International Congress of the History of Science, Technology and Medicine [ICHSTM]

International Commission on the History of Geological Sciences [INHIGEO]
History of Geology Group [HOGG] of the Geological Society, London

Pre-Congress Field Trip, 18-21 July 2013

THE SILURIAN OF 'SILURIA' AND THE IDEA OF A PALAEOZOIC ERA

Leaders: Martin Rudwick and Hugh Torrens

In the first decades of the 19th century, the application of what William Smith called *stratigraphy* elucidated the sequence of strata in western Europe, and their fossils, down to the base of what were termed *Secondary* formations. This sequence was interpreted by geologists as the record of the Earth's history from an age of mammals back through an age of reptiles into an age of fish; from an age of flowering plants back into an age of the much stranger giant plants of the Coal formation.

Below what were termed *Carboniferous* formations, however, the sequence was much more obscure, because the *Transition* and *Primary* rocks were generally much disturbed and had few or no fossils. However, the region of the Welsh Marches (the border country between England and Wales) was found to be an exception. Here the strata were in many places undisturbed and contained plenty of fossils. They provided Roderick Murchison with the basis for what he described as *Silurian* formations (named after the Silures, a tribe that had occupied a part of the Welsh Marches, *Siluria*, in Roman times), though he made much use – not always adequately acknowledged – of earlier work by several lesser-known local geologists. Around the same time, Adam Sedgwick tackled the more problematic strata that were thought to underlie the Silurian, which he named *Cambrian* after the Roman name for Wales itself, and which seemed to contain traces of the earliest forms of life.

In 1841 the whole sequence of formations in Britain and the rest of Europe (and potentially in the rest of the world), and the known history of the Earth, were summarised by John Phillips in terms of what he called *Palaeozoic*, *Mesozoic* and *Cenozoic*, the eras of 'ancient', 'middling' and 'recent' kinds of life. Within the Palaeozoic, the animals of the Silurian and Cambrian periods – the earliest organisms then known – turned out to be both diverse and complex. Later in the 19th century this had an important impact on evolutionary interpretations of the history of life.

This field trip will focus on 're-treading' some of the fieldwork by British geologists in the Welsh Marches, which contributed decisively to the idea of a Palaeozoic era. It will be a *historical* geological field trip: we shall try to see what they saw, through their 19th-century eyes, rather than in terms of geological ideas current today.

PRACTICAL MATTERS

On Thursday 18 July, participants should plan to arrive at the hotel in Church Stretton in time to check in before the evening meal at 7:00pm. The field trip will begin in effect after the evening meal, with an orientation session and introductory talks by the trip leaders. Friday 19 July and Saturday 20 July will be spent in the field, with packed lunches provided. The trip will end on the Saturday, after the evening meal at the hotel, with a final session for discussion and review.

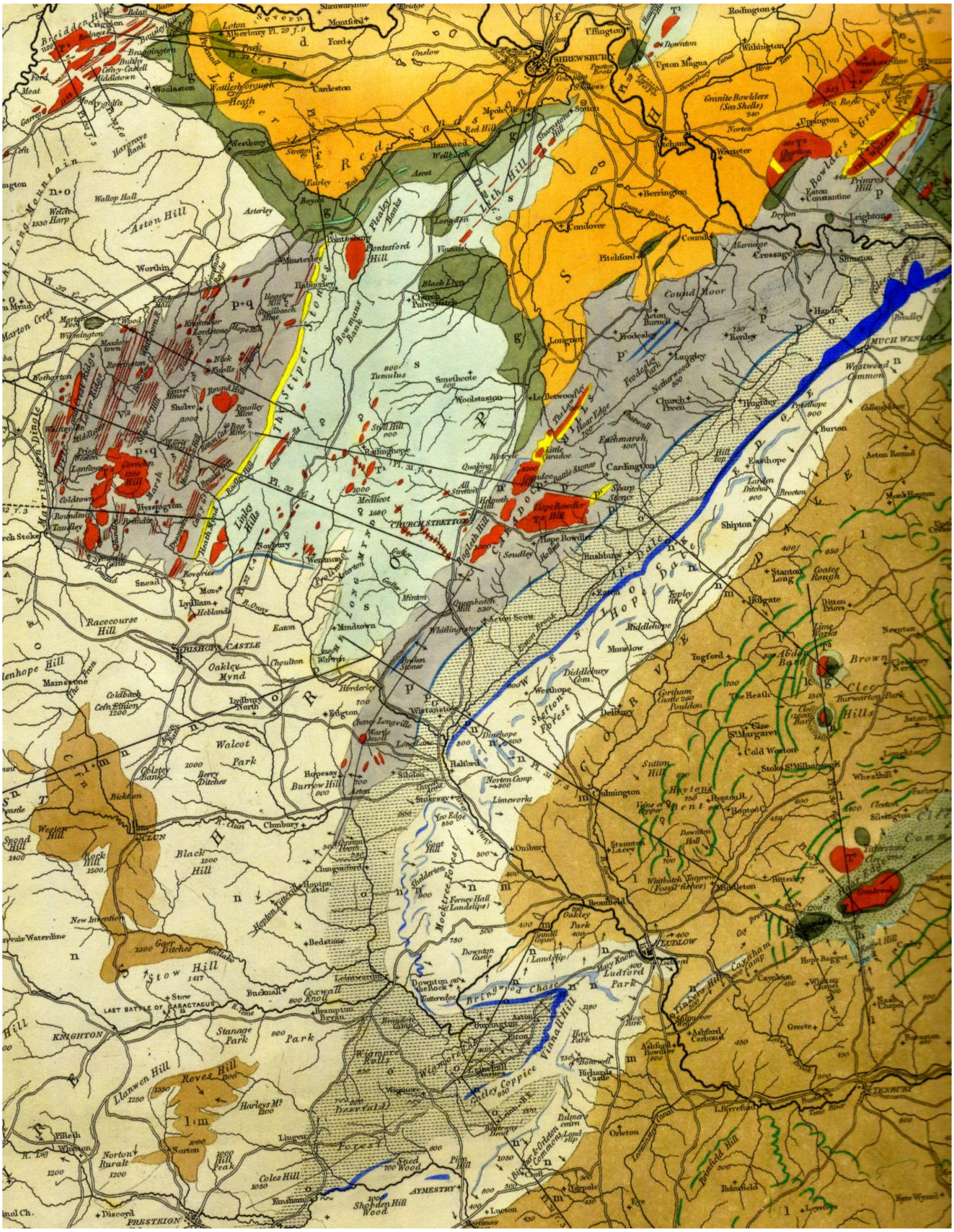
Although the trip does not involve any *lengthy* walking/hiking, we shall spend quite a lot of time away from the minibuses. The weather is impossible to predict: it may be warm or cold, sunny or overcast, calm or windy, dry or wet (in 2012 and 2013 British weather has been even more unpredictable than usual). Some warm clothes and wind- and rain-proof outer clothing are essential. Some of the ground underfoot is rough and may be muddy; hiking boots or other sturdy footwear is essential, and a hiking stick may be helpful. There may be waist-high bracken and stinging nettles, so shorts are not advisable. There may be midges and mosquitoes: bring some insect repellent.

