 4; *Eucrinurus*, 1; *Phacops*, 1; *Remopleurides*, 4; &c.

The calcareous brachiopods, which likewise occur in profusion in the limestone zones, comprise seven genera, including *Leptaena,* 9 species; *Meristella*, 1; *Orthis,* 15; *Strophomena,* 9; *Rhynchonella,* 11. The lamellibranchs number three genera, viz.: *Ambonychia,* 2 species; *Orthonota*, 1; *Pleurorhynchus,* 1. The gasteropods comprise thirteen genera, including *Maclurea,* 5 species; *Ophileta*, 1; *Murchisonia*, 5; *Pleurotomaria,* 2. The cephalopods are represented by three genera, viz.: *Cyrtoceras,* 2 species; *Orthoceras*, 3; *Trocholites*, 1.

Besides other forms of calcareous organisms, a few genera of horny brachiopods likewise occur, but chiefly in the graptolitic mudstones overlying the limestone, viz.: *Acrotreta*, 1 species; *Crania*, 2; *Discina; Lingula*, 5; *Siphonotreta,* 3. These are associated with several genera of graptolites; some of the forms *(Didymograptus superstes, Diplograptus euglyphus,* and *Clathrograptus cuneiformis)* having a marked Glenkiln facies, while others are common both to the Glenkiln and Hartfell groups of the Moffat region. Professor Lapwort'h has called attention to the bearing of this evidence on the horizon of the Stinchar and Craighead Limestone. While agreeing with him in regarding it as of Upper Llandeilo age, we are inclined to believe that it may belong to the close of that division of the Silurian system; for though some of the corals and some of the genera of the gasteropods *(Maclurea, Ophileta)* have a Llandeilo facies, the other groups of organisms have a marked Caradoc character.

Conditions of Deposition. — While the deposits to the south of the River Stinchar imply continuous sedimentation in Upper Llandeilo time, the conditions seem to have been on the whole unfavourable for the development and preservation of life. The lithological characters of the "Tapping beds" and of the Glen App conglomerate point to the erosion of Arenig igneous rocks at no great distance.

On the other hand, the evidence obtained from the north side of the Stinchar points to considerable disturbance and elevation of that area, whereby the charts and any overlying sediments were removed by denudation, and the volcanic and plutonic rocks were laid bare. The coarse conglomerates (Kirkland and Benan) represent the shore deposits which accumulated round that ancient volcanic bank as it slowly subsided, while the limestones reveal to us the calcareous organic sediment furnished by a rich and varied fauna that flourished near the margin of the Silurian sea.

Caradoc

Central Belt

Rocks. — The Hartfell Shales, which in the Central Belt represent the Caradoc Rocks of Wales, may be grouped in two sub-divisions, each characterised by distinct lithological characters: (a) a lower tolerably solid mass of slaty black shales with thin intercalations of pale mudstones, (b) an upper group of fine mudstones (Barren Mudstones), containing thin ribs of limestone and chert, nodules of ironstone and manganese, and two or more thin seams of black shale. In the Hartfell section thin seams of tuff are interleaved in the black shales of the lower group, and a band of volcanic breccia is met with in the mudstones of the overlying group.

Though the foregoing sub-divisions of the Hartfell Shales generally preserve their Ethological characters throughout the various anticlines of the Moffat series, still, in one section (Ettrickbridge-end), coarse grits appear near the top of the Barren Mudstones.

Fossils. — As in the black shales of the underlying Glenkiln division, graptolites form the distinctive group of organisms in the black shales of the Hartfell series. Professor Lapworth states that, while there is no actual pakeontological break between the Glenkiln and Hartfell divisions,<ref>The Moffat Series. Quart. Jour. Gaol. Soc. Vol. XXXIV., p. 307.</ref> "the fossils of the lower division die out one by one as we ascend the succession, and are as gradually replaced by others till the change of fauna is complete. Thus, although the two successive faunas are linked together by a large community of genera and species, yet, on the other hand, the typical beds of the two formations have scarcely a single fossil in common. At the summit of the Hartfell Shales, on the contrary, the palaeontological break is almost complete…

"There is an extraordinary mortality among the graptolites in this division. Not only do the peculiar types *Pleurograptus* and *Amphigraptus* arise, culminate, and decay within the formation itself, but *Dicellograptus, Dicranograptus, Lasiograptus, Glossograptus,* and *Leptograptus* — survivors from the Glenkiln Shales — all become extinct before we reach the highest beds. The allied genera *Climacograptus* and *Diplograptus are* all that remain to link on the richly varied forms of the Glenkiln beds to the highly prolific but monotonous fauna of the Birkhill Shales". The zonal graptolite forms of the Hartfell strata are as follows, in descending

UPPER GROUP	
Dicellograptus anceps	in thin black shale seam near top of Barren Mudstones
Dicellograptus complanatus	in thin black shale seam near base of Barren Mudstones
LOWER GROUP	
Pleurograptus linearis	
Dicranograptus Clingani	in Hartfell black shales
Climacograptus Wilsoni	

The Lower Hartfell fauna is farther characterised by the great abundance on different horizons of the genera *Dicellograptus, Dicranograptus, Diplograptus, Pleurograptus,* and *Corynoides.* In the case of *Dicellograptus,* for example — a survivor from the Glenkiln fauna — where it has a restricted development, Professor Lapworth truly says that in one zone of the Hartfell Shales "its individuals swarm in countless multitudes". (Plate 27).

The rare form *Buthograptus laxus* is confined to the *Climacograptus Wilsoni* zone in the Moffat region, where it is associated with numerous representatives of the glass-rope sponge, *Hyalostelia.*

Two genera of hingeless brachiopods — viz., *Acrotreta* and *Siphonotreta* — are of common occurrence in the Hartfell division.

Conditions of Deposition. — In. Lower Caradoc time the sea-floor throughout the central region must have remained at a sufficient depth and far enough from land to permit the fine sediment to accumulate in which the graptolites were entombed.

In Upper Caradoc time the phase of sedimentation implied by the Barren Mudstones probably points to a further depression of the sea-floor of the central region. For the physical conditions, including distance from land and depth of ocean, were probably intermediate between those which characterised the deposition of the black shales on the one hand and the radiolarian ooze on the other.

The thin seams of tuff and volcanic breccia likewise indicate sporadic outbursts of volcanic activity over the Central Belt.

Northern Belt

In this portion of the tableland there is conclusive evidence of the lateral variation in the character of the Caradoc strata as they are traced northwards towards its margin and westwards to Girvan.

Rocks. — Taking first the mass of black shales which in the Central Belt form the lower sub-division of the Hartfell group, we find it repeated in many of the anticlines of the Moffat series, along the southern portion of the Northern Belt, where it presents the normal lithological and palaeontological features which have just been described. For example, in the sections in Morroch Bay, south of Portpatrick, in the Scar Water and some of its tributaries which flow into the Nith, and again at the Friar's Nose [NT 51056 59812] on the slopes of the Lammermuirs, the Hartfell black shales possess their distinctive lithological characters and yield many of the zonal forms which occur in the Central Belt. But as they are followed northwards the black shales are gradually replaced by coarser sediments, and the characteristic graptolites appear, either in thin black seams interleaved in flaggy shales or in dark sandy shales. Indeed, the lateral variation in the lithological characters of the Hartfell black shales in the Northern Belt is merely the counterpart of that presented by the Glenkiln Shales, with this slight difference, that the change in the character of the sedimentation extends much further south in the case of the Hartfell black shales.

Various examples might be quoted for the purpose of illustrating this striking modification of the Hartfell black shales, but one or two may suffice. In the case of the black shale band which stretches from Burnmouth on the Nith to Dalshangan on the River Deugh, the lithological and palaeontological features of the *Dicranograptus Clingani* zone of the Hartfell Shales are admirably represented, but when traced northwards to the Polmorlach and Polhote Burns, within two miles of the margin of the tableland at New Cumnock, this band with its zonal forms is found to have disappeared. Thin black seams are there seen to be interleaved in blue and grey shales, which are charged with forms characteristic of the passage zone between the Glenkiln and Hartfell groups. (See page 369.) Confirmatory evidence of this change in the sedimentation, within a short horizontal distance, is to be found in the Glencaple Burn, south-west of Abington. (See page 289.) In like manner, in the Polcraig Burn, Meikle Carco, a characteristic Lower Hartfell form, *Climacograptus caudatus,* with many of its associates, is found in brown sandy shales.

The coarse sediments which gradually replace the Hartfell black shales in certain areas of the Northern Belt, and which may, in all probability, be regarded as their stratigraphical equivalents, are here given in ascending order: 1, dark micaceous shales, with black seams yielding graptolites, which frequently decompose into a yellowish brown ochreous clay; 2, grey greywackes, grits, and conglomerates, with limestone nodules and calcareous shales, which at certain localities in the Leadhills, Abington, and Broughton districts (Duntercleuch, Snar, Wallace's Cast, Kilbucho) are highly fossiliferous.

Frequently these sediments merge into coarse conglomerates, as, for instance, in the Shinnel and Chanlock Waters, north of Moniaive, on the hills near Carsphairn, and in the basin of the Afton Water, where the pebbles consist of acid and basic plutonic rocks, vesicular diabase-lava, radiolarian chert, blue and grey greywacke, grey shale, black shale with graptolites, quartzite from the Highlands, and other ingredients.

In certain districts of the Northern Belt, especially in the tract between Nithsdale and the valley of the Clyde at Abington, there is evidence of local elevation and erosion of the Arenig and Llandeilo Rocks. Various examples are given in the section of this memoir descriptive of the foregoing area, but one may here be quoted to show the nature of the evidence. In the Glenaylmer Burn, near the northern margin of the tableland, north of Sanquhar, there is an excellent section, showing the Arenig cherts with radiolaria covered unconformably by breccia and conglomerate, passing upwards into greywackes and shales. The basal breccia contains angular fragments of chert and black and grey shale, while the overlying conglomerate includes pebbles of greywacke, the largest of which measure nine inches in diameter. There can be no doubt that these materials are of local origin, and it is highly probable that this local elevation and erosion took place towards the close of Llandeilo time.

Along the northern margin of the tableland, from Loch Doon north-eastwards by Kirkconnel, Crawfordjohn, and the Cutter Water to Leadburn, there is a remarkable pebbly grit or fine conglomerate which is locally known as the "Haggis Rock". Its distinctive character is due to the presence of small fragments of red, green, and grey radiolarian cherts, and Arenig volcanic and plutonic rocks, while the matrix has been mainly derived from the disintegration of these igneous materials. The precise stratigraphical horizon of this band is not quite clear, for in that northern region the Hartfell black shales have disappeared, and even the Glenkiln black shales have been so modified that their characteristic forms are found in thin blue-black films interleaved in other sediments. In some instances, as, for example, near Fingland, between the Spango granite mass and Kirkconnel, the "Haggis Rock" overlies sediments yielding Glenkiln fossils (Upper Llandeilo); in others,

no Glenkiln graptolites have been obtained from the strata which intervene between this band and the radiolarian cherts. While in many of the horizontal sections in this volume the "Haggis Rock" of this northern region is represented as of Caradoc age, it is highly probable that bands of a similar petrological type may belong to a lower stratigraphical horizon.

In certain isolated sections in the Leadhills area and in the district south-west of Sanquhar (Craig North, Kiln Burn, Nether Whitecleuch, Shields Burn, Glengap Burn, Polmorlach Burn), diabase-lavas and andesitic tuffs appear at or near the base of the Caradoc Rocks.

The upper division of the Caradoc Rocks of the Northern Belt indicates a great variation from the lithological type of the Barren Mudstones of the central Moffat region, for they consist of grey and blue micaceous shales weathering with a buff colour (Lowther Shales), blue and grey slates (Stobo Slates), with occasional greywackes and grits. A notable feature of this sub-division is the occurrence of limestone nodules in the shales, which sometimes coalesce so as to form a continuous band and sometimes swell out locally into lenticular masses of limestone, as at Wrae and Glencotho, the latter yielding a considerable suite of fossils. These are associated with calcareous grits which yield a similar assemblage of organic remains.

Perhaps one of the most striking features of the Upper Caradoc Rocks of the Northern Belt is the occurrence of contemporaneous lavas and tuffs with the limestone and calcareous grits at Wrae, Glencotho, Hamilton Hill, and Winkston in the county of Peebles. Mr. Teall has shown that the lavas are of different petrographical types from those of Arenig age in the Southern Uplands, since they consist of soda-felsites or keratophyres and perlitic felsites. The development of these volcanic rocks is, however, merely local: at least they are traceable only over a very limited area. Their horizon is defined by the occurrence of Caradoc fossils in the calcareous tuff associated with the limestone, just as organic remains are embedded in the volcanic ash of Caradoc age on Snowden. North Wales.

Fossils. — The Lower Hartfell black shales of the Northern Belt yield nearly all the characteristic graptolites and hingeless brachiopods which have been found in the same sub-division in the central region. Two zonal forms, however, have not been recorded, so far as we know, from any portion of the Northern Belt, viz.: *Climacograptus Wilsoni,* which characterises the lowest sub-zone of the Hartfell black shales, and *Dicellograptus anceps,* which is the distinctive form of the black shale seam near the top of the Barren Mudstones, in the Moffat region. Where the black shales disappear and are replaced by coarser sediments (shales and flagstones) with thin dark seams or films containing graptolites, common to the Hartfell and Glenkiln divisions, considerable difficulty has been experienced in fixing the horizon of the latter strata. Indeed, in some instances, as, for example, in that of the Dally Shales in Dounan Bay, south of Corsewall Lighthouse, Wigtownshire, which yield the following forms: *Diplograptus foliaceus, D. euglyphus, Climacograptus Schärenbergi, C. bicornis, Dicranograptus ramosus, Dicellograptus sextans, D. divaricatus,* the stratigraphical horizon of the strata is not quite clear. Provisionally, they are regarded as the passage beds between the Llandeilo and Caradoc groups, but further careful searching of the fossiliferous seams will doubtless throw light on this question.

In addition to the foregoing types of life, calcareous organisms occur in considerable abundance in the coarser sediments, which accumulated round the areas of local elevation and erosion, as, for example, in the Leadhills and Abington districts. An analysis of the lists of fossils collected from various exposures of grit and conglomerate at Kilbucho, Wallace's Cast, and in the Leadhills region, reveals the following results. Corals are represented by eleven genera, including *Alveolites; Favosites,* 4 species; *Lindströmia*, 3; *Petraia*, 3; *Tetradium*, 2; Heliolites, 1. There are four genera of polyzoa, comprising *Ptilodictya, Fenestella, Ceriopora.* Trilobites number six genera, viz.: *Calymene*, 1; *Cheirurus*, 2; *Illaenus*, 1; *Phacops*, 3; *Remopleurides*, 3; *Trinucleus,* 1. (For complete lists see pp. 225, 243, 324.)

The calcareous brachiopods are represented by six genera, including *Leptaena,* 5 species; *Orthis,* 13; *Rhynchonella*, 4; *Strophomena,* 8 — all of which have a marked Caradoc facies. Indeed, in the "Supplement to the British Silurian Brachiopoda", page 229, Mr. Davidson refers the strata yielding brachiopods from these localities to the Caradoc group. The lamellibranchs number three genera, viz.: *Ctenodonta,* 2 species; *Modiolopsis*, 2; &c.; while the gasteropods comprise no fewer than twelve genera, including *Bellerophon,* 4 species; *Chelodes*, 1; *Cyclonema*, 1; *Macrocheilus*, 1; *Murchisonia*, 3; *Ophileta*, 1; *Pleurotomaria,* 3. The cephalopods are represented by two genera, viz.: *Cyrtoceras,* 1 species, and *Orthoceras,* 1.

The organic remains obtained from the limestones, calcareous grits, and volcanic tuff at Wrae, Glencotho, Winkston, and Hamilton Hill, which are referred to Upper Caradoc time, have a common general character, and belong, without doubt, to one horizon. The crinoids are represented by *Glyptocrinus,* the cirripedes by *Turrilepas;* while the trilobites number several genera, including *Cheirurus,* 3 species; *Harpes*, 1; *Illaenus*, 3; *Phacops,* 1. No fewer than eleven genera of brachiopods have been obtained from this horizon, among which occur *Leptaena,* 3 species; *Orthis,* 6; *Rhynchonella*, 1; *Strophomena,* 3. Only one genus of lamellibranchs has hitherto been recorded from this horizon *(Orthonota);* four genera of gasteropods have been obtained, among which occur *Cyclonema, Euomphalus, Holopea;* and four genera of cephalopods.

Conditions of Deposition. — The lower Hartfell black shales, which extend over a portion of tne Northern Belt, point to the accumulation of fine mud near the verge of sedimentation — conditions similar to those which prevailed throughout the Central Moffat area during this period. But there is also conclusive evidence of the transport of coarse sediment from the ancient land area which lay to the north-west of the Silurian sea, whereby each successive sub-division of the Hartfell group of the Moffat region was modified in turn. It is a remarkable fact that the change in the character of the sedimentation resulting from the transport of coarse terrigenous material from the north-west extends further south with each successive period. For example, the modification of the Moffat type of the Hartfell black shales extends further south throughout the length and breadth of the Northern Belt than that of the Glenkiln Shales, while the change in the character of the Barren Mudstones extends further south than that of the underlying Hartfell black shales. In the sequel it will be shown that similar phenomena are characteristic of the overlying Llandovery Rocks.

There is evidence also of small areas of local elevation and erosion whereby Llandeilo and other rocks were removed and the materials were redeposited in the overlying sediments.

Towards the close of Llandeilo and near the beginning of Caradoc time afew thin sheets of diabase-lava and andesite-tuff were discharged from isolated vents and buried underneath graptolitic mud and other sediment. The closing phase of volcanic activity in the Silurian locks of the Southern Uplands is represented by the soda-felsite and perlitic felsite-lavas and tuffs which were locally erupted during Upper Caradoc time, many of the calcareous organisms having been entombed in the ash which covered part of the sea-floor.

