To M. Studer 21

with the Authors Compliments

ON THE

PHYSICAL STRUCTURE AND SUCCESSION

OF SOME OF THE

LOWER PALÆOZOIC ROCKS

OF

NORTH WALES AND PART OF SHROPSHIRE.

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WITH NOTES ON THE FOSSILS,

By J. W. SALTER, Esq., F.G.S.

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The Sections to which this notice refers are on a scale of 6 inches to a mile, vertically and horizontally. Section No. 1 passes from Mochras Island in Cardigan Bay, over Cader Idris, Radnor Forest, and Hanter Hill, to the Old Red Sandstone near Fern Hall, south of Kington, Herefordshire. It is about 65 miles in length.

No. 2 commencing at Llanfair-is-gaer, Menai Straits, passes over Snowdon, Moel-wyn, Gors-goch (near Trawsfynydd), Aran Mowddwy, and Newtown, Montgomeryshire, and the Upper Silurian rocks and Old Red Sandstone of Clun Forest, Wigmore Valley, &c., near Ludlow. It is 90 miles in length.

No. 3 passes across the Shelve and Longmynd country to the Brown Clee Hills*. These Sections were constructed by Messrs. Aveline, Selwyn, Bristow, and Ramsay; and the mapping of the county to which they refer was executed by them and Mr. Jukes.

Sections Nos. 1 *&* 2.—The oldest rocks crossed by Sections Nos. 1 & 2 lie at the base of the Merioneth anticlinal of Professor Sedgwick. They are the Barmouth and Harlech sandstones, which are here and there interstratified with beds of purple slate. Their base is not exposed, and the lowest beds that rise in the centre of the area are from 6000 to 7000 feet beneath the base of the Lingula flags. In places they are pierced by numerous greenstone dykes, a few of which are magnetic. No fossils have heretofore been found in them. These and their equivalents are the rocks coloured as "Cambrian" by the Geological Survey.

In Section No. 1 the whole of the black and ferruginous slaty and sandy beds that lie between the Barmouth sandstones and the volcanic ash on the north slopes of Cader Idris belong to the Lingula flags. They are about 7000 feet thick. Here and there, both in the line of section and in the neighbouring areas, masses of greenstone are protruded among them. These generally have a tendency to pass into the lines of bedding, but not unfrequently they cut somewhat across the strike, and divaricate into two or more branches. They are therefore known to be intrusive.

The slaty Lingula flags are succeeded in the ascending station by about 3000 feet of felspathic and calcareous ashes, here and there interstratified with bands of slate, indicating the successive accumulation of the ashy beds with periods of intermittent repose. They are often conglomeratic and brecciated, and sometimes give the impression that bombs have been shot from the volcano into the air, and fallen among the felspathic dust in a viscous condition. Much of the ash is also porphyritic. The crystals of felspar are always scattered and frequently fragmentary, and may have been showered out along with the volcanic dust and lapilli in the same manner that corresponding phænomena occur at the present day, it being known that the ashes of existing volcanos are often composed, in great part, of fragmentary crystals. It is said that perfect crystals of augite have been ejected in showers of ashes from Etna.

Two large masses of intrusive felspathic traps lie between the out-

* The corresponding Horizontal Sections of the Geological Survey are sheets 26 & 27 for Section No. 1; sheets 28, 29, & 30 for No. 2; and sheets 35 & 36 for No. 3.

crop of these ashes and the estuary of the Mawddach. The higher part of Cader Idris is composed of two masses of felspathic trap, between which there lie various interstratifications of slate, greenstone, and felspathic ashes. Where the section crosses the mountain, the lower felspathic trap lies on the north side of the cliff, and the other to the south-east of Llyn-Cae on the slope towards Tal-y-llyn. The slaty beds are hardened at the points of junction, and, though the traps appear to be perfectly interbedded, yet they are certainly intrusive, seeing that, though here separated from each other by about 2000 feet of rocks, they coalesce at short distances both on the N.E. and S.W. The same holds true of the greenstones.

The Bala and Llandeilo beds overlie these rocks, passing across the country south-east, in a series of rapid contortions, to the neighbourhood of Llanbrynmair, where the Caradoc sandstone comes in in a small trough, which is the equivalent of the first larger undulating trough of Caradoc sandstone in the country east of Aran Mowddwy, as shown in Section No. 2. The Bala beds are repeated on the east of the Llanbrynmair trough, and are again capped by Caradoc sandstone on the west slopes of Pegwns-fawr; beyond which, as far as the neighbourhood of Radnor Forest, the Caradoc sandstone, with troughs of Wenlock shale, is spread across the country in numerous anticlinal and synclinal axes. These troughs are all laid down on the Survey maps. In the area between Cader Idris and Llanbrynmair no fossils have been discovered. The author found a few Graptolites in equivalent slates near Machynlleth, and further south, at the Devil's Bridge, the Bala fossils found by Professor Sedgwick are well known.

The Cader Idris traps are continuous with those of Aran Mowddwy; and in that direction, after the two felspathic bands of Cader Idris join, it continues on one geological horizon to the northwards perfectly interstratified with the aqueous rocks of the country. The slates that underlie it at the Arans are porcelanized, and those that overlie it are unaltered; whence it is believed that the intruded rocks of Cader Idris pass northwards into what was once a true contemporaneous felspathic lava-flow. The Bala beds succeed the trap of the Arans. The Bala limestone is about 6000 feet above the trap, and between the limestone and the Caradoc sandstone on the east there are about 8000 feet of slaty beds, mingled with occasional sandstones. East of the Arans, therefore, the whole Bala or Llandeilo series seems to be about 14,000 feet thick. The Caradoc sandstone that overlies it is not less than 5000 feet thick. It seems to rest conformably on the Bala beds. This gives in thickness for all the rocks above described :—

Cambrian	6,000
Lingula and Bala beds, with igneous rocks interstratified	26,000
Caradoc Sandstone	5,000
	42,000 feet of

rocks seemingly deposited conformably on each other, the whole having been at later periods contorted and faulted together.