Girvan area

Rocks. — The Caradoc Rocks of the Girvan area indicate a complete change in the phases of sedimentation from those which obtained in the central Moffat area during the same period. Here thick masses of sediment consisting of conglomerates, grits, greywackes, flagstones, mudstones, shales, and limestones are associated with finer materials, which yield graptolites characteristic of the Hartfell division of the Moffat series. In this region these rocks comprise the various divisions of the Ardmillan series established by Professor Lapworth and given here in descending order, to which have been added the Balclatchie beds:

Drummuck Group	Grey fossiliferous mudstones and occasional flagstones.
Barren Flagstone Group	Flagstones and shales usually unfos-siliferous.
Whitehouse Group	Red and green mudstones, with grey and black shales and limestones.
Ardwell Group	Dark grey flaggy shales, with carbonaceous shales and bands of coarse pebbly grit.
Balclatchie Group	Conglomerates, grits, and fossiliferous mudstones.

It is rather remarkable that the strata forming the highest sub-division of the Caradoc Rocks of Girvan (Drummuck group) are represented only in the Craighead inlier, north of the Girvan valley. They do not intervene between the Barren Flagstones and the overlying Llandovery strata on the south side of that river — a structural feature which will be referred to in the sequel.

Fossils. — The assemblage of organic remains in the Caradoc Rocks of Girvan is similar to that found in strata of the same period in the Northern Belt, with this difference, that the fauna is richer both in genera and species.

One of the most prolific horizons in these Caradoc Rocks, and indeed in the whole Girvan succession, is the zone of mudstones intercalated in the grits of the Balclatchie group, which group is regarded by Professor Lapworth as forming the passage beds between the underlying Barr series and the overlying Ardmillan series. The polyzoa are represented by three genera: (*Ptilodictya,* &c.); the cirripedes by *Turrilepas,* and the phyllopod crustaceans by *Pinnocaris.* One of the characteristic palaeontological features of this horizon is the profusion of trilobites, there being no fewer than twenty-one genera, including *Acidaspis,* 3 species; *Agnostus*, 1; *Barrandia*, 1; *Ampyx,* 6; *Asaphus*, 1; *Bronteus*, 1; *Bronteopsis*, 1; *Cheirurus*, 4; *Cybele*, 2; *Deiphon*, 1; *Illaenus*, 3; *Harpes*, 1; *Lichas*, 3; *Phacops*, 1; *Proetus*, 1; *Remopleurides*, 2; *Salteria*, 1; *Stygina*, 1; *Sphaerexochus*, 1; *Staurocephalus*, 2; *Trinucleus*, 3; &c. Of the brachiopods there are eleven genera, of the lamellibranchs 7, of the gasteropods 10, and of the cephalopods 5 genera.

There are four genera of graptolites found in these Balclatchie mudstones, viz.: *Dicranograptus, Dicellograptus, Diplograptus,* and *Climacograptus;* the species being common to the Glenkiln and Harden divisions of the Moffat series.

In the overlying Ardwell group various seams yield graptolites more or less characteristic of the lower sub-zones of the Harden black shales, as, for instance, *Climacograptus caudatus* in the flaggy shales near the top of the group on the shore at Ardwell.

An abundant fauna, partly graptolitic and partly calcareous, has been obtained from the members of the Whitehouse group. For the purpose of correlating the strata with those of the Central Belt, the occurrence here of the two zonal graptolites, *Pleurograptus linearis,* characteristic of the highest sub-zone of the Harden black shales, and *Dicellograptus complanatus,* of the lower portion of the Barren Mudstones, is of great interest.

Among the calcareous organisms, the corals are represented by *Halysites;* the polyzoa by the genus *Fenestella;* and the crinoids by *Glyptocrinus.* The annelides include the genera *Serpulites* and *Tentaculites.* Among the crustaceans, the cirripedes are represented by *Turrilepas,* and the ostracods by six genera, viz.: *Aparchites,* 2 species; *Beyrichia*, 2; *Cypridina*, 1; *Primitia*, 5; *Ulrichia*, 2; *Sulcuna,* 2. The trilobites number 11 genera, brachiopods 11, lamellibranchs 2, gasteropods 10.

The Barren Flagstone group, which overlies the Whitehouse beds, is remarkably destitute of fossils, but the mudstones, which constitute the dominant feature of the highest division of the Caradoc Rocks of Girvan (Drummuck), have yielded a large assemblage of organic remains. Indeed, they have become widely known from the abundance and excellent preservation of the trilobites, there being no fewer than thirteen genera, including *Ampyx,* 1 species; *Calymene*, 2; *Cheirurus*, 2; *Cybele*, 1; *Dionide*, 1; *Dindymene*, 1; *Illaenus*, 2; *Lichas*, 2; *Phillipsia*, 1; *Phacops*, 1; *Proetus*, 3; *Staurocephalus*, 1; *Trinucleus,* 3. While the species of trilobites have a marked Upper Bala facies, there are some points of considerable interest connected with the distribution in time of some of the forms. For example, the genus *Phillipsia,* which here makes its first appearance in the Silurian succession of the Southern Uplands, passes upwards into the Lower Carboniferous series; while *Phacops Brongniarti,* which is a characteristic fossil of the Stinchar Limestone, does not occur on any higher horizon. The brachiopods number 9 genera, the lamellibranchs 2, the gasteropods 14, the pteropods 3, the cephalopods 2.

Professor Lapworth has identified a specimen of *Dicellograptus anceps,* obtained by Mrs. Gray from the Drummuck mudstones — the characteristic graptolite of the upper portion of the Barren Mudstones of the Moffat region.

Another interesting palaeontological feature of the Caradoc Rocks of Girvan is the occurrence of a star-fish band at the very top of the series which has been made known through the researches of Mrs. Gray and Professor Lapworth. The starfishes, which occur in considerable abundance, are referable to *Tetraster Wyville-Thomsoni,* and are associated with many representatives of the various groups of organisms occurring in the underlying mudstones.

Conditions of Deposition. — The sequence of Caradoc Rocks in the Girvan region points to the existence of an extensive land-surface to the north of the Silurian sea. The strata represent shore-deposits which were accumulated on a gradually subsiding area, and an analysis of the fossil lists clearly proves that trilobites, brachiopods, and gasteropods must have swarmed in these shallow seas. But here, as elsewhere, the close of this period is marked by a great change in the life-history of the system. All the species of graptolites found in the Caradoc Rocks of Girvan disappear, and only

the genera *Diplograptus, Climacograptus,* and *Retiolites* pass up into the Llandovery formation. At this horizon also there is a striking change in the genera and species of the other life-groups, thus clearly indicating that, though no marked unconformability is traceable, there is nevertheless a distinct palaeontological break.

Upper Silurian

Llandovery and Tarannon

Central Belt

Rocks. — We have now reached an important stage in the history of the Silurian rocks of the Southern Uplands, for not only is there a marked change in the fauna when we cross the threshold of the Upper Silurian system, but there is also evidence that, while oceanic conditions of deposition prevailed over a large part of the Central Belt in Llandovery time, the coarse terrigenous materials were carried further south, till in Tarannon time they overspread the sea-floor of the whole central region.

In the Moffat region of the Central Belt the Llandovery Rocks are represented by the Birkhill Shales, divisible into two groups, a lower, composed of black flaggy shales, which near the top contains seams of clay with nodules and ribs of limestone, and an upper group of alternations of black and grey shales and mudstones, with abundant seams of white clay. Though they are lithologically connected with the underlying Hartfell and Glenkiln Shales, having been deposited under somewhat similar conditions, they are readily distinguishable in the field by the numerous seams of white clay and the peculiar character of the black shales. In one of the zones, that of *Monograptus gregarius,* in the typical Dobb's Linn section, there is a band of black grit intercalated in the finer sediments. Such are the lithological divisions of the Birkhill Shales in many of the anticlines along the strike of the Dobb's Linn fold in the central Moffat region.

Professor Lapworth showed that as the observer passes northwestwards from the central Moffat region, the Birkhill Shales are modified and replaced by other sediments — that, for example, in the Hartfell section to the north-west of the strike of the Dobb's Linn anticline, the upper division of the Birkhill Shales has disappeared. In like manner the highest sub-zone of the lower division *(Monograptus gregarius)* is no longer met with in the arch at Cow Linn in the Fruid Water, and when the bands are traced north to the junction of that stream with the River Tweed, the lower division is represented by blue-black seams in other sediments, from which one or two zonal forms have been obtained. Similar phenomena are observable along the northern portion of the Central Belt from the Lammermuir Hills in the far north-east to the Portpatrick coast line (see pp. 198–9). Indeed, there seems no escape from the conclusion that, along the northern margin of the Central Belt, the Llandovery Rocks are partly represented by coarse sediments (grits, greywackes, and shales) which contain thin carbonaceous seams, yielding dwarfed representatives of Lower Birkhill graptolites.

The Tarannon Rocks of the Central Belt comprise, in descending order:

3. Grey, green, and red shales, brown flagstones, and yellow-crusted greywackes with occasional grits (Hawick Rocks).

2. Massive grits and greywackes with local bands of conglomerate, with grey, green, and red shales (Queensberry Grits).

1. Brown flagstones, green and grey shales and mudstones (Abbotsford Flags).

The dominant type of the Tarannon Rocks of the Central Belt consists of massive grits and greywackes (Zone 2), which are specially characteristic of the central and northern portions, while the members of the highest sub-division (Zone 3) are confined mainly to the southern margin of the area. The Abbotsford flags occur in the region between Melrose and Moffat.

Certain local bands of conglomerate occur in the Llandovery and Tarannon area (Pinstane Hill, Craigenputtock Hill), containing pebbles of volcanic and plutonic rocks (Arenig), radiolarian chert, grey shale, black shale with graptolites, greywacke, grit, quartzite, and mica-schist from the Highlands, &c. The largest pebbles, consisting of greywacke and granitoid igneous rocks, measure from eight to ten inches in diameter.

Fossils. — The distinctive fossils of the Birkhill Shales are graptolites which, both in genera and species, differ in a marked degree from the faunas of the underlying Hartfell and Glenkiln divisions. Though there is here a perfect passage from the Hartfell (Caradoc) Shales to the overlying Birkhill division (Lower Llandovery), a striking palaeontological break nevertheless exists. The special features of this change in the fades of fossils are thus summarised by Professor Lapworth:

"Of the numerous genera of compound Graptoloidea which give such a varied character to the fauna of the Glenkiln Shales, and many of which have accompanied us in our upward progress into the typical beds of the Hartfell division, not one passes up into the Birkhill Shales. Here, on the other hand, the extraordinary prevalence of Monograptida) upon every zone is in striking contrast to what occurs in the inferior division, where not the slightest trace of any form of this family has ever been detected.

"The two genera *Monograptus* and *Rastrites* swarm abundantly in all except the lowest zone of the Birkhill Shales, and with the more sparingly distributed genera *Diplograptus, Climacograptus,* and *Retiolites* (together with a few scattered forms of Crustacea and Spongid) constitute the whole of the fossils of the group. Consequently, while there is no falling-off in respect of individuals or even species (many of the beds bearing favourable comparison with the most prolific horizons of the Harden Shales), yet, when contrasted with that afforded by the preceding divisions, the fauna of the Birkhill Shales is strangely monotonous throughout. No better proof could perhaps be adduced of our having clearly overstepped the limits of the great Llandeilo-Bala formation, where the Graptolithina attain their maximum, and that we are now almost on the threshold of those Upper Silurian Rocks where these strange old creatures disappear from our sight for ever".<ref>Quart. Jour. Geol. Soc. Vol. XXXIV., p. 317.</ref> (Plate 27)

The zonal forms of the various divisions of the Birkhill Shales established by Professor Lapworth are given below in descending order:

Upper Division.	3. *Rastrites maximus* zone.
	2. *Monograptus spinigerus* zone.
	1. *Cephalograptus cometa* zone.
Lower Division.	3. *Monograptus gregarius* zone.
	2. *Diplograptus vesiculosus* zone.
	1. *Diplograptus acuminatus* zone.

The graptolites are associated with certain phyllocarid crustaceans which are represented by four genera, *Aptychopsis, Discinocaris, Peltocaris, Ceratiocaris.*

The study of the distribution of the graptolites in the Lower Llandovery Rocks of the Central Belt reveals certain peculiar features. It is evident that their distribution and to some extent their development were affected by the transport of coarse sediment from the northern land area, for not only do the higher sub-divisions of the Birkhill Shales with their characteristic forms one by one disappear, but even in those cases where the Moffat type is represented by thin carbonaceous seams in coarse sediments, there are only a few dwarfed representatives of the abundant Birkhill fauna. The forms seem to indicate arrested stages of development, as if the conditions had been unfavourable for their progress. The disappearance of most of the Birkhill forms and the stunted character of the survivors along the northern margin of the Central Belt make it difficult to fix with precision the northern boundary-line of the Llandovery Rocks of this region. These dwarfed forms include representatives of *Monograptus tenuis, Dimorphograptus, Diplograptus,* and a *Climacograptus* like *C. normalis.* (See pp. 200–1.)

The coarse sediments in the Tarannon Rocks of the Central Belt are almost wholly destitute of fossils. The forms which do occur are mainly graptolites, which are restricted to dark shales or thin carbonaceous seams. In these rocks we find some survivors of the Birkhill fauna, some, which are peculiar to the Tarannon series, and some which pass up into the Wenlock strata. The following may be quoted as examples of the first group, viz.: *Rastrites maximus, Monograptus Sedgwicki, M. leptotheca, M. spiralis, Petalograptus folium,* and *Climacograptus normalis.* But, in addition to these, we find species which now appear in the sequence for the first time, viz.: *Monograptus exiguus, M. crispus, M. vomerinus, M. galaensis, Retiolites geinitzianus,* and *Cyrtograptus.* Some of these forms, as will be shown in the sequel, pass upwards

into the Wenlock formation; others, such as *Monograptus turriculatus, M. exiguus, M. crispus,* and *M. pandus,* are zonal forms, which, so far as our present knowledge goes, appear to be confined mainly if not exclusively to the Tarannon series.

In the Tarannon sub-division of the Stockdale Shales, in the Lake district, Messrs. Marr and Nicolson have established the following graptolite zones: (1) *Monograptus turriculatus,* overlain by (2) *M. crispus.* In the Central Belt of the Southern Uplands *M. turriculatus is* found in considerable abundance at certain localities in the shales immediately overlying the *Rastrites maximus* band, hut it also occurs in higher beds intercalated in grits associated with M. *crispus, M. exiguus,* and *Retiolites geinitzianus.*

An interesting palaeontological feature of these Tarannon Rocks is the abundance of tracks in red and green shales on certain horizons, as, for instance, *Crossopodia, Crossochorda, Dexolites, Myrianites, Nereites, Nemertites.* At present it is doubtful whether all these tracks are due to the burrowing of annelides; in some instances they may have been produced by univalve molluscs or even by crustaceans.

Some of the coarser grits and fine conglomerates in the eastern portion of the Central Belt yield fragments of corals, crinoids, and calcareous brachiopods.

Conditions of Deposition. — The lithological characters of the Birkhill Shales and their organic remains alike point to the continuance of oceanic conditions at the verge of sedimentation, in the central area, in Llandovery time. But stage by stage the coarse sediments from the northern land-surface invaded the floor of the Silurian sea, till eventually in Tarannon time they overspread the whole region. At intervals, however, during pauses in the transport of the coarse materials, fine dark mud was deposited, in which were entombed various species of graptolites.

The local conglomerates with pebbles of Highland schists, Arenig volcanic and plutonic rocks, greywackes, and shales point to local elevation and erosion of crystalline schists and Lower Silurian rocks outside the area of sedimentation.

Northern Belt

In this portion of the Southern Uplands no fossiliferous strata of Llandovery or Tarannon age have as yet been detected. It is not improbable, however, that there may be lenticular patches of these rocks in such a highly convoluted region, but, if so, they consist in all likelihood of barren sediments.

Girvan area

The Llandovery and Tarannon Rocks of the Girvan area are represented by a thick mass of sediments, containing many highly fossiliferous zones, among which appear several graptolite-bearing bands yielding many of the zonal forms characteristic of these groups.

Llandovery

Rocks. — In the Girvan area there is a striking departure from the Llandovery phase of sedimentation represented by the Birkhill Shales in the Central Belt. The prominent zones of conglomerate with pebbles of Arenig igneous rocks, radiolarian chert, quartzite, mica-schist, quartz, and other ingredients; the shelly sandstones, the fossiliferous limestones, and calcareous grits and graptolite shales, plainly indicate the vast change in the character of sedimentation. The classification of the Girvan Llandovery Rocks established by Professor Lapworth may thus be briefly summarised in descending order:

Camregan Group	Grits, shales, limestone, and graptolite shales
Saugh Hill Group	Conglomerates, grits, sandstones, shales, limestones, and graptolite shales of Woodland and Saugh Hill
Mulloch Hill Group	Conglomerates, shelly sandstones, and graptolite shales

It is a remarkable fact that the members of the lowest or Mulloch Hill group, like the underlying Drummuck group, tire confined to the Craighead inlier on the north side of the Girvan valley. Professor Lapworth has recorded a slight unconform-ability on the shore south of Girvan, where the Craigskelly conglomerate — the lowest sub-division of the Woodland beds (Saugh Hill group) — is believed to rest on the eroded edges of the Barren Flagstones (Caradoc). Whether or not this slight discordance may sufficiently account for the absence of these groups to the south of the Girvan valley, it is at least clear, from the recurrence of conglomerates with pebbles of Silurian rocks and Highland quartzite, that local elevation and erosion of the Silurian rocks must have taken place at no great distance to the north of the area of sedimentation.

Fossils. — The rich and varied fauna of the Llandovery Rocks of the Girvan area likewise affords strong proof of the great change in the sedimentation from that which prevails in the Central Belt. Though corals, trilobites, brachiopods, lamellibranchs, gasteropods, and cephalopods are largely represented, the group is also characterised by many graptolites.

The zonal Llandovery graptolites which have been recognised by Professor Lapworth in the Girvan area are given here in descending order:

4. *Rastrites maximus*

3. *Monograptus spinigerus*

2. *Monograptus gregarius*

1. *Diplograptus acuminatus*

The genus *Ptilograptus,* which occurs at the top of the Mulloch Hill sandstones, has not as yet been recorded from any other part of the Southern Uplands. The following genera of graptolites are represented in these Llandovery Rocks: *Climacograptus,* 1 species; *Diplograptus* 2; *Dimorphograptus*, 1; *Petalograptus*, 1; *Monograptus, 7; Rastrites*, 1; *Retiolites*, 1; *Dictyonema,* 1.

Of the other great life-groups, the amorphozoa are represented by two genera, *Nidulites* and *Ischadites.* The corals number nine genera: *Aulacophyllum,* 1 species; *Favosites*, 4; *Heliolites*, 3; *Halysites*, 1; *Lindströmia*, 2; *Palaeocyclus*, 1; *Petraia*, 2; *Pinnacopora*, 1; *Streptelasma,* 1. The echinoderms are represented by *Glyptocrinus;* the annelides by *Tentaculites;* and the polyzoa by *Ptilodictya,* 2 species; *Fenestella*, 1; *Retepora* 1.

Amongst the arthropods, the cirripedes include *Turrilepas* and the ostracods *Cythere;* while the trilobites number ten genera, viz.: *Calymene*, 1 species; *Cheirurus*, 1; *Encrinurus*, 1;*Illaenus,*

3; *Lichas*, 2; *Phacops*, 3; *Acidaspis*, 1; *Proetus,* 1; *Bronteus*, 1; *Staurocephalus,* 1.

The brachiopods, which are extremely abundant in some of the zones, comprise fourteen genera, viz.: *Atrypa,* 3 species; *Crania, 1 Dinobulus*, 1; *Leptocaelia*, 1; *Leptaena*, 3; *Lingula*, 1; *Meristella*, 1; *Orbiculoidea*, 1; *Orthis,* 9; *Pentamerus*, 2; *Pholidops, Rhynchonella*, 4; *Stricklandinia*, 1; *Strophomena,* 7. The lamellibranchs number eight genera: *Ambonychia,:* 1 species; *Avicula*, 1; *Cardiola*, 1; *Ctenodonta*, 1; *Orthonota*, 3; *Palaearca*, 2; *Pterinea,* 2; *Pleurorhynchus,* 1. The gasteropods are represented by eleven genera: *Bellerophon,* 7 species; *Cyrtolites, Euomphalus*, 2; *Holopea*, 1; *Holopella*, 2; *Macrocheilus*, 1; *Murchisonia*, 2; *Oriostoma*, 1; *Tochonema,*, 1; *Trochus*, 1; *Platyceras,* 1. The cephalopods number six genera: *Cyrtoceras,* 1 species; *Gomiphoceras, 1;Oncoceras*, 1; *Orthoceras*, 4; *Phragmoceras*, 1; *Trochoceras,* 1. Lastly, the pteropods so called number the following genera: *Conularia,* 2 species; *Hyolithes*, 1; *Pterotheca,* 1.

One of the distinctive palaeontological features of these Llandovery Rocks of Girvan is the presence of two well-marked zones abundantly charged with Llandovery species of *Pentamerus.* The upper zone (Camregan Limestone and Grit), characterised by *Pentamerus oblongus, P. undatus, P. rotundus,* immediately underlies the *Rastrites maximus* band; the lower zone (Newlands Grits and Sandstones), containing *P. oblongus*, *P. undatus,* is interposed between the

Monograptus gregarius shales (Glenshalloch) and the *Diplograptus acuminatus* mudstones (Glenwells). (See pp. 532–3).

Tarannon

Rocks. — The Tarannon Rocks of the Girvan area include the greater portion of the Dailly series established by Professor Lapworth, and may be briefly summarised as follows:

Tarannon	Drumyork Group	Unfossiliferous flagstones and shales
	Bargany Group	Thick-bedded flagstones and shales with zones of shales
	Penkill Group	Grits, flagstones, and shales with graptolitic mudstones and shales

It is worthy of note that the Tarannon Rocks of the Girvan area do not consist of such coarse sediments as those of the Central Belt; indeed the massive grits (Queensberry) of the latter region are sparingly represented at Girvan.

Fossils. — On several horizons graptolites of a distinct Tarannon facies appear; the zonal form of the Lower Penkill beds being *Monograptus exiguus,* and of the upper mudstones (Penkill group) *Cyrtograptus Grayae.* Altogether five genera of graptolites occur in these rocks, viz.: *Monograptus, Diplograptus, Rastrites, Cyrtograptus, Retiolites.*

An analysis of the list of fossils obtained from the Tarannon Rocks of Girvan shows a remarkable diminution in the number of genera and species of the other life-groups compared with their development -in the underlying Llandovery and Caradoc strata. For example, the corals are represented by two genera: *Heliolites, Palaeocyclus;* the phyllopod crustaceans by *Discinocaris;* while only two genera of trilobites *(Encrinurus, Cheirurus)* have been recorded from this group.

There is a similar striking decrease in the brachiopods, which number five genera, viz.: *Atrypa, Discina, Orthis, Pentamerus, Strophomena.* The lamellibranchs include two genera, *Cardiola* and *Lunulicardium;* the gasteropods one genus, *Oriostoma;* and the cephalopods one genus, *Orthoceras.*

In the Girvan area of the Tarannon Rocks those peculiar tracks *(Crossopodia, Myrianites, Eione)* which are such a characteristic feature of similar strata in the Central Belt occur in red and green shales in the Penkill group. Finally, traces of plant remains have been obtained from this series of strata, but too imperfectly preserved for determination.

Conditions of Deposition during Llandovery and Tarannon time. — The sequence of Llandovery and Tarannon Rocks in the Girvan area, comprising conglomerates, shelly sandstones, limestones, graptolitic shales, &c., and their associated fossils, alike point to deposition either close to the shore, or in shallow water, or in comparatively clear water with the deposit of fine sediment. Though the land-surface lay to the north-west of the Silurian sea, there must have been local elevation and erosion both within and to the north of the area of sedimentation. While the downward movement seems to have been in the ascendant, it is probable that the subsidence took place at intervals, the sea-floor being strewn with the prolific calcareous fauna, which gradually diminished in genera and species towards the close of the period.

Wenlock and Ludlow

Southern Belt

Rocks. — The strata of Wenlock and Ludlow age extending along the southern margin of the Silurian tableland may be briefly described as follows, in descending order:

3. Green mudstones, with nodular calcareous bands.

2. Mudstones, shales, greywackes, grits, and conglomeratic bands with graptolite shales.

1. Flaggy grits and grey shale bands.

The members of the middle group form the greater portion of the Southern Belt of Wenlock and Ludlow Rocks, there being little variety in the lithological characters of the strata. The graptolite-bearing bands differ petrologically from the normal black shales of the Moffat series; they sometimes occur in zones fifty feet in breadth, and sometimes in thin leaflike seams intercalated in the barren pale-coloured shales and flagstones.

Fossils. — The distinctive palaeontological feature of the Wenlock and Ludlow Rocks of the Southern Belt is the constant recurrence due to folding of dark brown flaggy shales charged with graptolites, orthoceratites, phyllopod crustaceans, and sometimes eurypterids. Occasionally the pebbly grits contain fragments of brachiopods, corals, crinoids, and other organic remains.

The zonal graptolite of the Wenlock Rocks is *Cyrtograptus Murchisoni* — a species which here makes its appearance for the first time, and is characteristic of the lowest band of graptolite shale all across the belt from Burrow Head, in Wigtownshire, to Stobs Castle, near Hawick. The following genera of graptolites are found in these Wenlock beds: *Cyrtograptus* 2 species, *Dictyonema* 1, *Monograptus* 8, *Retiolites* 1 — evidence which clearly points to the gradual extinction of this important group of organisms.

The sponges are represented by *Protospongia;* the corals by four genera, *Heliolites* 1 species, *Petraia* 2, *Stenopora, Syringopora;* the crinoids by *Glyptocrinus;* the annelides by *Cornulites;* the phyllopod crustaceans by three genera, *Aptychopsis* 3 species, *Ceratiocaris* 5, *Discinocaris 1;* the trilobites by two genera, *Phaeops* and *Trinueleus;* and the eurypterids by two genera, *Eurypterus* and *Slimonia.* The brachiopods number seven genera, *Athyris* 1,species, *Atrypa* 1, *Leptaena* 2, *Lingula* 1, *Orthis* 6, *Rhynchonella* 2, *Strophomena* 1; the lamellibranchs seven genera, *Cardiola* 1 species, *Ctenodonta* 1, *Cucullella* 1, *Goniophora* 1. *Orthonota* 1, *Mytilus* 1, *Pterinea* 1; the gasteropods two genera *(Bellerophon, Loxonema);* the pteropods two genera *(Hyolithes, Conularia);* while the cephalopods are represented by seven species of *Orthoceras.*

Conditions of Deposition. — The rapid alternation of graptolite shales with shales, flags,greywackes, and pebbly grits probably indicates minor oscillations of the sea-floor in the southern region during Wenlock and Ludlow time. The coarser sediments point to the transport seawards from the northern land-area of terrigenous materials during pauses in the downwath movement, while the graptolitic shale represents the zone where only the finest sediment accumulated so slowly as to permit of its being coloured by the organic matter of the sea-floor and by the pelagic organisms which fell from the surface of the ocean.

Blair and Stratton area

Rocks. — The strata which in the neighbourhood of Blair and Straiton, in Ayrshire, are regarded as of Wenlock age consist of, 1, flagstones and shales with graptolite-bearing seams (Blair and Knockgardner) overlain by (2) conglomerate, grits, and shales. They are the highest visible beds in the Silurian succession in that region.

Fossils. — Considerable difficulty has been felt in fixing the precise age of these beds in view of the palaeontological evidence, but on the whole the balance of evidence seems to be in favour of grouping them with the Wenlock rather than with the Tarannon Rocks. The fossils are confined to certain thin carbonaceous seams and some calcareous grits.

The graptolites are represented by three genera, viz.: *Monograptus (M. riccartonensis, M. Flemingi, M. priodon, M. vomerinus, M. galaensis), Retiolites geinitzianus,* and *Cyrtograptus.* Two of these species, *M. riccartonensis* and *M. Flemingi,* are specially characteristic of the Wenlock Rocks of the Southern Belt. The entomostracans include three genera, *Beyrichia, Entomis,* and *Primitia;* the trilobites five genera *(Aciclaspis, Calymene, Encrinurus, Phacops, Proetus),* and there is also a representative of *Eurypterus.* The brachiopods number seven genera *(Atrypa, Leptaena, Lingula, Orthis, Retzia, Siphonotreta, Spirifera).* Several of the species *(Atrypa reticularis, Orthis rustica, Retzia Barrandei, Spirifera sulcata)* are characteristic Wenlock forms. There are six genera of lamellibranchs *(Cardiola, Ctenodonta, Grammysia, Modiolopsis, Orthonota, Pterinea):* one of the species *(Cardiola fibrosa)* being a Wenlock form. The cephalopods are represented by three species of *Orthoceras (O. MacLareni, O. subundulatum, O. angulatum),* the first of these being a characteristic Ludlow and Wenlock form in the Pentland Hills.

Lanarkshire inliers

Rocks. — Several miles to the north of the Silurian tableland, in Lanarkshire, strata of Wenlock and Ludlow age are exposed along anticlinal folds among Lower Old Red Sandstone and Carboniferous rocks. These may be briefly summarised in descending order as follows:

Ludlow	Upper Zones	Sandy greywackes and shales passing downwards into shales and mudstones (*Trochus* beds) and flaggy shales *(Pterygotus* beds)
	Lower Zones	Flagstones, greywackes, and brown shales *(Ceratiocaris* beds) passing downwards into olive shales and greywackes.
Wenlock		Greywackes with partings of shale. (Base not seen.)

Compared with the prevalent petrological types of Silurian strata in the Southern Uplands, there is here a vast preponderance of sandy shales and mudstones.

Fossils. — Viewing the various "inliers" of Upper Silurian strata in Lanarkshire as one province, we find that several of the life-groups are poorly represented compared with their development in the Pentland Hills.

Only one or two fragments of graptolites *(Monograptus)* have been found in the Wenlock and Ludlow Rocks of Lanarkshire, and from one locality, near Carmichael Manse, south of Lanark. Only two genera of corals have been obtained *(Favosites asper, Lindströmia* sp.). Annelides are represented by two genera *(Spirorbis, Cornulites),* ostracods by *Beyrichia,* and trilobites by five genera *(Calymene* 1 *species, Entrinurus* 1, *Illaenus* 1, *Phacops* 1, *Proetus* 1).

The distinctive palaeontological feature of these rocks is the abundance and excellent preservation of the phyllocarid crustaceans and eur3rpterids, which are more or less restricted to certain definite horizons. The former are represented by seven species of *Ceratiocaris,* and the latter by the following five genera: *Eurypterus* 3 species, *Pterygotus* 2 species and 2 varieties, *Slimonia* 1, *Stylonurus* 1, *Neolimulus* 1.

No less interesting are the remains of a scorpion *(Pakeophonus)* and of a myriapod *(Archidesmus loganensis)* which have been obtained from these Upper Ludlow Rocks, proving the existence of air-breathers during this period in Scotland. From the description of *Pakeophonus* by Mr. B. N. Peach it appears that this organism differed in no essential features from its living representatives, save that the walking limbs terminate each in a claw-like spike. To the narrow end of the trunk is articulated a long tail of five joints and a poison gland with a sting after the manner of recent scorpions.

The brachiopods number four genera *(Athyris, Orthis, Rhynchonella, Strophomena);* the lamellibranchs three genera *(Ctenadonta, Modiolopis, Orthonota)*; the gasteropods are represented by *Platyscisma (Trochus) helicites;* and the cephalopods by several species of *Orthoceras.* In the upper zones certain bands of sandy mudstone are crowded with specimens of *Platyschisma (Trochus) ?helicites* and *Modiolopsis complanatus.*

The recent discovery of fishes in the Ludlow rocks of Lanarkshire is of special importance. They have yielded two species of *Thelodus,* together with a fragment of another form too imperfect for determination.

Pentland Hills

Rocks. — The various inliers of Upper Silurian strata in the Pentland Hills, which are there completely surrounded by subdivisions of the Old Red Sandstone, are of great interest from the rich fauna furnished by the Wenlock and Ludlow Rocks. These strata may be briefly tabulated as follows:

Ludlow and Wenlock

5. Green sandy and red shales underlain by brown sandy concretionary bands with *Platrchisma (Trochus) simulans.*

4. Concretionary brown sandstone with *Orthoceras MacLareni.*

3. Green and grey shales, mudstones, and sandy bands. Bands D and E of Henderson and Brown.

2. Massive sandstones and fossiliferous pebbly grits.

1. Thick group of grey, green, red, and purple shales, with occasional greywackes and grits containing the following subordinate zones in the middle of the series:

c. Buff-coloured mudstones (starfish band).

b. Flaggy micaceous greywackes (eurypterid band).

a. Thin limestone with encrinites and corals.

(Base of series not seen.)

Fossils. — The distinctive palaeontological feature of the Upper Silurian rocks of the Pentland Hills is the abundance of brachiopoda and of the various groups of mollusca. Indeed, since the original observations of the Geological Survey the researches of various local investigators, including Messrs. Henderson, Brown, Haswell, and others, have proved that brachiopods, lamellibranchs, and gasteropods must have swarmed in that portion of the Silurian sea, many forms being characteristic of Wenlock and others of Ludlow time.

Of considerable importance also is the occurrence of certain species of graptolites which, though few in number, are of zonal value in defining the Wenlock age of the strata at the North Esk reservoir, in the Gutterford Burn, and at Habbie's Howe. The following genera and species have been obtained from the various exposures of Wenlock Rocks in the Pentland Hills: *Monograptus colones, M. Flemingi, M. priodon, M. vomerinus, Retiolites geinitzianus, Dictyonema assimile, D. regulare, D. retiforme, D. (Chondrites) verisimile, Cyrtograptus Murchisoni (?).*

The eurypterid band in the Wenlock series has yielded to the researches of Mr. Malcolm Laurie for new species of *Eurypterus (E. conicus, E. cyclophthalmus. E. scotius, E. minor);* three new species of *Stylonurus (S. macrophthalmus, 8. ornatus, S. elegans);* and one new genus including three species, *Drepanopterus pentlanlicus, D. bembicoides, D. lobatus;* together with a new species of *Slimonia.* In addition to these forms, *Slimonia acuminate* has been recorded from the Upper Ludlow Rocks of the North Esk section.

Of the other life-groups, sponges are represented by three genera *(Amphispongia* 1 species, *Plectoderma, Protospangia);* corals by eight genera *(Alveolites* 2 species, *Favosites* 3, *Heliolites* 2, *Lindströmia* 1, *Monticulipora* 2, *Petraia* 4, *Stenapora, Streptelasma;* the echinoderms by five genera *(Protester, Perieschoechinus, Palaeaster, Palasterina.* The polyzoa number four genera, *Ceriopora* 2 species, *Diastopora* 2, *Glauconome* 2, *Ptilodictya;* the annelids two genera, *Cornulites* and *Serpulites;* the cirripedes two genera, *Antifopsis* 1 species, *Turrilepas* 3 species; the phyllocarid crustaceans are represented by *Ceratiocoris,* and the trilobites by four genera, *Acidaspis* 1 species, *Calymene* 2, *Encrinurus* 2, *Phacops* 2.

Of the brachiopods there are eighteen genera: *Athyris* 1 species, *Atrypa* 2, *Chonetes* 2, *Crania* 1, *Cyrtia* 1, *Discina* 2, *Leptaena* 3, *Lingula* 4, *Meristella* 1, *Nucleospira* 2, *Orbiculoidea.* 2, *Orthis* 9, *Pholidops* 1, *Rhynchonella* 4, *Skenedium* 1, *Spirifera* 1, *Strophomena* 9, *Whitfieldia* 1. The lamellibranchs are represented by twelve genera: *Ambonychia 1* species, *Anodontopsis* 4, *Cardiola* 2, *Ctenodonta* 5, *Cucullella* 2, *Goniophora* 1, *Lunulicardium* 1, *Mytilus* 1, *Modiolopsis* 3, *Orthonola* 11, *Pterinea* 5, *Tellinomya* 1. The gasteropods number twelve *genera: Cyrtolites* 1 species, *Bellerophon* 4, *Cyclonema* 1, *Ecculiomphalus* 1, *Euamphalus* 5, *Holopea* 1, *Holopella* 3, *Loxonema* 1, *Platyceras* 2, *Platyschisma* 3, *Pleurotomaria* 2, *Tremanotus* 1. The pteropods (?) are represented by three genera, *Conularia, Hyolithes, Theca;* and the cephalopods by *Orthoceras* 9 species, *Lituites* 1, *Phragmoceras* 2.