The ashes below the Aran traps are the equivalents of those of

Cader Idris. The Lingula beds lie underneath them between Aran Mowddwy and the Dolgelli and Bala road. They dip easterly at angles of from 50° to 60°. The section is unbroken, and the total thickness of these flags exposed is rather more than 6000 feet. They are cut off by a great fault, which passes from the borders of the Coal-measures, about six miles south-west of Chester, by Corwen and Bala lake, through Tal-y-llyn to Cardigan Bay. It appears to be covered up by the New Red Sandstone near Chester. From thence to the point where it enters the sea, the line is about sixty-five miles in length. It is invariably a downthrow on the *north-west*. On that side of the fault in the Bala country, Bala beds, traps, ashes, and Lingula beds are repeated in the same order in which they occur on the flanks of Aran Mowddwy. This constancy in the section proves the fault. From measured thicknesses, on Careg-llysog the top of the Aran trap must be thrown down to the level of the road, and the amount of the throw cannot be less than about 12,000 feet. The Barmouth sandstones must lie about 1000 feet beneath the surface at the Bala road. The supposed angles of the fault would scarcely affect these figures*.

Beyond the western outcrop of the ash-beds of Y-Dduallt, the Lingula flags crop out and undulate towards Gors-goch, near Trawsfynydd. Here and there they are pierced by masses and dykes of grey greenstone, often very felspathic. Near Trawsfynydd they abut against the Barmouth and Harlech sandstones. This fault cannot be less than 4000 feet. Near Trawsfynydd is the apex of the Merioneth anticlinal. Beyond that point towards Moel-wyn the rocks dip to the north-west. The boundary of the Barmouth and Harlech sandstones and the Lingula beds runs near the Tan-y-bwlch and Trawsfynydd road. The sandstones are succeeded by about 8000 feet of Lingula flags, if under this name we include the 3000 feet of flaggy mottled rocks that lie between the Ffestiniog syenite and Moel-wyn. These mottled rocks, however, on the south-west frequently pass into ash, and on the north-west by Manod-Mawr into sandstones and slates. The Ffestiniog syenite alters the rocks all around, in this respect being readily distinguishable from the contemporaneous felspathic traps which only alter the slates that *underlie* them. Above the mottled rocks there are beds of ash, conglomerate, felspathic slaggy-looking traps, and slates, all regularly interstratified.

On the south-east flank of Moel-wyn there are, in ascending order, first—350 feet of solid felspathic trap, then 120 feet of ashy conglomerate, then 130 feet of slate, which is succeeded by 180 feet of ashes. The ash is followed by 125 feet of slate, over which lies nearly 900 feet of slaggy felspathic trap, in some places columnar. The slates beneath these traps are altered by heat; those above are unchanged. This series occupies *the same general geological horizon* with the traps of Aran Mowddwy and the Arenigs†. Where unbroken by faults, they may be traced, as a mass, continuously about the top of the Lingula flags, circling round with the Merioneth anticlinal.

* See Horizontal Sections of the Geological Survey, sheet 29.
† See Horizontal Sections of the Geological Survey, sheet 28.

The succession in all the sections is the same, and the thicknesses nearly approximate to each other. The slates of the Ffestiniog slate-quarries succeed them. They lie in the lowest part of the Bala beds in their regular order of succession. The rocks at Tai-hirion, on the Bala road, near Arenig-bach, which contain *Trilobites* and *Lingulæ* (see Mr. Salter's note on the fossils, *infra*), are their equivalents. These *underlie* a set of ashy beds that form Arenig-bach and part of the country on the north that passes by Cerrig-y-lladron to the valley of Penmachno. An upper portion of this igneous series, therefore, belongs to the base of the Bala beds.

North-west of Moel-wyn, and in the country generally overlying the Ffestiniog felspathic traps towards Llyn Gwynant, numerous lines of greenstone occur. Like the same kind of intrusive rocks near Dolgelli, they are apt to run in the lines of bedding, but they also cut more or less across the strike.

No truly interstratified or contemporaneous traps occur between Moel-wyn and the Snowdon felspathic trap, which is 6000 feet by measurement *above* those of Moel-wyn and the other igneous rocks of the date of those of the Arans. All of these have heretofore been considered as belonging to one igneous group. The above thickness can be well measured on section No. 2. Notwithstanding the intruded lines of greenstones, the dip is steadily north-west as far as Castell and Yr-Arddu, which hills are capped by outliers of the Snowdon trap. The Castell trap lies in a synclinal of the Bala beds. The fault on the west, which repeats this trap, gives about 4300 feet of downthrow. The rock so repeated forms part of the great mass of the Snowdon trap, which from thence undulates westward in a great trough of about five miles in width*. It is about 1300 feet thick on the east side of Snowdon, but westward it splits into three thin bands of slate separating the masses. Above it lies about 1000 feet of calcareous, sandy, and felspathic ashes, largely intermingled with slaty sediment. Sometimes one element predominates, sometimes another: on the whole, the slaty and calcareous elements prevail. When this is the case, the rock is frequently fossiliferous. The fossils are those of the Bala limestone. Its position also proves that it is the equivalent of these beds; a conclusion long since arrived at by the Officers of the Geological Survey, first on physical, and afterwards on palæontological grounds. The traps and fossiliferous ashy beds of Snowdon and the true Bala limestone are each, therefore, about 6000 feet above the lower igneous series of Moel-wyn and the Arans†. The physical and palæontological evidence are thus in perfect accordance.

On the ridges of Crib-goch and Llewedd (parts of Snowdon), on Glyder fawr, and on Moel Hebog, near Beddgelert, there are eight small patches of another mass of columnar felspathic rock, that must once have entirely *overlaid* the ash. It may have been as large as the whole mass of the Snowdon trap that underlies it.

* This trough has been noticed by Prof. Sedgwick (Quart. Journ. Geol. Soc. vol. iii. p. 138).