Conditions of Deposition.---The strata of Wenlock and Ludlow age at Straiton, in Ayrshire, in Lanarkshire, and in the Pentland Hills imply a phase of sedimentation differing in some respects from that which obtains in similar rocks along

the Southern Belt of the tableland. In the former case, while flaggy shales and sandy mudstones predominate, the marine fauna is richer and more varied; some of the bands yielding genera and species of different life-groups rivalling in number those of the prolific zones of Llandeilo, Caradoc, and Llandovery age in the Girvan area.

Downtonian

Inliers in Lanarkshire and Pentland Hills

Rocks. — The series of strata grouped under the term Downtownian has hitherto been regarded as of Lower Old Red Sandstone age, owing to the prevalence of red and yellow sandstones and shales which are the prominent feature of that formation. The recent discovery by the Geological Survey, in shales and mudatones intercalated in these sandstones, of a marine fauna which in some respects is identical with that of the underlying Ludlow Rocks has led to a revision of the classification hitherto adopted. These passage beds are now viewed as forming the highest sub-division of the Upper Silurian rocks (see page 569). They may be briefly tabulated in descending order as follows:

Lower Old Red Sandstone, the basal bed being a coarse conglomerate or conglomeratic sandstone, with pebbles composed mainly of greywacke derived from the Southern Uplands.

Unconformability in the Pentland Hills and in Ayrshire, apparent conformability in Lanarkshire.

Downtonian	4. Chocolate-coloured sandstones. 3. Conglomerate with quartzite pebbles derived from the Highlands. 2. Green and red mudstones with bands of greywacke and brown flaggy carbonaceous shales with fishes and eurypterids. 1. Red and yellow sandstones and mudstones, underlain in the Hagshaw Hills by a fine conglomerate of local occurrence, resting conformably on Upper Ludlow Rocks.

Fossils. — The organic remains, which are restricted to Zone 2 of the foregoing series of strata, consist of plants, ostracods, phyllocarid crustaceans, eurypterids, and fishes.

Among the fragments of plants obtained from this horizon, Mr. Kidston has identified *Pachytheca* and one specimen as belonging to the genus *Parka,* though of a different species from *P. decipiens.* The ostracods are represented by *Beyrichia,* a form which is common in the Upper Silurian rocks of the Southern Uplands; the phyllocarid crustaceans by *Ceratiocaris.* Most of the genera of eurypterids found in the Wenlock and Ludlow Rocks in Lanarkshire and the Pentland Hills, viz.: *Eurypterus, Pterygotus, Slimonia, Stylonurus,* have been obtained from the Downtonian fish-band (Zone 2 of above Table).

The most striking palaeontological feature, however, is the remarkable assemblage of fishes procured from this horizon which are wonderfully complete when carefully extracted from the carbonaceous shales. Dr. Traquair has identified in the collection of the Geological Survey five genera of fishes, four of which are new, and seven new species. One genus *(Thelodus)* is common to the Upper Ludlow Rocks of Lanarkshire and Wales and to the Lower Old Red Sandstone of Forfarshire and Oban.

Conditions of Deposition. — The Downtonian strata indicate a marked change in the phases of sedimentation from those which obtained in Ludlow and Wenlock time in the South of Scotland. While it is true that the green mudstones, greywackes, and brown carbonaceous shales yielding fossils resemble lithologically Upper Silurian rocks, still the dominant feature of the series as a whole is red and yellow false-bedded sandstones. It seems just to infer that the Downtonian fish-hand and the associated mudstones and greywackes are marine deposits, for some of the eurypterids found in the latter strata are the associates of graptolites in the Wenlock Rocks of the Pentland Hills, and of brachiopods *(Lingula minima)* in the Ludlow Rocks of Lanarkshire. Moreover, the occurrence of the Polyzoon, *Glauconome,* together with *Spirorbis* and sponges, likewise points to the marine origin of some of the Downtonian strata. The red and yellow

false-bedded sandstones, on the other hand, evidently herald those conditions which prevailed during Old Red Sandstone time, when the open sea gave place to brackish-water or inland lakes.

A further noteworthy feature is the abundance of pebbles of quartzite derived from the Highlands, in the conglomerate overlying the Downtonian fish-band — a fact which suggests that the Downtonian sediment may still have been derived chiefly from the Northern land area. The greywacke conglomerate at the base of the Lower Old Red Sandstone which extends from the Pentland Hills into Ayrshire points to the final elevation and denudation of the Silurian tableland; for in the Pentland Hills this conglomerate rests unconformably on the folded and eroded edges of the Wenlock, Ludlow, and Downtonian strata, and in Ayrshire on the Arenig lavas and sediments.

II Tectonic arrangement of the strata

I'Ve have now to describe briefly the present tectonic arrangement of the Silurian rocks as produced by the elevation of the tableland and modified by prolonged denudation.

Period of Elevation. — Towards the close of Downtonian time, and perhaps partly during earlier stages of that period, the Silurian strata were subjected to enormous lateral compression, whereby they were thrown into a series of folds, the axes of which run in a north-east and south-west direction, that is at right angles to the direction of pressure and parallel to the major axis of the tableland. By means of various denuding agencies this complex mass of folded strata was greatly worn down. Reference has been made in this chapter to the fact that local elevation and erosion of Silurian strata had taken place in Llandeilo, Caradoc, and Llandovery time, but this local ridging was insignificant compared with the elevation and erosion of the broad tableland of the Southern Uplands. Though the latter has been profoundly modified by denudation during subsequent geological periods, it is clear that this plane of erosion must have been in process of formation before the deposition of those portions of the Lower Old Red Sandstone which rest on the upturned and abraded edges of Silurian strata.

Isolation of Silurian Sub-formations by Denudation. — One striking result of the elevation and erosion of the tableland, aided by subsequent powerful faults, has been to separate various divisions of the system which were formerly continuous. For example, the Wenlock and Ludlow Rocks are restricted to the Southern Belt and to the north-west margin at Straiton, in Ayrshire; while to the north of the great boundary fault which truncates the tableland they appear as inliers in Lanarkshire and in the Pentland Hills. Indeed, from the latter evidence it seems just to infer that Wenlock and Ludlow Rocks extend continuously from Ayrshire to the Lothians under younger Palaeozoic strata. In like manner, the Tarannon Rocks form the greater portion of the Central Belt, being completely disconnected from strata of the same age in the Girvan area, while in the Northern Belt the greatest development of Lower Silurian rocks is to be found. From these data it is evident that the tectonic centre of the tableland does not lie midway between its present north and south limits, nor does it coincide with the existing watershed of the region, but rather with the trend of the Northern Belt.

Types of curvature

The dominant tectonic feature of the Silurian tableland is the extraordinary plication of the strata, of which striking proofs can everywhere be obtained. Indeed, so complicated is the system of folding and so misleading is the apparent order of succession that all hope of solving the structural difficulties of the region might be abandoned, were it not for the key furnished by the vertical distribution of the graptolites. Various types of curvature are illustrated in the Southern Uplands, which may be grouped generally in the following order:

Simple folds	1. Normal or symmetrical folds, where the strata dip away from a central axis at nearly equal angles. Usually they form sharp arches, the beds being highly inclined. A modification of this type sometimes occurs where the strata on one limb dip at gentle angles while those on the other side are highly inclined. (Figure 1.) 2. Inverted folds, where the strata on both limbs of the flexure dip in one direction, form the dominant type in the Southern Uplands. Sometimes the axial planes of the inverted flexures are highly inclined; sometimes they form an angle of 15° to 30° with the horizon. Where this system of isoclinal folding prevails, and where the tops of the arches have been removed by denudation, the same zones may be repeated over miles of country, and thus give rise to deceptive estimates of their thickness. (Figure 2)a. 3. Inverted folds with reversed faults, where the strata have snapped and the beds of the upper limb have been thrust for a short distance and made to overlie younger rocks. (Figure 2) b.
Composite folds	4. Fan-shaped folds ("fan structure", Heim; anticlinorium, Dana; endocline, Lapworth; pseudo-synclines), where the primary fold is composed of a series of flea-urea, the axial planes of which are vertical in the centre and *dip towards* the central axis on the north-west and south-east sides, thus giving rise to a pseudo-synclinal arrangement of the strata. (Figure 3)a. 5. Inverted fan-shaped folds (synclinorium, Dana; exocline, Lapworth; pseudo-anticlines), where the primary fold is composed of a series of flexures, the axial planes of which are vertical in the centre and *dip away* from the *central* axis on the north-west and south-east sides, thus producing a pseudo-anticlinal arrangement of the strata. (Figure 3) h.

In the course of his researches into the complicated stratigraphy of the Southern Uplands, Professor Lapworth recognised all the foregoing types of curvature, and showed how they explained many of the structural anomalies of the region. His observations have been confirmed and extended by the subsequent investigations of the Geological Survey.

Structural features of the Silurian belts

Southern Belt. — Along the southern margin of the tableland the Wenlock and Ludlow Rocks are repeated by innumerable isoclinal folds, the axial planes of which generally dip in a southeast direction. Though of a limited thickness, their constant repetition can be proved by means of the recurrence of the graptolite-shales. (See (Index map))

Central Belt. — In the tract between Dumfries, Eskdalemuir, and Hawick, the strata (Hawick Rocks, Ardwell beds) form an inverted fan-shaped series of folds (Group 5 of foregoing Table). In the centre of the group of composite folds the axial planes are vertical, and on the north-west and south-east sides they dip away from the central axis, thus forming a pseudo-anticline.

The Moffat Shales appear at the surface along sharp anticlinal folds usually inverted, which may extend along the strike for several hundred yards or a few miles, the strata on either side being of Tarannon age. The total thickness of the black shale series (Upper Llandeilo, Caradoc, Llandovery) does not exceed 300 feet, while that of the Tarannon Rocks may be about 4000 feet. By constant reduplication these rock-groups cover a belt of country twenty-five miles wide. In the region between Moffat and Tweedsmuir and Beattock Summit — a distance of about ten miles — the prevalent dip of the axial

planes of the isoclinal folds is towards the north-west.

As might be expected, the Moffat Shales have been compressed into minute folds or wrinkles, which, in many instances, are accompanied by reversed faults. (Figure 4) Professor Lapworth proved the existence of the latter in the Selcoth Burn and other sections in the Moffat region. In the case of the inverted fold at Ettrickbridge-end, Selkirkshire, the southeastern limb has been truncated by a reversed fault (Figure 20), whereby the radiolarian cherts have been made to overlie the Tarannon flags and shales. But though reversed faults are not infrequent, there is here no evidence of great horizontal displacement as in the North-west Highlands. (See (Index map))

Northern Belt. — In the tract between Nithsdale and Eddlestou, in Peeblesshire, there is a remarkable development of Arenig volcanic rocks, radiolarian cherts, and Glenkiln–Hartfell shales which are constantly repeated by folding of the strata. Here the lavas appear in the cores of the anticlines, forming exposures, which measure sometimes only a few square yards in extent, and sometimes several hundred yards in length. Wherever a sufficiently low portion of the Silurian succession is laid bare by denudation the Arenig volcanic rocks invariably appear. A glance at the geological map of the Southern Uplands shows how, between Broughton and Leadburn, the great fault bounding the northern margin of the tableland truncates fold after fold of Lower Silurian strata with the Arenig lavas in the heart of the anticlines. Indeed, the radiolarian cherts and overlying black shales, which are sometimes so reduplicated as to form a continuous outcrop across the strike for about a mile, are here but a thin veneer concealing the underlying volcanic platform (see (Figure 59) and (Figure 60)). While this volcanic series is exposed on numerous anticlines in the Northern Belt, it must have a wide extension throughout the Southern Uplands, for it has been followed from Girvan to Glenluce, from a point near Dalmellington to Trowdale, near Castle-Douglas, and again far to the north-east in the Moorfoot Hills. In short, it has been traced for a distance of about 100 miles from south-west to north-east over a part of the tableland sometimes thirty miles wide. If we assume that the Arenig volcanic series is continuous within these limits, then the area which it covers must be at least about 1500 square miles. (See Map.)

Evidence has recently been obtained in the course of the Geological Survey of the Eastern Highlands which probably points to an even greater extension of the Arenig volcanic rocks. Igneous rocks and radiolarian cherts have been recognised along the Highland border, by Mr. George Barrow between Cortachy, in Forfarshire, and Stonehaven; by Mr. C. T. Clough and Mr. J. R. Dakyns between Callander and Loch Lomond. The results of their work are thus briefly summarised by the Director-General: "For the purpose of our present inquiry two chief features of interest are presented by these rocks. They include a group of sedimentary strata among which occur bands of jasper or chert containing radiolaria, and one of their most conspicuous members is a series of volcanic rocks, consisting chiefly of dolerites and basalts, some of which have been crushed and cleaved, but in which vesicular structures can still occasionally be recognised.

"The striking resemblance of both the aqueous and igneous members of this marginal strip of rocks along the Highland border to the Arenig cherts and their accompanying lavas of the South of Scotland, the remarkable association of the same kind of material in the same order of sequence, the occurrence of radiolaria in the siliceous bands in both regions, furnish strong presumptive evidence that a strip of Arenig Rocks has been wedged against the Highland schists…

"The distance between the last Arenig volcanic outcrop in the Southern Uplands and the band of similar lavas along the margin of the Highlands is about 50 miles. If the volcanic ejections were continuous across the intervening tract, the total area over which the lavas and tuffs of the Arenig volcanoes were distributed must be increased by at least 6000 square miles in Scotland".<ref>Ancient Volcanoes of Great Britain. Vol. 1., p. 201.</ref>

The radiolarian cherts which invariably accompany the Arenig volcanic rocks have a greater visible extension in. Scotland than that of the associated lavas, for they have been traced along the Highland border and across the Southern Uplands to Glenling, Wigtownshire, and south-eastwards to Ettrickbridge-end and Coldshiels Loch, near Melrose. The same zone has been recently recognised by the Geological Survey of Ireland among the Silurian rocks of that country, so that it must have extended far to the south-west of the present limits of the Scottish Silurian areas. For example, they occur at various localities in the eastern counties, where they are accompanied by black or dark shales, yielding Llandeilo or Arenig graptolites. Far to the west, at Tourmakeady, on Lough Mask, they have been detected with black shales of Lower Llandeilo or Arenig age;<ref>Annual Report of the Geological Survey. 1897. Pages 48–49.</ref> while at Pomeroy they

appear in association with volcanic rocks like the exposures along the eastern border of the Highlands of Scotland. They have been found still in great force in the Slieve Bernagh mountains, at the extreme south-western limit of the exposed Lower Silurian rocks of the British Isles.

In the central portion of the Northern Belt (Leadhills and Abington) there is a striking example of "fan structure", where in the centre of the primary fold the strata are folded on vertical axes while the axial planes dip inwards on the north-west and south-east sides, thus producing a pseudo-syncline. A glance at the horizontal sections of that region (see Sections 1, 2, 3 on (Index map)) will show how strata not exceeding from 200 to 300 feet in thickness have been so compressed as to form continuous outcrops more than a mile across. Along the south-east side of the fan, the Lowther shales (Upper Caradoc) plunge underneath the Arenig cherts and Glenkiln–Hartfell black shales, with an inverted dip. In like manner, on the north side, along the margin of the tableland, the general dip of the strata is to the south-east. These inversions can be traced along the northern border to the Girvan area, where, in Penwhapple Glen, the Tarannon Rocks dip south-east underneath the Llandovery strata, and the latter appear to underlie Caradoc beds.

Inliers. — In the midst of the younger Palaeozoic rocks interesting structural features occur in connection with the Silurian "inliers". For example, in the case of the Lesmahagow anticline in Lanarkshire, the Ludlow and Wenlock Rocks on the north limb of the fold dip away from the central axis at angles of 25°, while those on the south limb are more highly inclined and are abruptly truncated by a normal fault. This type of flexure is evidently the incipient stage of an inverted fold, for only a few miles to the south the Ludlow Rocks reappear in the Hagshaw Hills along an inverted arch which culminates in a reversed fault. (See (Figure 118) and (Figure 119))

Modification of outcrop by pitch of folds

Among the highly convoluted rocks of the Silurian tableland curious structural features arise from the modification of outcrop by pitch of folds. The pitch of any anticlinal fold may be defined as the angle of inclination which the long axis of that arch makes with the horizon. Many of the inverted folds are merely elongated domes, which at their north-east and south-west limits pass underneath overlying strata. In the Northern Belt it sometimes happens that along the same line of strike, owing to the high pitch of the folds, strata are exposed in the valleys which are geologically higher than those on the adjoining hills. For example, in the Abington area of the Northern Belt the radiolarian cherts frequently form lofty ground, while in the same line of strike the overlying Glenkiln–Hartfell Shales appear in the valleys.

Conversely, it happens that along the same line of strike strata may be exposed on the low ground which are geologically lower than those on the adjoining heights. For instance, in the fine section of the Moffat series in Morroch Bay, south of Portpatrick (Figure 98), the highly corrugated black shale series forms nearly the whole of the bay, while the adjoining lofty cliff is mainly composed of the overlying shales, flags, and greywackes.

Schistosity and cleavage

In consequence of the great lateral pressure to which the strata have been subjected, schistosity and cleavage have been superinduced on the rocks in certain areas. These structures are restricted to certain belts or zones where probably the mechanical strain producing interstitial movement has been most intense.

A prominent narrow belt of schistose rocks extends from New Galloway, north-east by Moniaive and the Dalveen Pass, to the watershed between Nether Howecleuch on the Eyan Water and Little Clyde. This belt lies at the southern edge of the great fan in the northern section of the tableland, where the axial planes are inclined to the north-west. Though microflaser structure has here been developed in the grits and greywackes, yet, from Mr. Teall's observations, it appears that "peripheral granulation, so common in the gneissose grits of the Southern Highlands, is entirely absent". It is worthy of note that the rocks showing extreme phases of contact alteration near the granite of New Galloway, described by Miss Gardiner, occur within this belt of schistosity.

Again, within the Northern Belt, near the head of Menock Water, south of Wanlockhead, there is a small area where the Arenig igneous rocks, the cherts, and black shales have all been cleaved and where no fossils can be obtained to prove the horizon of the strata. Cleavage has also been superinduced in the Silurian strata on Ettrick Pen, on the north side of

the inverted fan (pseudo-anticline) of the Hawick Rocks, and in the Hawick and Wenlock Rocks of Kirkcudbright and other localities along the southern margin of the tableland.

Intrusive igneous rocks earlier than the Upper Old Red Sandstone

After their plication, cleavage, and denudation, but before the deposition of the Upper Old Red Sandstone, the Silurian strata of the Southern Uplands were invaded by various eruptive rocks which now form prominent geological features in the tableland. The largest of these plutonic masses (1, Criffel and Dalbeattie; 2, Cairnsmore of Fleet; 3, Loch Dee) occur in Galloway, where they cover many square miles of ground, but minor bosses appear at intervals across the chain from the headlands of Berwickshire to the Portpatrick coast-line. As examples of these smaller protrusions, reference may be made to the bosses at Kirkmaiden, near the Mull of Galloway; at Burnhead, north-west of Dalry; at Cairnsmore of Carsphairn, Knipe Hill, south of New Cumnock; Spango Water, north of Sanquhar; Cockburn Law and Priestlaw in the Lammermuir Hills, and the Dirrington Laws in Berwickshire. In addition to these, there are numerous dykes radiating from the large plutonic masses and likewise appearing in groups and isolated veins throughout the length and breadth of the tableland.

From the researches of Mr. Teall, which will be more fully given in Chapter 26, it appears that the numerous granitic protrusions throughout the Uplands all belong to one petrographical province. The main portion of the Criffel mass is a hornblende-granitite, containing basic inclusions of diorite, both being traversed by aplite veins of orthoclase and quartz. This dominant type is associated with quartz-diorites of the tonalite type. Both the hornblende-granitites and quartz-diorites sometimes contain a nearly colourless augite, thus giving rise to quartz-augite-diorites. Mr. Teall further shows that the Loch Dee mass is, petrographically, intermediate between that of °rile' and that of Cairnsmore of Fleet, comprising quartz-mica-diorites, hornblende-biotite-granites, and biotite-granites or granitites, the most acid rock being a granitite with microcline. He has also identified a group of rocks termed hyperites, representing the most basic facies of the granitic magma in the Loch Dee area. On the other hand, the dominant rock of the Cairnsmore of Fleet mass is granitite with microcline, which forms only a subordinate part of the Loch Dee mass and has not yet been detected in the Criffel area.

While the granite occurs mainly in its usual massive form in the various protrusions, there is one region, on the eastern slopes of Criffel, where it has a marked foliated character. The evidence obtained in the field points to the conclusion that the foliation must have been superinduced on the massive granite after it had reached its present position and after the formation of the acid veins. For the hornblende-granitite, quartz-diorite, the basic inclusions, and the aplite, pegmatite, and quartz-veins have been foilated in one common direction. The general trend of the foliation in that region is north-east and south-west, in accordance with the general strike of the Silurian rocks, the dip of the foliation planes being in the same direction as that of the altered sediments. It is obvious, therefore, that these secondary structures have been developed in this portion of the granite mass of Criffel by dynamic action connected with earth-movements.

After the development of the foliation, the foliated granite was injected by a well-marked series of dykes of the same character and composition as some of those traversing the normal granite and the contact zone of Silurian sediments.

The numerous dykes radiating from the granite masses and occurring throughout the Silurian tableland comprise porphyrites, diorites of the camptonite type, mica-traps, and hyperites.

Contact metamorphism

Striking evidence is obtained of the contact alteration of the Silurian sediments by the granitic masses. The principal minerals of the altered strata, as given by Mr. Teall, are quartz, biotite, white mica, garnet, andalusite (including chiastolite), sillimanite, felspar, graphite, pyrite, rutile, tremolite, and malacolite. Owing to the variable nature of the sediments truncated by the granite masses, the aureoles of metamorphism cannot be divided into concentric zones, based on one type of rock. But in some instances it is possible to trace particular zones along the strike to their junction with the granite, and thereby follow the different stages in the alteration of the sediments. By this method Miss Gardiner has proved that the Silurian grits pass at the granite junction [NX 62101 76178] on Knocknairling Hill, New Galloway, into garnet-sillimanite-hornfels. The black shales also pass into graphite-schists with andalusite and chiastolite; the

crypto-crystalline radiolarian chert into coarsely crystalline quartz-rock, the latter being accompanied by the development of minute biotite.

In like manner Mr. Teall has shown that the Arenig lavas, and in one instance near the edge of the Cairnsmore of Carsphairn mass, the intrusive ophitic dolerites, have been altered by the granitic protrusions, the minerals of the former being almost wholly of secondary origin.

It is highly probable that the granitic masses of the Southern Uplands and their apophyses may represent the plutonic rocks of the volcanic period of the Lower Old Red Sandstone. On the one hand they traverse sediments of Llandovery, Wenlock, and Ludlow age, and on the other hand they must be older than Upper Old Red Sandstone time, for strata of the latter period rest unconformably on Upper Silurian rocks pierced by apophyses of the granite. It is further evident (Explanation of Sheet 5, one-inch, p. 29) that the sediments under which the granite lay buried must have been removed and the igneous rocks exposed, before the formation of the beds of arkose, grit, and conglomerate which are such a conspicuous feature in the Lower Carboniferous series of the Colvend and Rerwick shores.

Excavation of the valley system

It is foreign to our present purpose to trace the development of the valley system of the Southern Uplands, which everywhere shows abundant proofs of sub-aerial erosion. But a brief reference is necessary to show that while the existing topography dates from Tertiary, and even post-Tertiary time, some of the valleys extend back to ancient geological periods when they were filled with younger Palaeozoic deposits. Lauderdale may be taken as an example of those transverse hollows which traversed the tableland in Upper Old Red Sandstone time, when the conglomerates and sandstones were there laid down which are now being eroded by the Leader Water. Nithsdale and Loch Ryan represent pre-Carboniferous hollows, since, along the valley of the Nith and round the western shore of that loch, relics of Carboniferous strata are still to be found. And when we reflect that Annandale is floored with breccia and sandstone which are provisionally referred to the Permian period, and that similar deposits rest unconformably partly on Carboniferous and partly on Silurian strata in Nithsdale and Loch Ryan, successive phases in the evolution of the valley system are strikingly apparent. And yet, the main features of the existing valley system must be of much more recent date. From the relations of the Tertiary dykes which cross mountain and valley without interruption, and traverse alike Silurian and all younger Palaeozoic rocks, it is obvious that the valleys must have been excavated since the eruption of these dykes. Thus we learn that only after prolonged denudation, during successive geological periods, the Southern Uplands have acquired their present topographical features.

Upper Silurian

[2024 note: The following content was provided in a complex table. Its been simplified for GeoGuide. To see the original tables: Upper Silurian is (Table 2) Lower Silurian is (Table 3)

Central and Southern Belts

Downtonian

Nil

Ludlow

Kirkcudbright Shore and Riccarton:

(2) Raeberry Castlee Beds — Mudstones with limestone nodules and Balmae grits. *Athyris Atrypa, Orthoceras Etheridgei*. Thickness, 500–750 feet.

Wenlock

(1) Riccarton Beds. Burrow Head, Kirkcudbright Shore, Dumfriesshire, Riccarton, and Cheviots. — Conglomerates, grits, greywackes, shales, and mudstones *Cyrtograptus Murchisoni, Monograptus vomerinus, M. priodon.* Thickness, 1000–1500 feet.

Tarannon

Hawick Rocks, Ardwell Beds

Brown and grey greywackes and shales. Protovirgularia.

Queensberry Group

Grieston Shales — Grits and shales. *Cyrtograptus, Monograptus convolutus, M. priodon, Retiolites geinitzianus.*

Buckholm Grits and Abbotsford flags. — Massive conglomerates, flags, shales, and red mudstones *Monograptus exiguus, M. crispus, M. turriculatus.* Approximate maximum thickness, 3000–4000 feet.

Llandovery

Birkhill Shale Series.

Upper Thickness 46 feet.

3. *Rastrites* maximus-zone.

2. *Monograptus spinigerus*-zone.

1. *Cephalograptus cometa*-zone.

Lower. Thickness, 52 feet.

3. *Monograptus gregarius*-zone.

2. *Diplograptus vesiculosus*-zone.

1. *Diplograptus acuminatus*-zone

Northern Belt and Inliers of Lanarkshire and Pentland Hills

Downtonian

Lanarkshire:

(2) Red sandstone, quartzite conglomerate, green and red mudstones (fish bands). Fishes, eurypterids, myriapods, plants, &c.

(1) Red and yellow sandstones with basal conglomerate. Total thickness — in Lesmahagow area, 2,700 feet; in Hagshaw Hills, 2,300 feet.

Pentland Hills:

(2) Quartz conglomerate, sandstones, red and green mudstones. Fishes, polyzoa &c. Thickness uncertain

(1) Red sandstones with basal conglomerate. Thickness, 700 feet.

Ludlow

Lanarkshire:

(2) Mudstones, sandstones, greywacke, and flaggy shales. *Platyschisma helicites*, *Orthoceras dimidiatum*. Phyllopods, eurypterids, scorpion, fishes. Thickness, 1480 feet

Pentland Hills:

(2) Concretionary mudstone, sandtstone, and shales. *Platyschisma simmulans*. Thickness, 800 feet.

Wenlock

Lanarkshire:

(1) Greywacke and shales. Thickness, 1300 feet. Base not seen.

Pentland Hills

(1) Concretionary mudstones, grits conglomerates, shales. Brachiopods, lamellibranchs, eurypterids, scorpions. *Cyrtograptus, Monograptus* Thickness, 2200 feet. Base not seen.

Tarannon

Nil.

Llandovery

Nil.

Girvan area

Downtonian - Nil

Nil

Ludlow

Nil

Wenlock

Blair and Straiton Beds — Conglomerates, grits, flags, and shales. Bey*richia Kloedeni, Cardiola interrupta, Orthoceras Maclareni.* Thickness, 500 feet.

Tarannon

Drumyork Flags, Bargany Group — Flagstones and shales. *Cyrtograptus Grayi, Monograptus priodon,* &c. Thickness, 1100 feet.

Penkill Group. — Grits, flagstones, and purple shales. *Monograptus exiguus, Crossopodia, Protovirgularia* &c. Thickness, 1000 feet.

Llandovery

Camregan Group — Grits, limestones, and shales. *Rastrites maximus*, *Pentamerus.* Thickness, 200 feet.

Saugh Hill Group — Flagstones and shales. *Monograptus spinigerus, Rastrites peregrinus.* Thickness, 500 feet.

Mulloch Hill Group — Conglemerate, sandstones, and shales. *Diplograptus acuminatus*, *Meristella angustifrons, Atrypa*. Thickness, 350 feet.

Lower Silurian (Table 3)

Central and Southern Belts

Caradoc

Hartfell Shale Series.

*Upper Barren Mudston*e. Thickness about 60 feet

Mudstones with thin seams of black shales, thin tuffs, and agglomerate.

2. *Dicellograptus anceps*-zone.

1. *Dicellograptus complanatus*-zone. *Diplograptus socialis.*

Lower

Black flaggy graptolite shales.

3. *Pleurograptus linearis*-zone.

2. *Dicranograptus Clingani-zone*

1. *Climacograptus Wilsoni*-zone *Buthograptus laxus.*

Llandeilo

Glenkiln Shale Series.

4. Thin black shales underlying *Climacograptus Wilsoni*-zone. *Dicranograptus zic-zac, Climacograptus caelatus* var. *antiquus, C. peltifer, Lasiograptus bimucronatus.* Thickness about 2 feet.

3. Orange coloured mudstones, radiolarian charts, and fine volcanic tuffs, Thickness at Dobbs Linn, 4 feet.

2. Glenkiln Shales. — Black shales with cherty ribs. *Caenograptus gracilis, Didymograptus superstes.* Thickness, 8–12 feet.

1. Radiolarian charts, mudstones, and volcanic tuffs.

Arenig

Radiolarian cherts and mudstones with volcanic tuffs (Castle Douglas district, &c.). Thickness about 150–200 feet at Trowdale, Castle-Douglas (Arenig and Lower Llandeilo cherts, &c.).

Base not seen.

Northern Belts

Caradoc

Lowther Shales (Wrae, Glencotho, Winkston). — Grey and blue micaceous shales with conglomerates and limestones. Trilobites, brachiopods, cephalopods, &c. Volcanic rocks — felsitic lavas and tuffs (Wrae, Glencotho, Hamilton Hill,

Winkston). Thickness about 800 feet.

Black shales and flinty bands with Lower Hartfell graptolites (40 feet) passing laterally into greywaekes and shales and calcareous conglomerates with Lower Caradoc fossils. Brachiopods, trilobites (Wallace's Cast, Duntercleugh, Bilbucho). Local unconformabilities in the districts of Channelkirk, Leadhills, Crawfordjohn, Sanquhar, and Shinnel Water. Volcanic rocks in lowest beds (Sanquhar district). Thickness about 1000 feet.

Llandeilo

Black shales with cherty bands (8 to 12 feet). *Didymograptus superstes, Caenograptus gracilis, Lasiograptus bimucronatus, Dicranograptus zic-zac, Dicellograptus divaricatus.*

Black shales pass towards the north and west into grits, greywackes, and shales. Approximate thickness, 900–1200 feet.

Volcanic rocks are associated with the beds between the Llandeilo and Caradoc divisions in the Sanquhar district.

Radiolarian churls and mudstones.

Arenig

3. Radiolarian charts. Thickness,70 feet (Arenig and Lower Llandeilo cherts).

2. Mudstones with thin dark seams. *Obolella, Lingulella, Tetragraptus, Caryocaris Wrighti.* Thickness, 4 feet.

1. Volcanic series, comprising lavas, tuffs, agglomerates, and intrusive igneous ' rocks. Approximate thickness about 500 feet (Sanquhar).

Base not seen.

Girvan area

Caradoc

Ardmillan Series.

Drummuck Group (Green Mudstones). — *Palaeaster, Dicellograptus anceps, Trinucleus seticornis.* 400 feet.

Barren Flagstone Group. — *Diplograptus truncatus, Nemetolites Grayi.* Thickness, 800 feet.

Whitehouse Group. — *Dicellograptus complanatus, Pleurograptus linearis, Diplograptus,* trilobites. Thickness, 300 feet.

Ardwell Group. — Flagstones and shales. *Climacograptus caudatus, Dicranograptus ramosus.* Thickness, 1,200 feet.

Balclatchie Group. — Mudstones, grits, and conglomerates. *Glossograptus Hincksi, Climacograptus bicornis.* Trilobites, brachiopods, &c., abundant. Thickness, 100 feet.

Llandeilo

Area S. of the Stinchar Valley.

4. Boulder conglomerate (Glenapp, Corsewall). Approximate thickness, 500 feet.

3. Unfossiliferous mudstones and grits ("Tappins group").Thickness about 500 feet.

2. Fossiliferous mudstones, *Didymograptus superstes, Caenograptus*, *Dendrograptus,* 6 feet thick (Portandea).

1. I. Mudstones and radiolarian charts, passing conformably downwards into Arenig cherts and volcanic rocks.

Area N. of the Stinchar Valley.

Barr Series.

4. Benan conglomerate, about 500 feet thick.

3. Graptoloitic mudstones. *Didymograptus superstes.* Thickness, 30 feet.

2. Stinchar Limestone group, 60 feet thick.

1. Kirkland group, sandstones and conglomerates, *Orthis confinis* beds, 240 feet thick.

Local unconformability.

Arenig

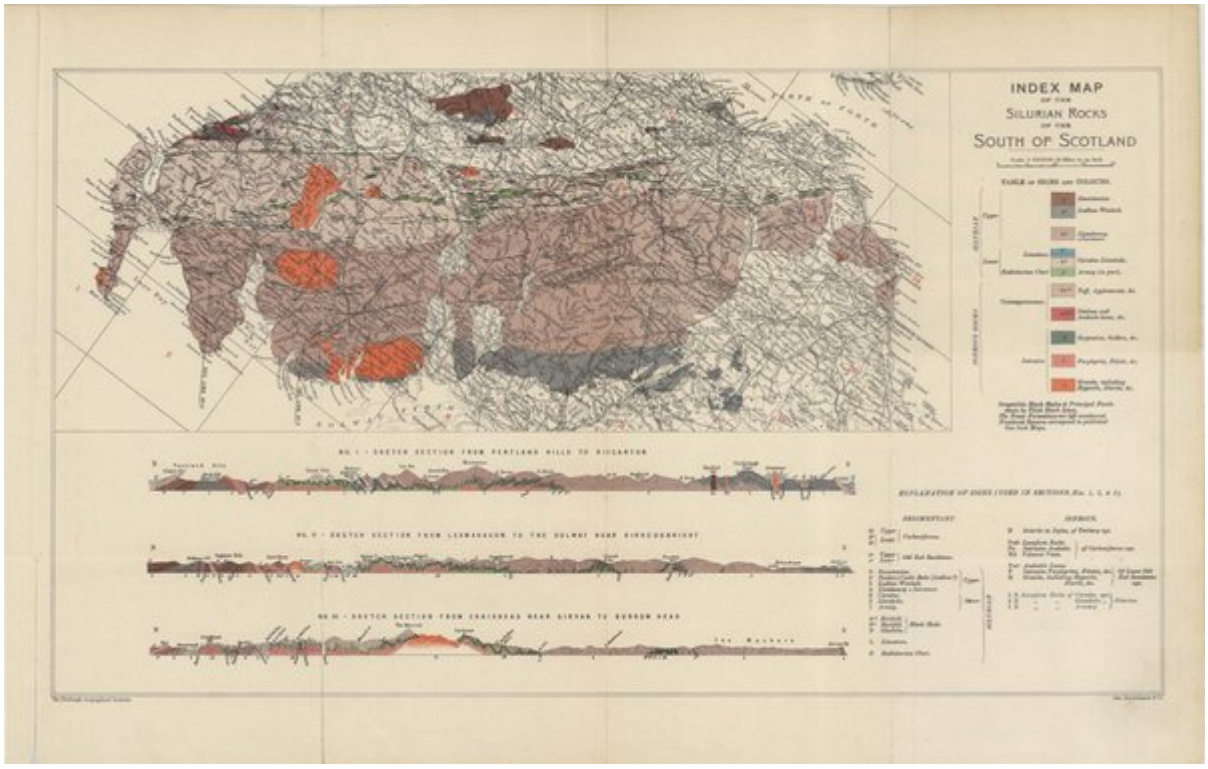
Radiolarian cherts, mudstones, and volcanic tuffs. About 70 feet thick (Arenig and Lower Llandeilo cherts).