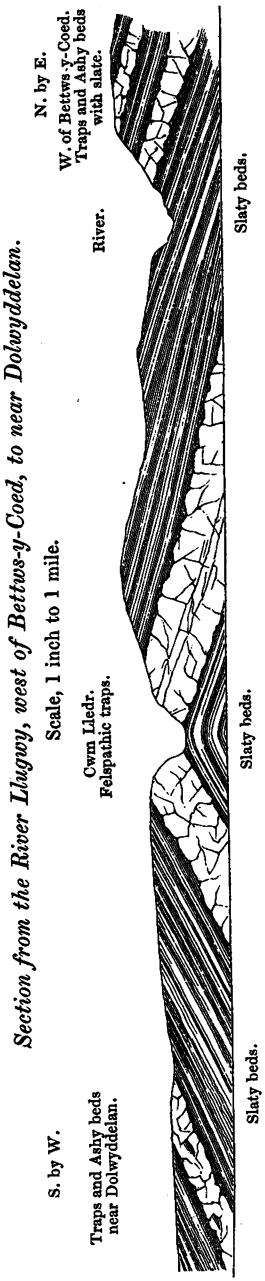
† Horizontal Sections Geol. Survey, sheets 28 & 29.

The Snowdon igneous rocks can be followed to Carnedd Dafyd, where certain lower beds of trap come in, interstratified with bands of fossiliferous slates and sandstones; these also form parts of Carnedd Llewelyn. Most of these rocks may be traced from Carnedd Llewelyn to Nantfrancon, on the sides of the steep hill west of Llyn Ogwen called Braich-du. There they dip easterly at a high angle, and rise again with a westerly dip in the great peak of Y-Tryfan. From thence they roll over in a large anticlinal and form the heights of Gallt-y-gogo, on the south side of the Bangor road, within two miles of Capel-Curig. The two bands of slate that separate the igneous mass into three, cease in the valley of the Llugwy, and the trap becomes one thick band. This great band of felspathic trap can then be traced by Ffynnon Llugwy and Llyn Dulyn almost to Conway. It is broken here and there by faults. Its dip is invariably easterly. Above it, on the east, are beds of sandstone, slate, and felspathic traps and ashes. The sandstones, especially, are often fossiliferous, and contain the fossils common to Snowdon and Bala. These, with igneous interstratifications, extend with many contortions to the vale of the Conway. Their finest development lies between Ffynnon Llugwy and Llanrwst, around Llyn Cwlyd, Llyn Crafnant, and Llyn Geirionydd. Their position above the rocks of Y-Tryfan and Carnedd Llewelyn proves them to be the equivalents of the Snowdon traps and ashes, and their fossils are also the same. The calcareo-felspathic quality of some of the ashy beds nearly resembles some of the rocks of Snowdon and Y-Glyder-fawr. The slates and traps of Glyn Lledr (two miles south-west of Bettws-y-Coed) dip under the rocks that lie between Ffynnon Llugwy and Llanrwst. The Glyn Lledr rocks also dip under those in the Dolwyddelan Valley.

A reference to the published maps of the Geological Survey shows that the Snowdon trap bounds Nant Gwynant on the east. Together with the slates that immediately underlie it, it dips westerly,

Section from the River Llugwy, west of Bettws-y-Coed, to near Dolwyddelan.

Scale, 1 inch to 1 mile.



and, the whole rolling over in an anticlinal, the same traps and ashes are thrown across to Y-Foel-goch at the upper end of the Valley of Dolwyddelan*. Hence the highly calcareous ashes of that valley (almost a limestone in some places) are the precise equivalents of the Snowdon rock of the same kind, and also of the ashy beds towards Llanrwst; and all of these are, in parts, the equivalents of the Bala limestone and of the rocks immediately associated therewith. South-east of Bettws-y-Coed this limestone in its normal state actually appears, and, together with a thin associated bed of trap, it seems to bear the same relation, as regards superposition, to the Glyn Lledr traps, that the traps and ashes of Dolwyddelan and the neighbourhood of Llanrwst bear to the same rocks. There is, therefore, no doubt that the uppermost Snowdon rocks are represented by the limestone and its immediately associated strata, and the two extremely thin ashy beds that lie at some distance beneath it in the Bala country are all that remain to represent the thick igneous masses that spread across Caernarvonshire from Moel Hebog to Conway and Llanrwst, and which Section No. 2† proves to be about 6000 feet above the igneous rocks of Moel-wyn, just as the Bala limestone lies about 6000 feet above the *equivalents* of Moel-wyn,—viz. the igneous masses of Arenig and the Arans.

To return to the rocks that lie between Snowdon and the Menai Strait‡. On the sides of the Pass of Llanberis and of Nant-Francon, dark blue slates dip under the traps at angles of from 70° to 80°. Towards their base, sandstones and ferruginous slates occur, in which, at Marchlyn Mawr, I found *Olenus micrurus* and *Lingula Davisii*. These are the Lingula beds. The rocks that lie betwixt them and the Snowdon trap are therefore the representatives of the Bala beds that lie beneath the Bala limestone. No fossils have been found in them, neither does there appear in these sections any trace of the great igneous interstratifications of the Arans, the Arenigs, and Moel-wyns§. These have, therefore, entirely thinned out under the great Snowdon trough. As already stated, they dip northerly at Moel-wyn and the Manods, underneath 6000 feet of the lower Bala beds. Then the Snowdon trap and ashes come on, dipping to the north-west. They rise again in the Pass of Llanberis, but the igneous masses that *underlie* the Bala beds in the meanwhile *have entirely thinned away underground*; and this ~~impossibility of tracing the beds~~ erroneously is the reason why it has been heretofore supposed that the Snowdon traps were the equivalents of those of the Arans and of Cader Idris. The whole of the stratified series is much thinner on the Llanberis side of the trough than on the side of their outcrop towards Harlech and Ffestiniog. The Lingula flags, especially, are probably not of half the thickness; their upper limit, however, is uncertain.

From beneath the Lingula beds, both at Nant-Francon and Llanberis, sandstones crop out, which, it is well known, are the equivalents of the Barmouth and Harlech grits of Professor Sedgwick.

* Geological Map 75 N.E.
† Sheet 28 of the Horizontal Sections of the Geological Survey of Great Britain.
‡ Maps 78 S.E. and S.W.
§ Moel-wyn is in Map 75 N.E.