Bennane Head black shales *(Tetragraptis bryonoides)* interleaved with volcanic agglomerate, 3–4 feet.

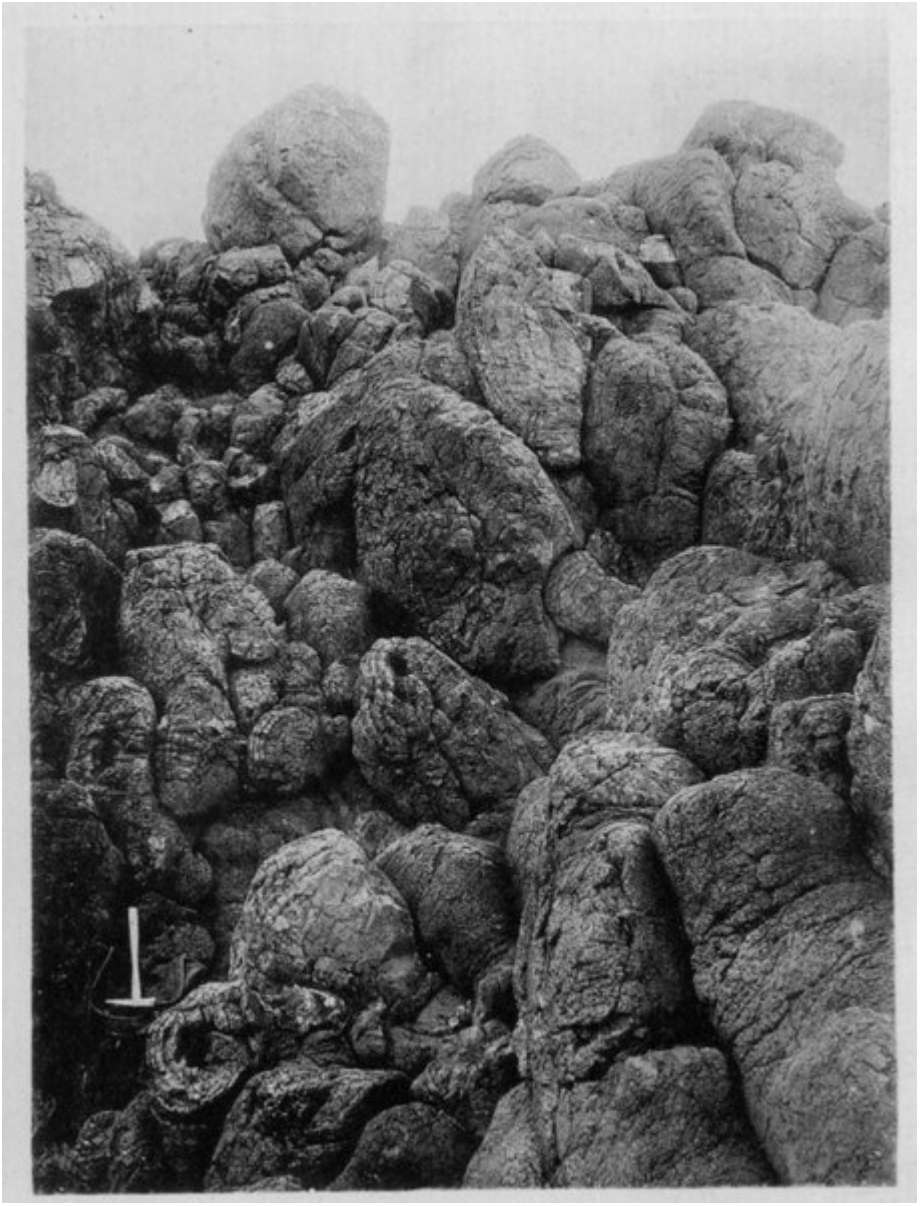
Volcanic rocks, laves, and tuffs, with fossiliferous intercalations yielding Middle Arenig graptolites. Approximate thickness, 1500 feet.

Base not seen.

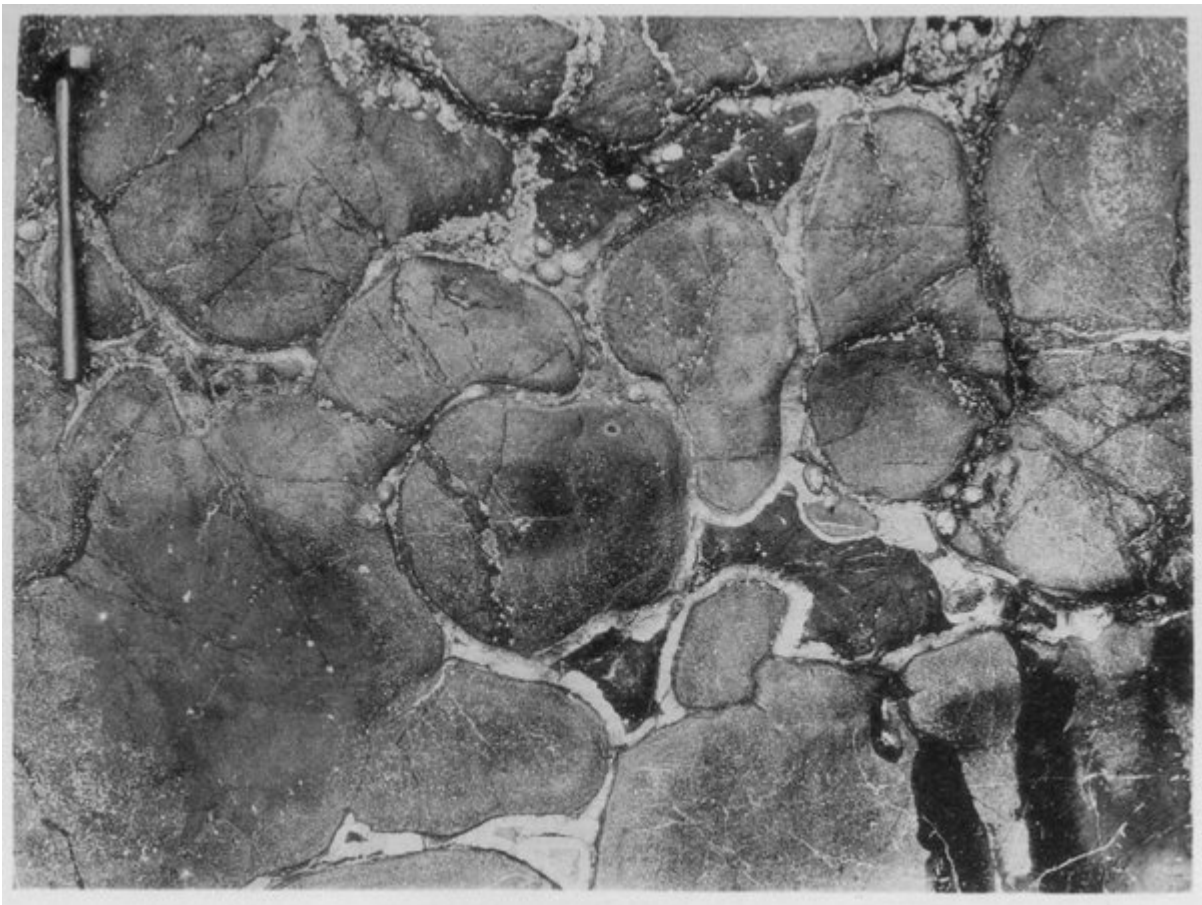
[end of table]



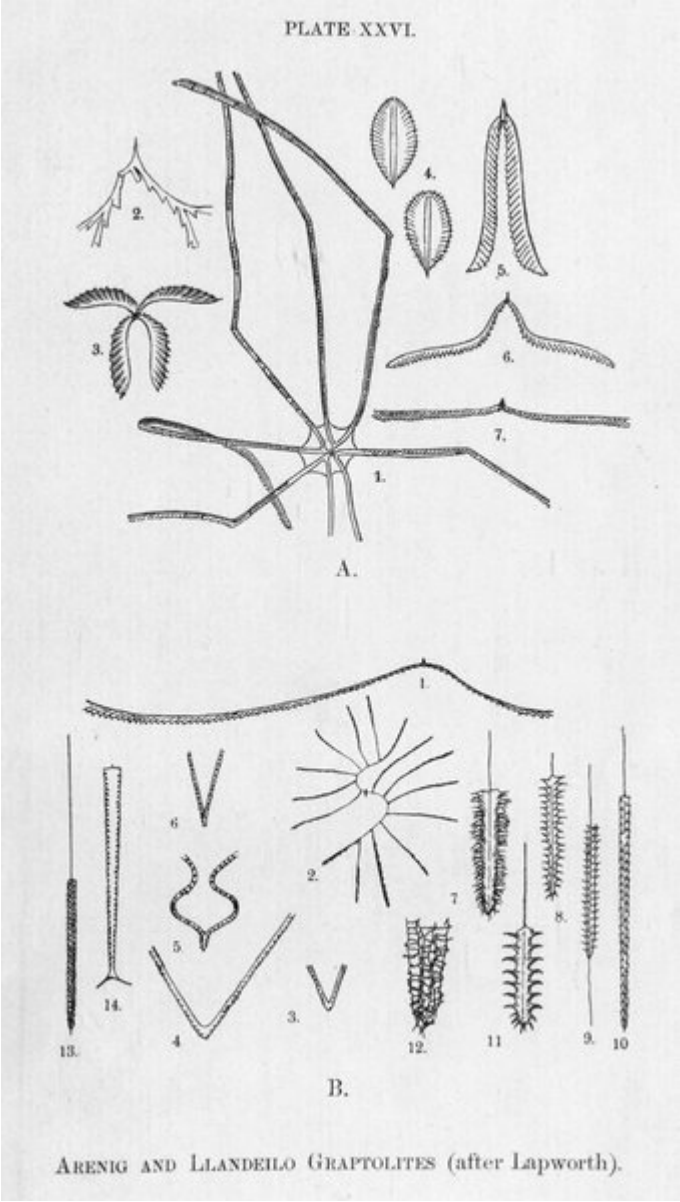
Index map of the Silurian rocks of south Scotland.



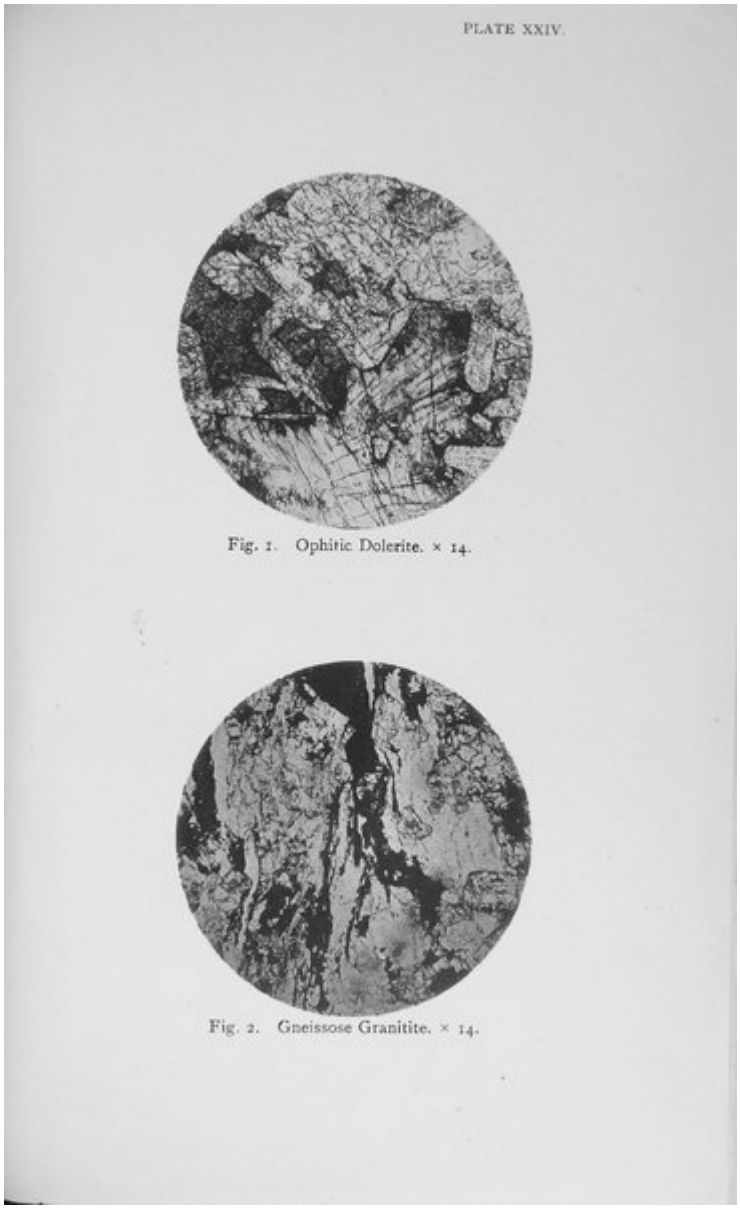
(Plate 1) Sack-like pillow-form structure in Diabase Lava on shore ¾-mile south of Downan Point 2½ miles south of Balantrae.



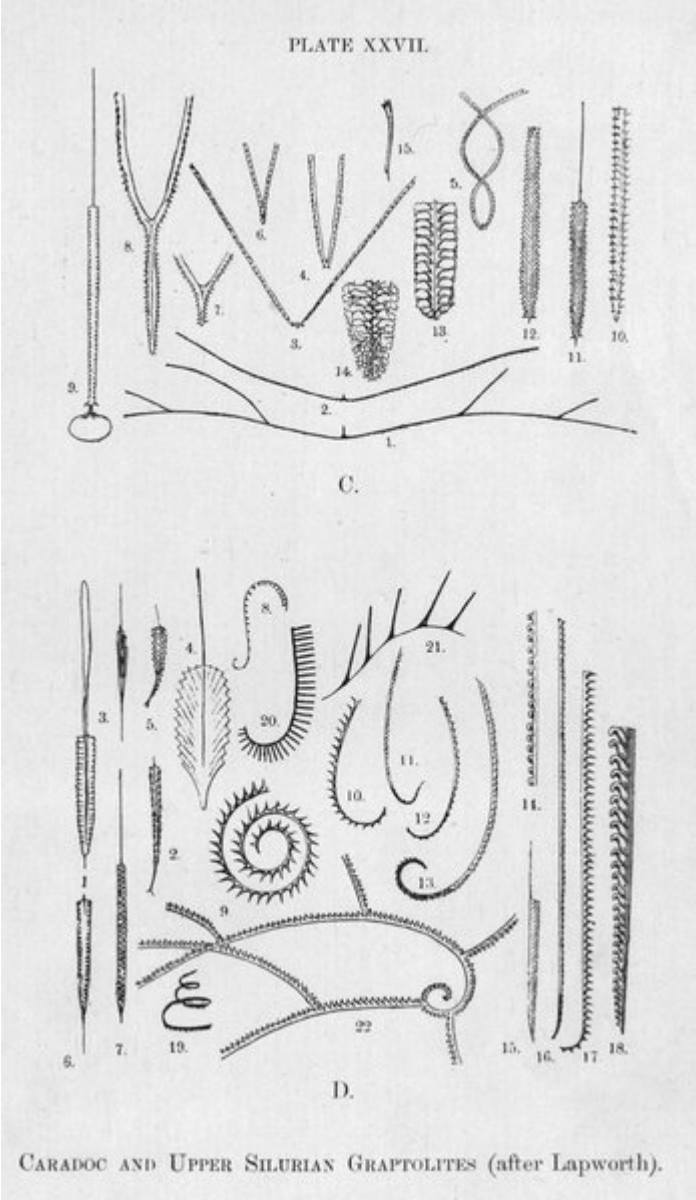
(Plate 2) Limestone filling spaces between pillow-form masses of lava exposed near beach near Downan, 1½ miles south of Ballantrae.



(Plate 26) ***A. Arenig and Lower Llandeilo graptolites.*** *1. Dichograptus octobrachiatus (Halt.) x ½ 2. Bryograptus Kjerulfi (Lapw.) x 2. 3. Tetragraptus bryonoides (Hall.) 4. Phyllograptus typus (Hall.) x ½ 5. Didymograptus Murchisoni (Barr.) 6. Didymograptus fractus (Salt.) 7. Didymograptus nitidus (Hall).* ***B Upper Llandeilo (Glenkiln) graptolites.*** *1. Didymograptus superstes (Lapw.) 2. Caenograptus gracilis (Hall.) 3. Dicellograptus sextans (Hall.) 4. Dicellograptus divaricatus (Hall.) 5. Dicranograptus zic-zac (Lapw.) 6 Dicranograptus formosus (Hopk.) 7 Lasiograptus bimucronatus (Nich.) 8. Diplograptus mucronatus (Hall.) 9. Diplograptus Whitfieldi (Hall.) 10. Diplograptus angustifolius (Hall.) 11. Glossograptus Hincksi (Hopk.) 12. Clathrograptus cuneiformis (Lapw.) x 3 13. Climacograptus Scharenbergi 14. Climacograptus bicornis (Hall.) Arenig and Llandeilo graptolites (after Lapworth).*



(Plate 24) 1. (S6470). Another portion of the same slide.