Here, however, they are largely interstratified with purple slates. They are in places much contorted, and, on this account, the thickness of slaty beds, as wrought in the quarries, appears much larger than in reality it would do, but for the repetition of the same beds by contortion. But little more than 2000 feet of these rocks rise to the surface by the sides of the Lake of Llanberis, whereas more than 6000 appear in Merionethshire.

The slates, I believe, are the equivalents of some of the sandy beds of Merionethshire. The sandy sediment has passed into mud, or *vice versâ*,—a phænomenon found to be of constant occurrence when we take in detail the strata of the Caernarvonshire development of these rocks, where slates, sandstones, and conglomerates in many places pass rapidly into each other. The interstratified sandstones and conglomerates are sometimes singularly inconstant. Most of them, even some of the more slaty conglomerates, are highly cleaved, and the pebbles are elongated in the lines of cleavage,—a circumstance remarked by Mr. D. Sharpe in regard to some of the rocks of Cumberland. Some of the conglomerates of Llanberis, in this the most ancient of the Welsh formations, contain pebbles of quartz, quartz-rock, felspathic trap, and quartz-porphyry, purple slate, black slate, red jasper, &c. They lie among the lowest exposed beds on the banks of Llyn Padarn, and the inference is undeniable that this conglomerate has been formed from the waste of a set of beds that formed some old land in many respects similar to Wales of the present day. The pebbles of purple slate resemble those of the very strata amid which they are found. The quartz-rock and jaspers resemble some of the metamorphic rocks of Anglesea, which metamorphism, it will be shown, probably took place subsequent to the deposition of this conglomerate; and the black slates and felspathic traps and porphyries are indistinguishable from those that occur about the base of the Bala beds in the district of Cader Idris, the Arans, the Arenigs, and Moel-wyn; or of the higher Bala beds in the heights of Snowdon, Carnedd Dafyd, and Moel Hebog*. In many of the pebbles of this old conglomerate there is no appearance of metamorphism, in the extreme sense of the term, as applied to foliated rocks; in others metamorphism may have occurred.

In a large sense of the term, I know of no *formation* in England or Wales of older date than these Cambrian slates, sandstones, and conglomerates; and the facts above described therefore, more than in any other case with which I am acquainted, prove that the same kind of slates, purple and black, of porphyries, and of metamorphic rocks formed some land of which we should have had no knowledge were it not that its former existence is revealed in the structure of these conglomerates. The oldest formation now known in Wales, therefore, does not represent the beginning of those phænomena of ordinary deposition, of ordinary volcanic action, and of metamorphism, which last in this, and in other parts of Europe is characteristic of many epochs in time as ~~high~~ late at least as the Eocene rocks

* There can be no mistake about the position of these conglomerates. They distinctly underlie the whole of the workable beds of purple Cambrian slate.

of the Alps. We can find no beginning to the existing order of physical phænomena.

To the west of the intruded porphyry that ranges from Llanllyfni to St. Ann's Chapel, near the Penrhyn quarries, a fault, that runs from Aber to Dinlle, again throws in the Lingula beds and probably the lower part of the Bala series. The down-throw varies in amount from 2000 to 6000 feet*. East and south of Bangor the greenish sandstones and green and purple slates again crop out from beneath the Lingula shale. They are much altered by the intrusion of an igneous rock which runs from Bangor to Caernarvon. It is composed of quartz and felspar, sometimes well crystallized. Such rocks have been sometimes termed "Granitella." By the addition of mica this rock at Caernarvon would become a perfect granite. This rock is also cut off by a downcast fault on the north-west, by means of which the Carboniferous Limestone and part of the Coal-Measures abut on the trap. A conglomerate forms part of these Carboniferous rocks, seemingly formed from the waste of the traps and palæozoic rocks of the neighbourhood. Some of the pebbles are much altered. Such metamorphism as the older palæozoic rocks had undergone took place, therefore, before the Carboniferous period. The base of the Lingula shales, which at Bangor lies on altered chloritic green and purple sandstones and slates, strikes across the Menai Straits, a little west of Beaumaris, where they lie on chloritic schists and sandstones still more metamorphosed. It is believed that all the rocks of Anglesea coloured light pink on the Survey Maps belong to the same series as the Barmouth and Harlech grits, and the Llanberis and Penrhyn green and purple sandstones and slates, but, the rocks being generally much metamorphosed, the colouring on the map is changed to express such an alteration. At Bangor the same beds graduate by alteration into rocks of the Anglesea type, and the typical Cambrian colour is shaded on the map into that which expresses Metamorphic Cambrian. The dark blue shales and grey sandstones and conglomerates of Anglesea, coloured pink on the map, represent Lingula beds and part of the Bala or Llandeilo rocks. Near Amlwch two masses of granite are intruded among them, and the strata surrounding them have been changed into mica-schist and gneiss. A patch of Old Red Sandstone on the coast opposite Ynys-dulas rests unconformably on these altered rocks. *It has been formed by their waste and by that of the intruded granite.* The date of the metamorphism was therefore prior to the deposition of the Old Red Sandstone, and the country had also at that time been already much denuded to admit of an originally deep-seated granite being exposed to the wasting action of water at the surface. The metamorphic rocks on the north-west side of the great Caernarvonshire promontory are believed to be the equivalents of the same species of rocks in Anglesea, and of the Barmouth and Harlech grits, &c. The strike of the latter beds near Clynnog-fawr would lead to the inference that the Porth-dinlleyn metamorphic beds are the equivalents of the Llanllyfni purple slates, and of the highly altered sandstones of Glynllifon. Half-way between

* See Geological Survey Maps, 78 S.E. & S.W.

these points the slates of Trwyn-y-tâl on the coast dip southerly. They contain pisolitic iron-ore, and belong to that part of the Lingula flags in which the pisolitic iron-ore of Llyn Cwellyn (above the road from Caernarvon to Beddgelert) occurs. Iron-ore, probably on the same parallel, again crops out in the black shales between St. Tudwall's Road and Hell's Mouth. They dip northerly, and the rocks, therefore, that occupy the midst of the promontory, lie in a trough, and belong to part of the Bala series. The fossils of the district confirm this idea. Wherever any junction of these beds and of the metamorphic schists is exposed, they are always found to be brought against each other by faults. Greenstones, felspathic porphyries, and syenites are intruded in great bosses amid the above-mentioned strata.

Recapitulation.—Such is a brief outline of the disposition and structure of the rocks of North Wales that lie beneath the Caradoc Sandstone. I shall briefly recapitulate the sequence. The lowest rocks are the Barmouth and Harlech grits, or their sandy and slaty equivalents of Llanberis and Penrhyn, which are also the equivalents of the main masses of metamorphic strata of Anglesea and the north horn of Cardigan Bay. Their greatest known thickness is about 6500 feet. Then come the Lingula beds, about 7000 feet in thickness. Both of these are pierced by greenstone dykes, and by bosses of intrusive greenstone, syenites, and felspathic traps. Toward the close of the Lingula flag depositions volcanic outbursts took place, in consequence of which great ashy deposits were formed interstratified with ordinary muddy sediment, and here and there associated with thick beds of felspathic lava. It has been stated that these rocks forming the Arans and the Arenigs are on different horizons. This has not been found to be the case. They are all on the same horizon and merely repeated by faults. Numerous greenstones are associated with them, especially among the ashes. Although these often run in the lines of bedding for a space, yet they frequently break suddenly across the strike, and are therefore intrusive. Much of the ash seems to have been subaërial. Islands, like Graham Island, may have sometimes raised their craters for various periods above the water, and by the waste of such islands some of the ashy matter became water-worn,—whence the ashy conglomerates. Viscous matter seems also to have been shot into the air, as volcanic bombs, which fell among the dust and broken crystals (that often form the ashes) before perfect cooling and consolidation had taken place. The volcanic activity ceased for a time, during which 6000 feet of the ower Bala beds were accumulated. It then broke out afresh in a new area, further north, and the volcanic rocks of Moel Hebog, Snowdon, Carnedd Llewellyn, Conway, &c., were produced. Numerous lines of intrusive greenstone occur in the slates that lie between these two great igneous series. They often run in the line of strike, but they also sometimes cut across it and branch into two. The rocks also both below and above are altered, which is never the case with the slates that rest on the contemporaneous felspathic lavas. The great centre of this later volcanic outburst was in the Snowdonian range.

The faintest traces of its ashes are associated with and underlie the Bala limestone in the Bala country. The great centre of the older volcano or volcanos was further to the south-east.

Now it is worthy of remark, that the great bosses and lines of intruded felspar- and quartz-porphyries, greenstones, and syenites are always found in rocks as old as or older than the rocks with which the ashes and lava-flows are associated. My belief, therefore, is that they form the original deep-seated nuclei that were connected underground with the volcanic rocks that in this neighbourhood are interstratified with the Lingula and Bala beds. Further, that the long lines of greenstone that are associated with the rocks lying between Snowdon and Moel-wyn bear the same relation to the Snowdon volcanic series that similar greenstones do at a lower level to the volcanic series of the Arenigs and Arans; and that, instead of being contemporaneous, as implied by Professor Sedgwick, they merely originated in melted matter, being injected and burrowing into lines of weakness deep underground during two periods of volcanic activity, and that both they and the greater masses of intrusive porphyry and syenite have all been subjected to those subsequent forces that bent and contorted the whole of the ancient palæozoic rocks. From an examination of many sections, I have no doubt that the greater intrusive nuclei partially partake of these contortions, because in the upward progress of the melted matter towards the volcanic mouths it sometimes was more or less injected in great sheets somewhat in the lines of bedding, while sometimes it broke across the beds with comparative abruptness. When in sheets, there is no reason why it should not have been equally bent with the thick masses of truly interstratified porphyries. They are certainly affected by faults in the same manner as the strata, and if so, they can in no sense be looked upon as the cause of the great disturbances that contorted and faulted the country. These were of later date.

I have said that the intrusive traps are of the same general dates with the interstratified igneous rocks. The mass that runs from St. Ann's Chapel to Llanllyfni is a quartz-porphyry. Crystals of quartz are imbedded in a felspathic base. The neighbouring mass, nearer the Menai, often much resembles it, but is also much more granitic in texture. The Anglesea granite often quite resembles the Menai igneous rock, and sometimes by addition of mica becomes a true granite. There is no reason why they should be referred to different dates, and, if the previous conclusions be correct, then the granite is of Lower Silurian date, and the metamorphism of at least part of the Anglesea rocks took place at one of the previously mentioned periods of volcanic activity, and probably at a depth of not more than from 8000 to 10,000 feet beneath the surface*. As the granitic rocks of Anglesea and the Menai break out at many places and at many different levels, there is reason to conclude that the island generally is underlaid by a great mass of granite; and, if this be so, then it may be probable that all the altered rocks of Anglesea were principally

* The Lingula flags and superincumbent Bala beds thin out considerably between Bala and the Menai.

metamorphosed during the Lower Silurian period. The foliation of the Anglesea rocks is probably a result of this metamorphism, and this may account for the fact that this foliation lies not altogether, but exceedingly frequently, in or approximately in the direction of the lines of bedding; for it must be recollected that the principal cleavage of the Silurian and Cambrian strata of Wales took place at a period long subsequent to the date of the volcanic and supposed metamorphic phænomena. The whole of the strata that have heretofore been mentioned in this memoir, and also the igneous, were bent and distorted before the great cleavage of the country began; but the foliation of the rocks of Anglesea was of prior date*.

It is not intended to be implied in the above remarks that foliation in all cases generally follows the planes of bedding, but only that, if the rocks be uncleaved when metamorphism takes place, the foliation planes will be apt to coincide with those of bedding; but, if intense cleavage has occurred, then it may be expected that the planes of foliation will lie in the planes of cleavage†.