(Plate 27) ***C. Caradoc (Hartfell) Graptolites.*** *1. Pleurograptus linearis (Carr.) 2. Leptograptus flaccidus (Hall.) 3. Dicellograptus complanatus (Lapw.) 4. Dicellograptus Morrisi (Hopk.) 5. Dicellograptus caduceus (Lapw.) 6. Dicranograptus Clingani (Hopk.) 7. Dicranograptus Nicholsoni (Hopk.) 8. Dicranograptus ramosus (Hall.) 9. Climacograptus Wilsoni (Lapw.) 10. Diplograptus quadrimucronatus (Hall.) 11. Diplograptus foliaceus (Mwrch.) 12. Diplograptus truncatus (Lapw.) 13. Lasiograptus margaritatus (Lapw.) 14. Neurograptus fibratus (Lapw.) 15. Corynoides calycularis (Nich.)* ***D. Upper Silurian Graptolites*** *1. Diplograptus vesiculosus (Nich,.) 2. Diplograptus acuminatus (Nich.) 3. Cephalograptus cometa (Geinitz.) 4. Petalograptus folium (His.) 5. Dimorphograptus Swanstoni (Lapw.) 6. Climacograptus rectangularis (M'Coy.) 7. Climacograptus normalis (Lapw.) 8. Monograptus crispus (Lapw.) 9. Monograptus spiralis (Iteinitz.) 10. Monograptus triangulatus (Harkn.) 11. Monograptus exiguus (Nich.) 12. Monograptus gregarius (Lapw.) 13. Monograptus cyphus (Lapw.) 14. Monograptus lobiferus (M'Coy.) 15. Monograptus colonus (Barr.) 16. Monograptus jaculum (Lapw.) 17. Monograptus Sedgwicki (Portl.) 18. Monograptus priodon (Bronn.) 19. Monograptus turriculatus (Barr.) 20. Rastrites perigrinus (Barr.) 21. Rastrites maximus (Carr.) 22. Cyrtograptus Murchisoni (Carr.) Caradoc and Upper Silurian graptolites (after Lapworth).*

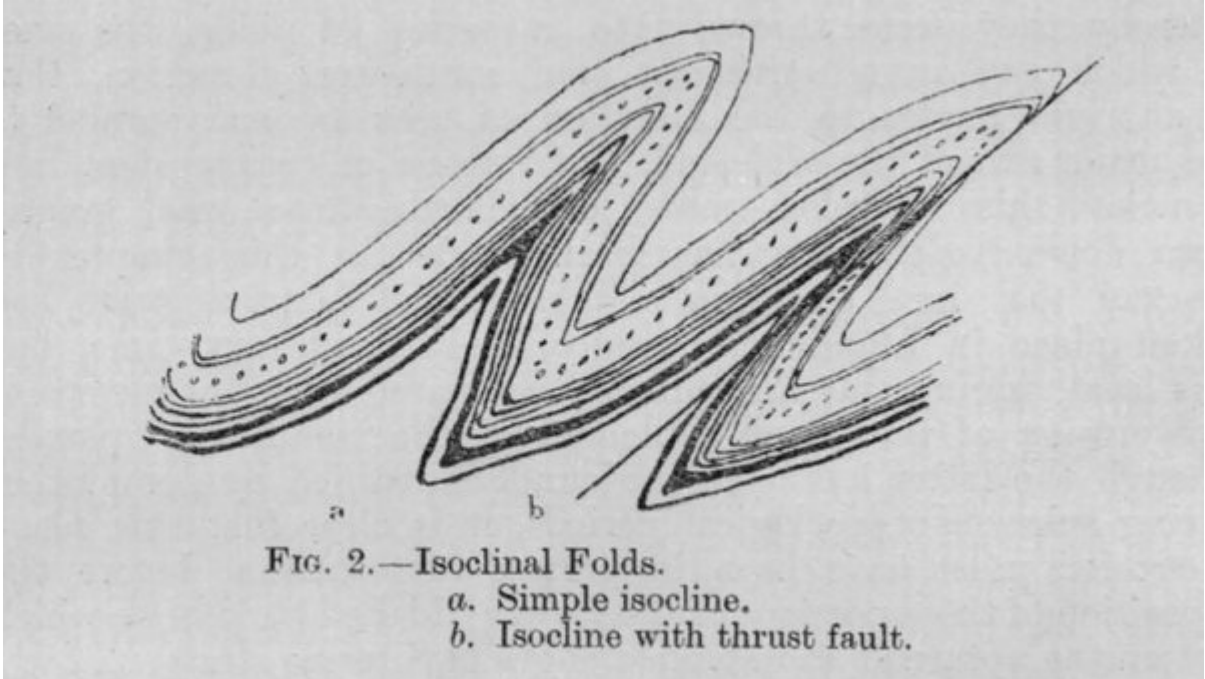


FIG. 2.—Isoclinal Folds.
a. Simple isocline.
b. Isocline with thrust fault.

(Figure 2) Isoclinal Folds. a. Simple isocline. b. Isocline with thrust fault.

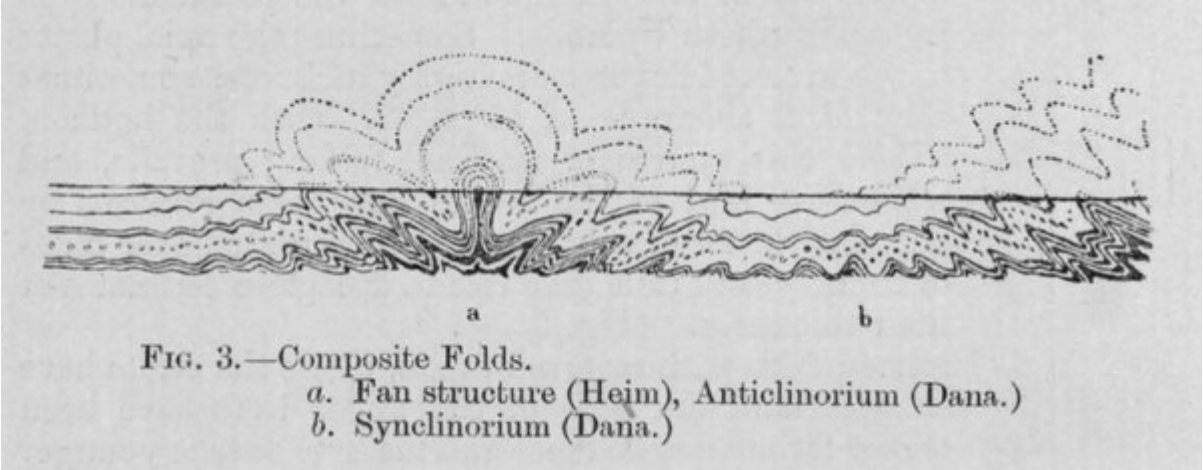


FIG. 3.—Composite Folds.
a. Fan structure (Heim), Anticlinorium (Dana.)
b. Synclinorium (Dana.)

(Figure 3) Composite Folds. a. Fan structure (Heim), Anticlinorium (Dana.) b. Synclinorium (Dana.)

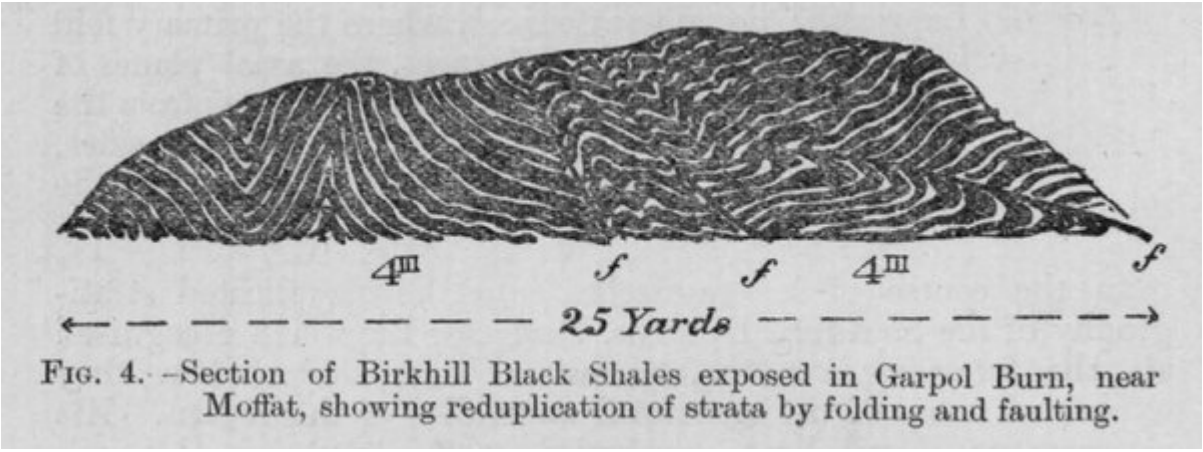


FIG. 4.—Section of Birkhill Black Shales exposed in Garpol Burn, near Moffat, showing reduplication of strata by folding and faulting.

(Figure 4) Section of Birkhill Black Shales exposed in Garpol Burn, near Moffat, showing reduplication of strata by folding and faulting.

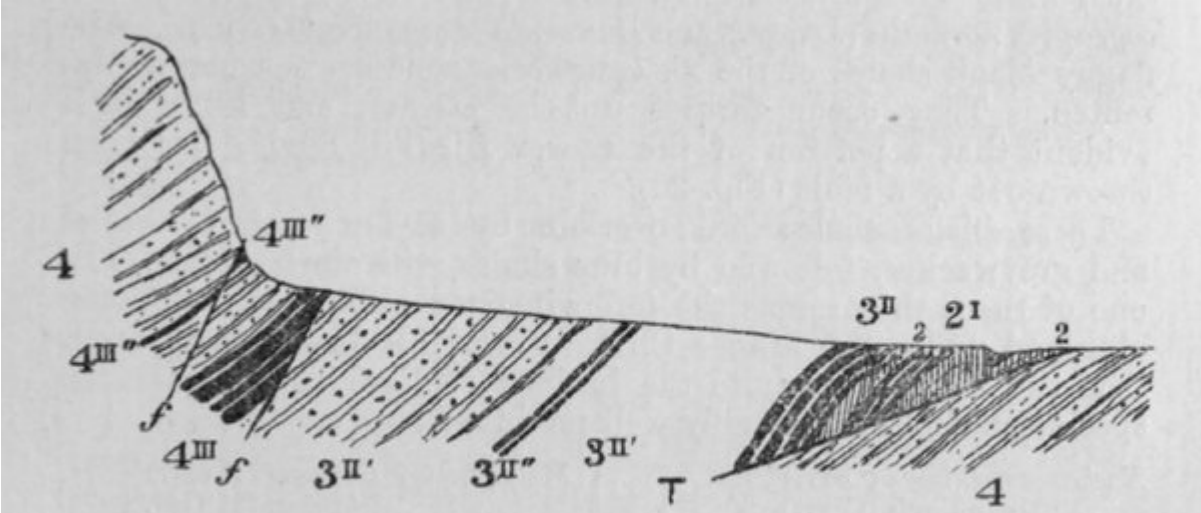


FIG. 20.—Section in River Ettrick from Manse Cliff to foot of Baillie Burn (No. 1 in Fig. 19).

2. Glenkiln chert. *(For further explanation, see Fig. 19.)*

(Figure 20) Section in the River Ettrick from manse Cliff to foot of Baillie Burn (No. 1 in (Figure 19)). 2. Glenkiln chert (For further explanation, see (Figure 19).)

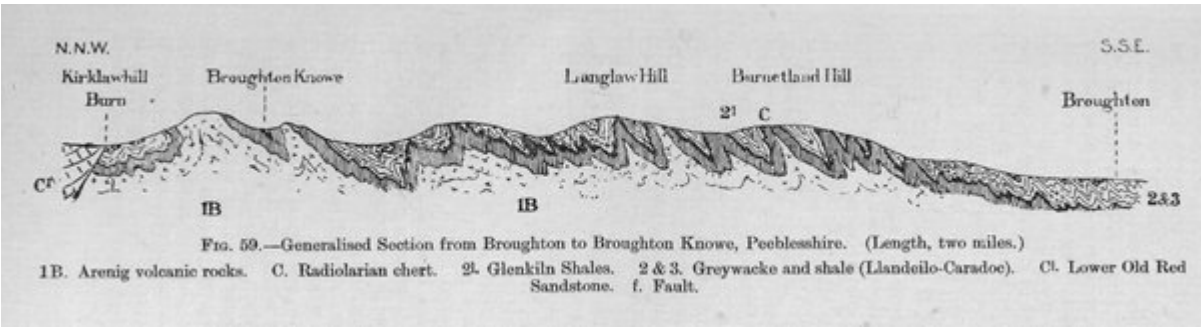


FIG. 59.—Generalised Section from Broughton to Broughton Knowe, Peeblesshire. (Length, two miles.)

1B. Arenig volcanic rocks. C. Radiolarian chert. 2I. Glenkiln Shales. 2 & 3. Greywacke and shale (Llandeilo-Caradoc). Cl. Lower Old Red Sandstone. f. Fault.

(Figure 59) Generalised Section from Broughton to Broughton Knowe, Peeblesshire. (Length, two miles.) 1B. Arenig volcanic rocks. C. Radiolarian chert. 2I. Glenkiln Shales. 2 & 3. Greywacke and shale (Llandeilo–Caradoc). CI. Lower Old Red Sandstone. f. Fault.

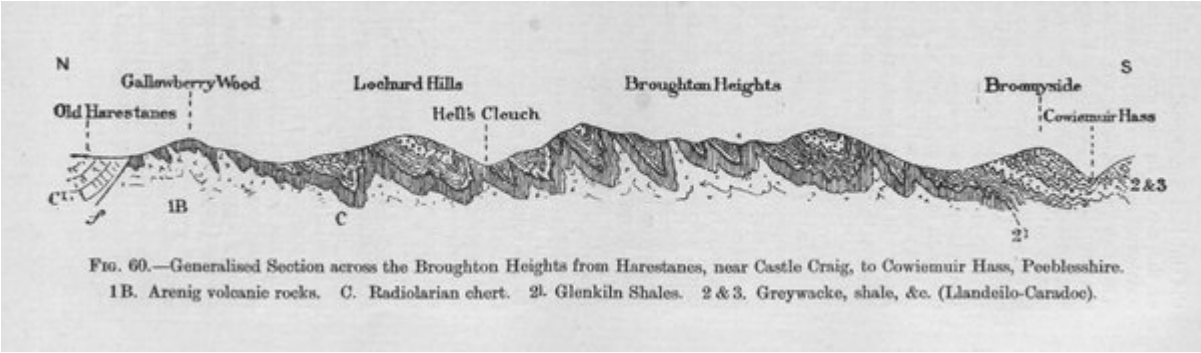


FIG. 60.—Generalised Section across the Broughton Heights from Harestanes, near Castle Craig, to Cowiemuir Hass, Peeblesshire.

1B. Arenig volcanic rocks. C. Radiolarian chert. 2I. Glenkiln Shales. 2 & 3. Greywacke, shale, &c. (Llandeilo-Caradoc).

(Figure 60) Generalized section aross The Broughton Heights from Harestanes, near Castle Craig to Cowiemuir Hass, Peebleshire. 1B. Arenig volcanic rocks. C. Radiolarian chert. 2I. Glenkiln Shales 2&3 Greywacke, shale &c. (Llandeilo–Caradoc).

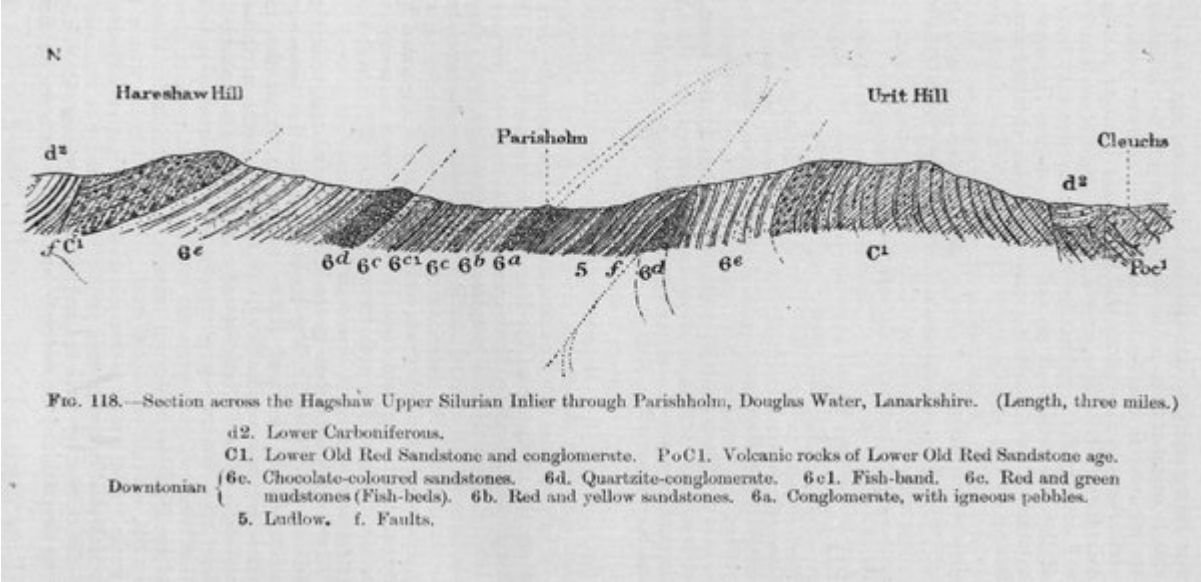


Fig. 118.—Section across the Hagshaw Upper Silurian Inlier through Parishholm, Douglas Water, Lanarkshire. (Length, three miles.)

d2. Lower Carboniferous.
C1. Lower Old Red Sandstone and conglomerate. PoC1. Volcanic rocks of Lower Old Red Sandstone age.
Downtonian { 6e. Chocolate-coloured sandstones. 6d. Quartzite-conglomerate. 6c1. Fish-band. 6c. Red and green mudstones (Fish-beds). 6b. Red and yellow sandstones. 6a. Conglomerate, with igneous pebbles.
5. Ludlow. f. Faults.

(Figure 118) Section across the Hagshaw Upper Silurian Inlier through Parishhohn, Douglas Water, Lanarkshire. (Length, three miles.) d2. Lower Carboniferous. C1. Lower Old Red Sandstone and conglomerate. PoC1. Volcanic rocks of Lower Old Red Sandstone age. Downtonian: 6e. Chocholate -coloured sandstone. 6d. Quartzite conglomerate. 6c1 Fish-band. 6c. Red and green mudstones (Fish-beds). 6b. Red and yellow sandstones. 6a. Conglomerate with igneous pebbles. 5 Ludlow. f. faults.

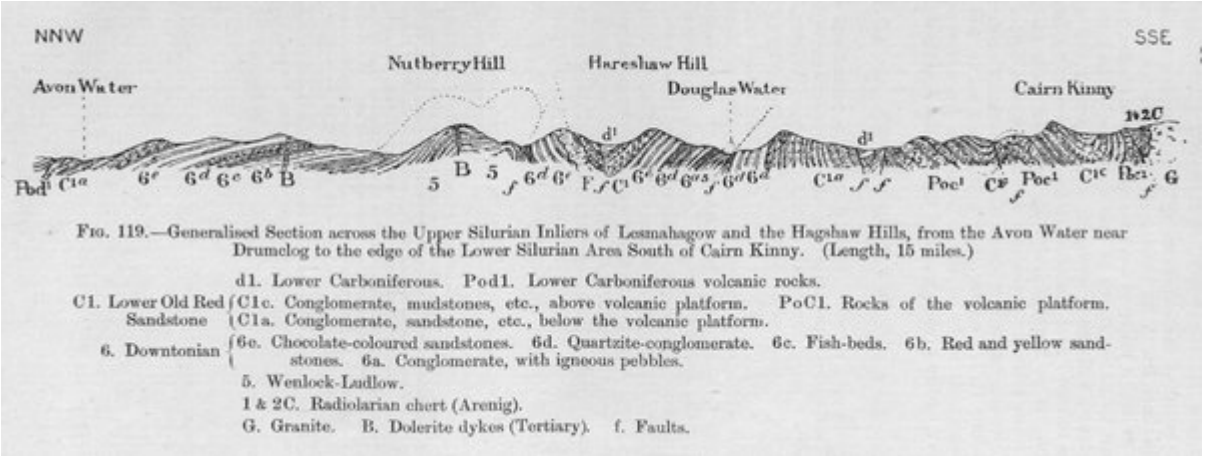


Fig. 119.—Generalised Section across the Upper Silurian Inliers of Lesmahagow and the Hagshaw Hills, from the Avon Water near Drumclog to the edge of the Lower Silurian Area South of Cairn Kinny. (Length, 15 miles.)

d1. Lower Carboniferous. Pod1. Lower Carboniferous volcanic rocks.
C1. Lower Old Red Sandstone { C1c. Conglomerate, mudstones, etc., above volcanic platform. PoC1. Rocks of the volcanic platform. C1a. Conglomerate, sandstone, etc., below the volcanic platform.
6. Downtonian { 6e. Chocolate-coloured sandstones. 6d. Quartzite-conglomerate. 6c. Fish-beds. 6b. Red and yellow sandstones. 6a. Conglomerate, with igneous pebbles.
5. Wenlock-Ludlow.
1 & 2C. Radiolarian chert (Arenig).
G. Granite. B. Dolerite dykes (Tertiary). f. Faults.

(Figure 119) Generalised Section across the Upper Silurian InHers of Lesmahagow and the Hagshaw Hills, from the Avon Water near Drumclog to the edge of the Lower Silurian Area South of Cairn Kinny. (Length, 15 miles.) d1. Lower Carboniferous. Pod1. Lower Carboniferous volcanic rocks. C1. Lower Old Red Sandstone: C1c. Conglomerate, mudstones, etc., above volcanic platform. P C1. Rocks of the volcanic platform. C1a. Conglomerate, sandstone, etc., below the volcanic platform. 6. Downtonian 6e. Chocolate-coloured sandstones. 6d. Quartzite-conglomerate. 6c. Fish-beds. 6b. Red and yellow sandstones. 6a. Conglomerate, with igneous pebbles. 5. Wenlock-Ludlow. 1 & 2C. Radiolarian chert (Arenig). G. Granite. B. Dolerite dykes (Tertiary). f. Faults.

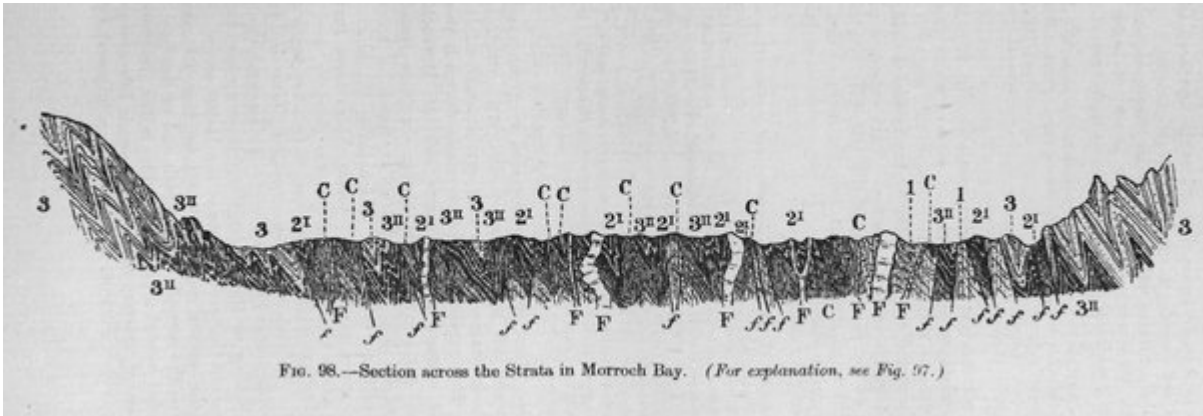
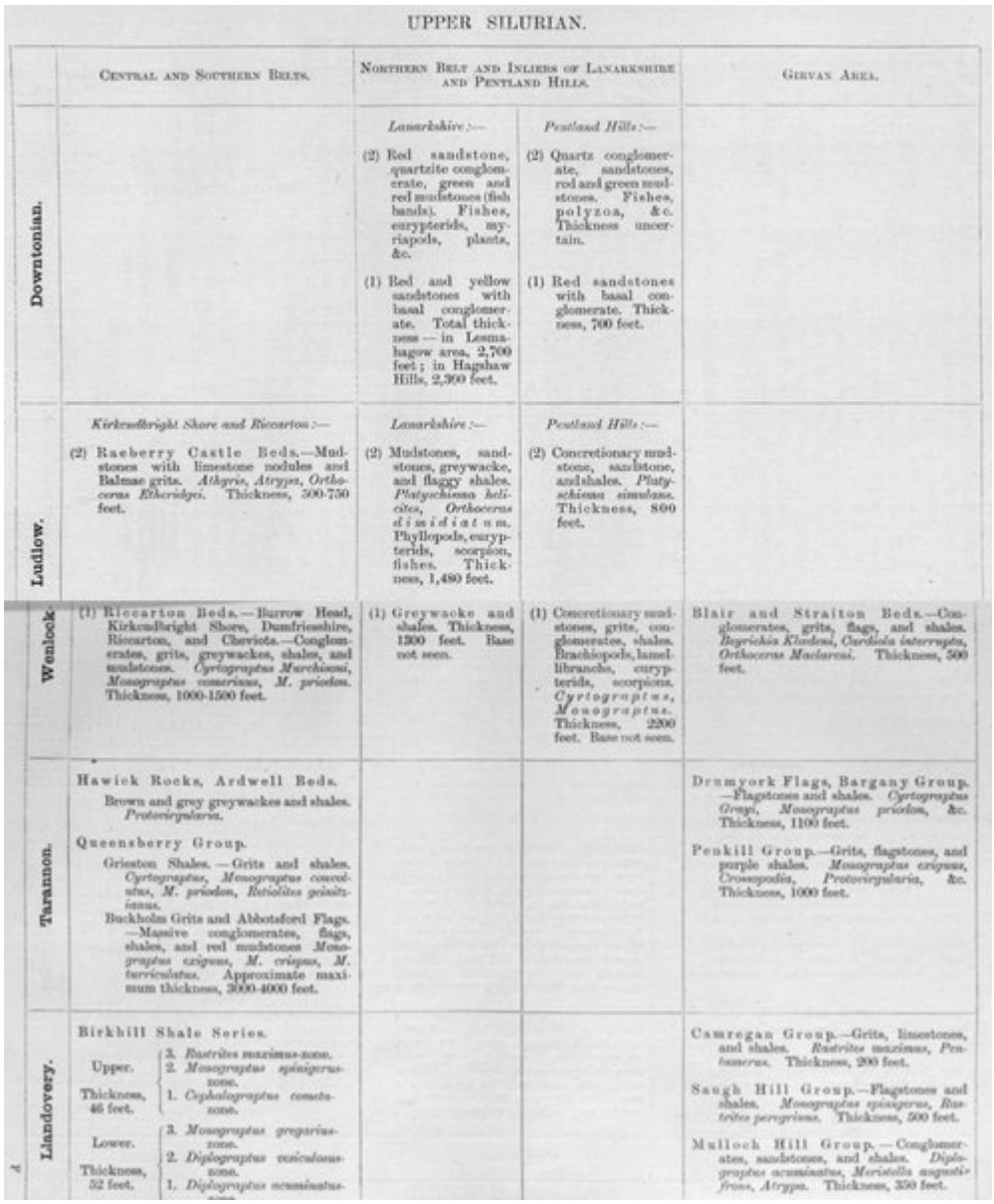


Fig. 98.—Section across the Strata in Morroch Bay. *(For explanation, see Fig. 97.)*

(Figure 98) Section across the Strata in Morroch Bay. (For explanation, see (Figure 97).)



UPPER SILURIAN.

	Central and Southern Belts.	Northern Belt and Inliers of Lanarkshire and Pentland Hills.		Girvan Area.
		Lanarkshire :—	*Pentland Hills :—*	
Downtonian.		(2) Red sandstone, quartzite conglomerate, green and red mudstones (fish bands). Fishes, eurypterids, myriapods, plants, &c. (1) Red and yellow sandstones with basal conglomerate. Total thickness — in Lesmahagow area, 2,700 feet; in Hagshaw Hills, 2,360 feet.	(2) Quartz conglomerate, sandstones, red and green mudstones. Fishes, polyzoa, &c. Thickness uncertain. (1) Red sandstones with basal conglomerate. Thickness, 700 feet.	
Ludlow.	*Kirkcudbright Shore and Riccarton :—* (2) Raeberry Castle Beds.—Mudstones with limestone nodules and Balmae grits. *Athyris, Atrypa, Orthoceras Etheridgei.* Thickness, 500-750 feet.	*Lanarkshire :—* (2) Mudstones, sandstones, greywacke, and flaggy shales. *Platyschisma helicites, Orthoceras dimidiatum.* Phyllopods, eurypterids, scorpion, fishes. Thickness, 1,480 feet.	*Pentland Hills :—* (2) Concretionary mudstone, sandstone, and shales. *Platyschisma simulans.* Thickness, 800 feet.	
Wenlock.	(1) Riccarton Beds.—Burrow Head, Kirkcudbright Shore, Dumfriesshire, Riccarton, and Cheviots.—Conglomerates, grits, greywackes, shales, and mudstones. *Cyrtograptus Murchisoni, Monograptus vomerinus, M. priodon.* Thickness, 1000-1500 feet.	(1) Greywacke and shales. Thickness, 1200 feet. Base not seen.	(1) Concretionary mudstones, grits, conglomerates, shales. Brachiopods, lamellibranchs, eurypterids, scorpions. *Cyrtograptus, Monograptus.* Thickness, 2200 feet. Base not seen.	Blair and Straiton Beds.—Conglomerates, grits, flags, and shales. *Bygrichia Klodeni, Cardiola interrupta, Orthoceras Maclarani.* Thickness, 500 feet.
Tarannon.	Hawick Rocks, Ardwell Beds. Brown and grey greywackes and shales. *Protovirgularia.* Queensberry Group. Grieston Shales.—Grits and shales. *Cyrtograptus, Monograptus convolutus, M. priodon, Retiolites geinitzianus.* Buckholm Grits and Abbotsford Flags.—Massive conglomerates, flags, shales, and red mudstones *Monograptus exiguus, M. crispus, M. turriculatus.* Approximate maximum thickness, 3000-4000 feet.			Drumyork Flags, Bargany Group.—Flagstones and shales. *Cyrtograptus Grayi, Monograptus priodon,* &c. Thickness, 1100 feet. Penkill Group.—Grits, flagstones, and purple shales. *Monograptus exiguus, Crossopodia, Protovirgularia,* &c. Thickness, 1000 feet.
Llandovery.	Birkhill Shale Series. Upper. Thickness, 46 feet. 3. *Rastrites maximus*-zone. 2. *Monograptus spinigerus*-zone. 1. *Cephalograptus cometa*-zone. Lower. Thickness, 52 feet. 3. *Monograptus gregarius*-zone. 2. *Diplograptus vesiculosus*-zone. 1. *Diplograptus acuminatus*-			Camregan Group.—Grits, limestones, and shales. *Rastrites maximus, Pentamerus.* Thickness, 200 feet. Saugh Hill Group.—Flagstones and shales. *Monograptus spinigerus, Rastrites peregrinus.* Thickness, 500 feet. Mulloch Hill Group.—Conglomerates, sandstones, and shales. *Diplograptus acuminatus, Meristella angustifrons, Atrypa.* Thickness, 350 feet.

(Table 2) Upper Silurian — general description

LOWER SILURIAN.

	Central and Southern Belts.	Northern Belt.	Girvan Area.	
Caradoc.	**Hartfell Shale Series.** Upper or Barren Mudstone. Thickness about 60 feet. Mudstones with thin seams of black shales, thin tuffs, and agglomerate. 2. *Dicellograptus anceps*-zone. 1. *Dicellograptus complanatus*-zone. *Diplograptus socialis.* Lower. Thickness about 40 feet. Black flaggy graptolite shales. 3. *Pleurograptus linearis*-zone. 2. *Dicranograptus Clingani*-zone. 1. *Climacograptus Wilsoni*-zone. *Buthograptus laxus.*	**Lowther Shales** (Wrae, Glencotho, Winkston).—Grey and blue micaceous shales with conglomerates and limestones. Trilobites, brachiopods, cephalopods, &c. Volcanic rocks—felsitic lavas and tuffs (Wrae, Glencotho, Hamilton Hill, Winkston). Thickness about 800 feet. Black shales and flinty bands with Lower Hartfell graptolites (40 feet) passing laterally into greywackes and shales and calcareous conglomerates with Lower Caradoc fossils. Brachiopods, trilobites (Wallace's Cast, Dunterclough, Kilbucho). Local unconformabilities in the districts of Channelkirk, Leadhills, Crawfordjohn, Sanquhar, and Shinnel Water. Volcanic rocks in lowest beds (Sanquhar district). Thickness about 1000 feet.	**Ardmillan Series.** Drummuck Group (Green Mudstones).—*Palæaster, Dicellograptus anceps, Trinucleus seticornis.* 400 feet. Barren Flagstone Group.—*Diplograptus truncatus, Nematolites Grayi.* Thickness, 800 feet. Whitehouse Group.—*Dicellograptus complanatus, Pleurograptus linearis, Diplograptus*, trilobites. Thickness, 300 feet. Ardwell Group.—Flagstones and shales. *Climacograptus caudatus, Dicranograptus ramosus.* Thickness, 1,200 feet. Balclatchie Group.—Mudstones, grits, and conglomerates. *Glossograptus Hincksi, Climacograptus bicornis.* Trilobites, brachiopods, &c., abundant. Thickness, 100 feet.	
	Glenkiln Shale Series.		Area S. of the Stinchar Valley.	Area N. of the Stinchar Valley. **Barr Series.**
	4. Thin black shales underlying *Climacograptus Wilsoni*-zone. *Dicranograptus zic-zac, Climacograptus calatus* var. *antiquus, C. peltifer, Lasiograptus binucronatus.* Thickness about 2 feet.	Black shales with cherty bands (8 to 12 feet). *Didymograptus superstes, Cænograptus gracilis, Lasiograptus binucronatus, Dicranograptus zic-zac, Dicellograptus divaricatus.*	4. Boulder conglomerate (Glenapp, Corsewall). Approximate thickness, 500 feet.	4. Benan conglomerate, about 500 feet thick.
Llandeilo.	3. Orange coloured mudstones, radiolarian cherts, and fine volcanic tuffs. Thickness at Dobb's Linn, 4 feet.	Black shales pass towards the north and west into grits, greywackes, and shales. Approximate thickness, 900-1200 feet.	3. Unfossiliferous mudstones and grits ("Tappins group"). Thickness about 500 feet.	3. Graptolitic mudstones. *Didymograptus superstes.* Thickness, 30 feet.
	2. Glenkiln Shales.—Black shales with cherty ribs. *Cænograptus gracilis, Didymograptus superstes.* Thickness, 8-12 feet.	Volcanic rocks are associated with the passage beds between the Llandeilo and Caradoc divisions in the Sanquhar district.	2. Fossiliferous mudstones, *Didymograptus superstes, Cænograptus, Dendrograptus*, 6 feet thick (Portandea).	2. Stinchar Limestone group, 60 feet thick.
	1. Radiolarian cherts, mudstones, and volcanic tuffs.	Radiolarian cherts and mudstones.	1. Mudstones and radiolarian cherts, passing conformably downwards into Arenig cherts and volcanic rocks.	1. Kirkland group, sandstones and conglomerates, *Orthis confinis* beds, 240 feet thick. Local unconformability.
Arenig.	Radiolarian cherts and mudstones with volcanic tuffs (Castle-Douglas district, &c.). Thickness about 150-200 feet at Trowdale, Castle-Douglas (Arenig and Lower Llandeilo cherts, &c.). Base not seen.	3. Radiolarian cherts. Thickness, 70 feet (Arenig and Lower Llandeilo cherts). 2. Mudstones with thin dark seams. *Obolella, Lingulella, Tetragraptus, Caryocaris Wrighti.* Thickness, 4 feet. 1. Volcanic series, comprising lavas, tuffs, agglomerates, and intrusive igneous rocks. Approximate thickness about 500 feet (Sanquhar). Base not seen.	Radiolarian cherts, mudstones, and volcanic tuffs. About 70 feet thick (Arenig and Lower Llandeilo cherts). Bennane Head black shales (*Tetragraptus bryonoides*) interleaved with volcanic agglomerate, 3-4 feet. Volcanic rocks, lavas, and tuffs, with fossiliferous intercalations yielding Middle Arenig graptolites. Approximate thickness, 1500 feet. Base not seen.	

(Table 3) Lower Silurian — general description