Section No. 3. *The Longmynd district.*—It is foreign to my present purpose to enter on descriptions of the Berwyns. It has been already shown by Professor Sedgwick, and confirmed by the Officers of the Geological Survey, that the Berwyn rocks partly represent the Bala Series. I may now add, that it seems possible to trace the evidences of both the igneous series of Merionethshire and Caernarvonshire in these rocks. Neither shall I enter on any description of the Caradoc sandstone and Wenlock and Ludlow rocks that run from the neighbourhood of Conway to the country south-west of Builth. The Builth rocks and those of the Shelve country, associated with igneous rocks, are well known, from the descriptions of Sir Roderick Murchison and other authors, to form part of the Llandeilo or Bala group, and there can be no doubt that the Longmynd rocks bear the same relation to the lowest black slates below the Stiper Stones, that the Barmouth and Harlech grits do to the Lingula flags of Merionethshire. One important result, however, has arisen in the construction of the sections across the Longmynds by Mr. Aveline,—I allude to the thickness of the strata.

Between the Church-Stretton valley and the country from half a

* There is no doubt that in many cases the foliation of the Anglesea rocks runs much across the dip of the strata. The author hopes to enter on the subject more at large in a subsequent communication.

† See Ramsay's Geology of Arran, 1841, pp. 88 and 89, where foliation is described as having taken place approximately in the planes of bedding. The word "foliation," not having been then invented, is not used, but the phænomenon is described. In 1846 Mr. Darwin, in his 'Geology of South America,' takes notice of the probability of foliation being found in the general direction of the planes of bedding and oblique lamination, and minutely and ably describes the passage of cleavage into foliation. His remarks on this subject form a perfect model of the true mode of investigating the subject.

It is worthy of remark, that the foliation of the schists of Arran took place previously to the deposition of the Old Red Sandstone. The Grampian rocks were also altered before that date, for the Old Red Sandstone contains pebbles of the altered rocks. May it not be that the granites and syenites of these districts are of the same age as those of Wales, viz. of Lower Silurian date?

mile to a mile east of the Stiper Stones lies the hilly tract of the Longmynds*, long ago referred by Sir Roderick Murchison to the Cambrian strata. The Geological Survey has adhered to this nomenclature. No fossils have been found in these rocks. The main mass of the rocks constitute a block of country about 8 or 9 miles long by about $5\frac{1}{2}$ miles wide. A long spur of the same rocks protrudes from the principal block as far as the ancient camp four miles N.E. of Shrewsbury. It is nearly continuous, and about eleven miles long. Between Le Botwood, Shrewsbury, and the Camp it is partly overlaid by the Coal-measures, partly by the Lower New Red Sandstone. On the south the Wenlock shale overlies it unconformably, and on the west it is overlaid conformably by the black Silurian shales that underlie the Stiper Stones. On the east it is bounded by a great N.E. and S.W. fault that runs from the New Red Sandstone near Uppington ($7\frac{1}{2}$ miles E.S.E. of Shrewsbury) to the neighbourhood of Gladestry between Builth and Kington. The fault extends about 45 miles. South of Church-Stretton the throw is about 2000 feet. West of the fault the rocks of the Longmynd country generally dip W.N.W. at angles varying between 50° and 80°. Contortions are few, and there is no positive appearance of a complete doubling up of any portion of the country with subsequent denudation of the curve. The entire thickness between the Church-Stretton fault and the western boundary, carefully measured (see the Sections of the Geological Survey, sheets 33 and 36), is about 26,000 feet. The superficial area that these rocks occupy is small; their thickness is as great as or greater than that of any one division of rocks heretofore measured in Britain. The Llandeilo flag-beds with their igneous interstratifications lie on these in perfect conformity, and between the neighbourhood of the Stiper Stones and Chirbury (where the Llandeilo flags are overlaid unconformably by the Wenlock shale) they attain a thickness of about 14,000 feet. The entire thickness of conformable strata between the Church-Stretton fault and the Wenlock shale at Chirbury is 40,000 feet, and on the west we do not reach the top of the Llandeilo beds, because of the unconformity of the Wenlock shale; while on the east we do not reach the base of the Cambrian strata, because they are cut off by the Church-Stretton fault†. The Longmynd rocks are often hardened, brittle, and flinty in appearance, but they are by no means metamorphosed, even at the bottom, in the sense in which the term "metamorphic" may be applied to the rocks of Anglesea. There is nothing gneissic or foliated in their structure. The old Huttonian doctrine, therefore, that rocks may be expected to be metamorphosed in proportion to their age and the depths to which they have been depressed, is not always a safe guide. The lowest rocks near Church-Stretton have been buried at least four times deeper than the Anglesea rocks were, before the deposition of the Wenlock shale, and they are less altered than many of the rocks of Anglesea and Caernarvonshire.

Roughly estimating the increment of heat in proportion to increase

* See Geological Survey Maps, 60 N.E. and S.E., and 59 N.W. and S.W.

† Horizontal Sections of the Geological Survey, sheet 36.

of depth, and supposing the same rule that is now approximated to by physicists obtained when the rocks were formed, the lowest beds of the 40,000 feet thickness would not be heated beyond 700°, unless indeed other Lower Silurian strata, now concealed by the Wenlock shale, still increased the pile.

Various igneous rocks come through in the main fault, or in the minor dislocations that accompany it. They occur near Kington, at Hanter Hill, Old Radnor, and Stanner Rocks; and near Church-Stretton, at Cardington, Caer Caradoc, and the Lawley, and, still further north, at Dryton Bank, Charlton Hill, Brockwardine, and the Wrekin. These traps are altogether of a different date from those of North Wales, Builth, the Breidden Hills, and the Shelve country. All these are of the close of the Lingula flags, or else belong to the age of the Llandeilo or Bala period. But the traps that come through in the great line of the Church-Stretton fault are of the date of that dislocation, viz. at some time after the close of the Silurian period. Near Church-Stretton the Caradoc Sandstone is highly altered by these traps. Near Kington the traps alter Caradoc Sandstone on Old Radnor Hill, and Ludlow rocks near Hanter Hill. The date of the origin of the fault is unknown. It is later than the deposition of the Coal-measures, because they are affected by it. It is also later than the New Red Sandstone, because it runs into that formation. It is probably of various dates, and its present amount may be the result of various throws. The Caradoc Sandstone east of Caer Caradoc is *altered* by the trap. The Wenlock shale which is brought against the west side of Caer Caradoc by the fault is *unaltered*. The downthrow has been increased probably on that side since the melted matter was first injected into the crack. In the Permian rocks, in the neighbourhood of the Forest of Wyre, part of Staffordshire, and round the Abberleys, there is a trappean breccia, many of the fragments of which seem more likely to have been derived from the traps about Church-Stretton, &c. than from any other known rocks. If the conjecture that they have been derived from the waste of these rocks be true, then not only have the traps been injected into a dislocation of older date than the Permian æra, but also denudation has gone on to such an extent, that these originally deep-seated masses have been then exposed at the surface while Permian strata were being deposited. But the fault passes into the Bunter or Upper New Red Sandstone, and this may be on account of a repetition of throw in the old line of dislocation.

There is one other point to notice with regard to the Longmynd country:—in April 1848 Mr. Aveline and myself described in the Journal of the Society two bands that underlie the Wenlock shale where it bounds the Longmynds on the south-east and south. The uppermost is a band of limestone, the lower is a band of conglomerate, then called Caradoc Sandstone, and which is there correctly said to rest "unconformably on the Longmynd Cambrians, in such a manner that it is plain the latter formed an original boundary of the sea of the period." I may now state that we are agreed to modify that part of the opinion there given which unequivocally refers this thin

band of rock to the Caradoc formation. The fossils it contains, as noted by Professor E. Forbes, are mentioned in the Journal of the Society, vol. iv. p. 297–299. They are generally the same as those in a band of limestone that occurs between the Caradoc Sandstone and the Wenlock shale west of Wenlock edge. These fossils have always been considered as characteristically "Caradoc," nevertheless the rock that contains them is physically connected with the Wenlock shale. It is conformable with the Wenlock beds and rests unconformably on the Caradoc Sandstone, and (associated with the Wenlock shale) it entirely overlaps the latter in a distance of less than two miles between Acton Scott and the Longmynds. It was the sandy and pebbly beach of the Wenlock sea; and, just as in the Llandeilo flags at Castell Craig Gwyddon, in Caermarthenshire, and other places, where sandy and pebbly Caradoc-looking beds occur, there is an occurrence of Caradoc Sandstone fossils, so in this coarse littoral development of part of the Wenlock series the life of the Caradoc times seems for a season to have been partially prolonged. The typical Caradoc Sandstone of Shropshire is essentially a sandy deposit, and seems to have been mostly accumulated in shallow water. Under similar conditions, whether in Llandeilo Flag pebble banks or in Wenlock beaches, Caradoc-looking assemblages of fossils may occur. In such cases they form an exceptional development; they are not the rule, for the mass of the Wenlock shale is a deep sea deposit. The Longmynd and Shelve country (Llandeilo) stood above water when it began. They were gradually depressed, and, as the depression progressed, the beach crept inland until the old island was entirely encased and buried under the Wenlock shale. The outlying patches of sandstone, therefore, on the high land near the Bog Mine, Shelve, are part of a Wenlock beach of somewhat later date than the conglomerates and limestones that underlie the Wenlock shale at lower levels on the south of the Longmynd. Scattered pebbles of these rocks (the remains of denudation) strew many parts of the surface of the Shelve country and of the Longmynds.

It must always be borne in mind that the relative height of the Longmynds to the Wenlock sea was very different from that which the rocks on the opposite sides of the fault now maintain to each other. The Church-Stretton fault is a downthrow on the west of at least 2000 feet, and, the fault having taken place at a late geological period, the Longmynds were probably at least 2000 feet higher (as regards the Wenlock rocks, while these were being deposited), than the height they now maintain with reference to that formation. This would materially modify the conditions of deposition, and the Longmynds must have stood out amid the waters as a bold and rocky islet, from the waste of which in part the Wenlock littoral sandstone beds of Shropshire were derived.

Denudation.—The denudation which North Wales and parts of Shropshire have undergone is of vast amount. To describe it fully would itself occupy a long memoir. It is worthy of remark, however, that, as shown in the Shelve and Longmynd country and in the neighbourhood of Builth in Radnorshire (see Sections of the

Geological Survey, sheets 5, 6, and 36), the Cambrian and Llandeilo rocks had suffered immense denudation before the deposition of the Wenlock shale, which rests often nearly at right angles on the upturned edges of the older rocks.

Respecting other and, in great part, later denudations, that of the Merionethshire district is at first sight the most remarkable, and is therefore here mentioned by way of a special example. From the lowest exposed beds of the Cambrian strata to the top of the Snowdon rocks on one side, and to the Bala limestone on the other, there is at least a thickness of 23,000 feet. All this has been removed by denudation, for the sequence of rocks round the Cambrian central axis is perfect and quite conformable; and, for the reason, that, if we could sink deep enough through the Snowdon and Bala rocks, we should certainly arrive at a given depth at the Harlech grits; there can be no doubt that originally these grits were covered by the Lower Silurian strata, that surround them in Merionethshire, on the south, east, and north. Indeed, so far from the rocks that form Snowdon (the Bala beds) being the highest rocks that origmally overlaid the Merionethshire Cambrians, there can be little doubt that the additional 8000 feet of strata that lie above the Bala limestone must also have been once continuous across this space; and the amount of matter removed, and, perhaps, the curves of the strata during the process of denudation, may be deduced from the arrangement of the beds as shown in the published geological sections of this part of North Wales, which have been drawn with much accuracy of detail.

Respecting the amount of matter removed; I believe that the subject should be treated in the same manner that the author has already dealt with the denudation of South Wales and Somersetshire*. This can only be done by the employment of sections on a corresponding vertical and longitudinal scale. Numerous other questions in geological physics will by-and-by be opened out and settled by this style of work,—questions that it is rash to touch upon with data less perfect than such sections afford.

* Memoirs of the Geological Survey of Great Britain, vol. i. p. 297.

NOTES *on the* FOSSILS. By J. W. SALTER, Esq., F.G.S.

The 'Lingula Flags' contain, at Dolgelly, Trawsfynydd, Ffestiniog, and Tremadoc, as stated in the Reports of the Brit. Assoc. 1852 (Trans. Sect. p. 57),

Hymenocaris vermicauda. Olenus micrurus. Lingula Davisii.

The last ranges upwards through a great part of the igneous series.

Near Llanberis and Bangor the *Olenus* and *Lingula* are still found, and with them two fucoids,

Cruziana semiplicata. Chondrites acutangulus?

Fucoids are also said by Prof. Sedgwick to abound at Tremadoc, Ffestiniog, and Dolgelly.

In the black slates at Pont Seiont, Caernarvon, there occur Fragments of Crustacea, and Graptolites (Didymograpsus Murchisonæ?); and at the Bath-house, Bangor, in similar black slates,

Bellerophon perturbatus (Euomphalus, Sil. Syst.), a single specimen.

The higher parts of the igneous series have yielded fossils at two or three points only:—Tai-hirion, Arenig-bach; and four miles N.E. of Dolgelly.

Asaphus Selwynii. Calymene parvifrons. Lingula—probably L. Davisii.

The black slates above the igneous rocks of the Arans and Arenigs, though well-adapted for the preservation of Graptolites, have yielded scarcely any, but in their lowest beds, immediately over the igneous rocks of Arenig-bach, are numerous fossils, first discovered by Professor Ramsay, and exactly like those of Bala, mentioned below.

The Snowdonian slates, as exhibited in the Pass of Nant Francon, are full of fossils—occurring in five or six bands between the beds of ash and felspathic traps; and are all of species common in the Bala limestone, and distinct from those of the Lingula beds below. Prof. Sedgwick has described this great "fossiliferous trough, half a mile wide, which ranges from this point through the highest parts of the Caernarvon chain," and has given some of the fossils.

Calymene Blumenbachii and C. brevicapitata,
Homalonotus bisulcatus,
Lichas laxatus,
Trinucleus concentricus,
Beyrichia complicata,
Tentaculites annulatus,
Strophomena expansa* and S. depressa,
Orthis flabellulum* and O. elegantula,
Leptæna sericea,
Rhynchonella serrata*,
Murchisonia scalaris*,
Turbo crebristria,
Bellerophon ornatus, and B. carinatus?*,
Modiolopsis, 2 or 3 species,
Stenopora fibrosa,

are the prevailing fossils, and all but one are common at Bala.

* These are in great abundance.

The characteristic fossils of the Bala limestone and slates have now been often quoted. Those in the limestone itself are ordinarily distinct from those found in the more sandy strata above and below; but in the more earthy parts of the limestone this distinction is lost: the following may be considered quite characteristic of the group:—

Fossils of the Bala limestones.	*Fossils of the sandstones and ash-beds.*
CRUSTACEA.	
Trinucleus seticornis.*	Trinucleus concentricus.*
Illænus Davisii.	Illænus Bowmanni.
Cybele rugosa.	Asaphus Powisii.*
Encrinurus sexcostatus.	Phacops apiculatus.*
Phacops alifrons, rare.	—— conophthalmus.
Calymene Blumenbachii, rare.	Calymene brevicapitata.*
Lichas laxatus.*	Lichas laxatus.
Cheirurus bimucronatus.*	
—— octolobatus.	
—— clavifrons.	
Ampyx tumidus.*	
Agnostus trinodus.	
Remopleurides radians.	
Cythere, 2 small species.	Beyrichia complicata.*
MOLLUSCA.	
Oncoceras, 2 or 3 species.	
Lituites cornu-arietis.	
Holopea, 2 or 3 species.	Turbo crebristria.*
Murchisonia scalaris.	Murchisonia scalaris.*
Orthis biforata.**	Orthis biforata.*
—— Vespertilio.*	—— Vespertilio.*
—— calligramma (plicata, Sil. Syst.).*	—— calligramma (plicata).*
—— Actoniæ.*	—— flabellulum.*
—— elegantula.*	—— elegantula.*
Leptæna sericea.*	Leptæna sericea.*
—— tenuicincta.	
—— quinquecostata.	
Strophomena tenuistriata.*	Strophomena depressa.
Crania divaricata.	—— orthisoides.
RADIATA.	
Cystideæ—several species.*	
Encrinite stems, abundant.	Glyptocrinus basalis.*
Stenopora fibrosa.*	Stenopora fibrosa.*
Retepora Hisingeri.	Retepora Hisingeri.
Ptilodictya fucoides.	Petraia subduplicata.

The same fossils are repeated, species for species, on the opposite or eastern side of the trough of Caradoc sandstone, at Llanfyllin, Llanwyddyn, Meifod, &c.; and the calcareous bands S. of Llangollen present the same assemblage, with some trifling variations, and with a larger proportion of corals.

The fossils of the Hirnant or Upper Bala limestone have been enu-

* The abundant species are indicated by asterisks.

merated by Prof. M'Coy; they are few in number and peculiar. The slates that occur at the top of the Bala rocks in the neighbourhood of Llanfyllin and Meifod contain several species identical with those of Bala, but their fossil contents are not yet fully worked out. There are many Upper Silurian species, as already stated by Prof. Sedgwick, and occasionally *Pentamerus oblongus*.

Lastly, the Caradoc sandstone of Denbighshire, taken at three localities not far from Llanrwst, presents the following fossils:—

Calymene Blumenbachii.
Phacops caudatus.
—— Downingiæ.
Beyrichia tuberculata.
Holopella gregaria.
Mytilus unguiculatus.
Clidophorus ovalis.
Nucula levata?
Leptæna sericea.
—— transversalis.
Orthis elegantula.
—— virgata?
Strophomena compressa.
—— depressa.
Atrypa reticularis.
Rhynchonella nucula.
—— borealis?
Chonetes sarcinulata.
Spirifer plicatellus.
—— elevatus.
Arca Edmondiiformis.
Encrinite stems.
Favosites alveolaris.
Stenopora fibrosa.

These fossils are by no means characteristic of the "Caradoc sandstone of Shropshire" [now ascertained to belong to the Bala and Llandeilo group, July 1853], and, with few exceptions, are species found in Upper Silurian strata. Prof. Sedgwick formerly referred these beds, on fossil evidence, to the Wenlock shale (*antea*, vol. i. p. 21).