Hammers are not essential: hammering is prohibited at many localities and strongly discouraged at others; adequate rock samples can generally be collected from loose spoil.

For those who like to follow the route on their own maps, the most convenient map to buy in advance is the Ordnance Survey 'Landranger' [1:50,000] sheet 137, "Church Stretton and Ludlow". On a larger scale, the Ordnance Survey 'Explorer' [1:25,000] sheet 217, "The Long Mynd & Wenlock Edge", covers most though not all of the area to be visited, and will also be useful if, for example, you want to walk on the Long Mynd on the Sunday before leaving Church Stretton. (It may be possible to buy these maps at Ludlow Museum, which we shall visit on the first day, or in Church Stretton.) The modern Geological Survey map of the area is not helpful: it necessarily incorporates modern knowledge that is positively misleading if we are to see the country and the rocks through 19th-century eyes.

ITINERARY

On a two-day field trip we can only scratch the surface in 're-treading' some of the extensive fieldwork that underlay the original descriptions of Silurian and Cambrian formations and their fossils. In view of the practical constraints, we shall concentrate on Murchison's classic area in south Shropshire, centred on the town of Church Stretton. However, this area also includes some of the formations that he and Sedgwick initially agreed were older than any 'Silurian' and belonged properly in the 'Cambrian': see the **Reference Map**, reproduced from the relevant part of Murchison's great map of 1839. So what we shall see encompasses some of the problems that arose between them. Our itinerary will, as far as is practicable, take us in order *down* the sequence from the youngest formations to the oldest (our programme may have to deviate from what is described below, for contingent reasons of time, weather etc.). This brief summary describes what we shall see in 19th-century terms, *not* those of modern geologists.



REFERENCE MAP: Part of Murchison's map of "The Silurian Region", published with his *Silurian System* (1839). Church Stretton is near the centre. See the enlarged portions below. Murchison did not map any of the *faults* that later geologists detected in this region, notably along the Stretton valley (the straight lines here are the lines of the sections published with the book).

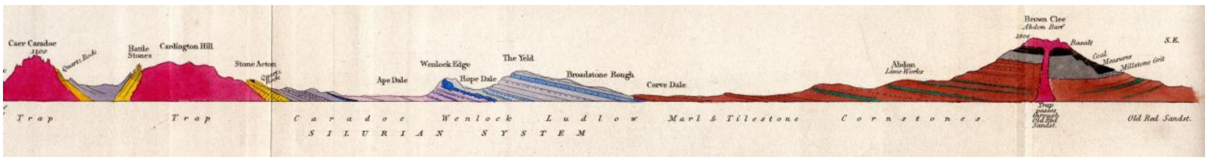
DAY ONE (Friday 19 July): see **Section** and **Map for Day One**.

From **Church Stretton** we drive south and up on to **Titterstone Clee** hill; we walk to the summit, which – weather permitting – gives a superb 360° panoramic view of the whole region and its main topographical features. The hill is capped with prismatic basalt (formerly quarried extensively for road stone), immediately below which are Carboniferous formations (formerly mined on a small scale for coal), and below them a great thickness of Old Red Sandstone (assigned, from the 1840s, to the then newly-defined Devonian).

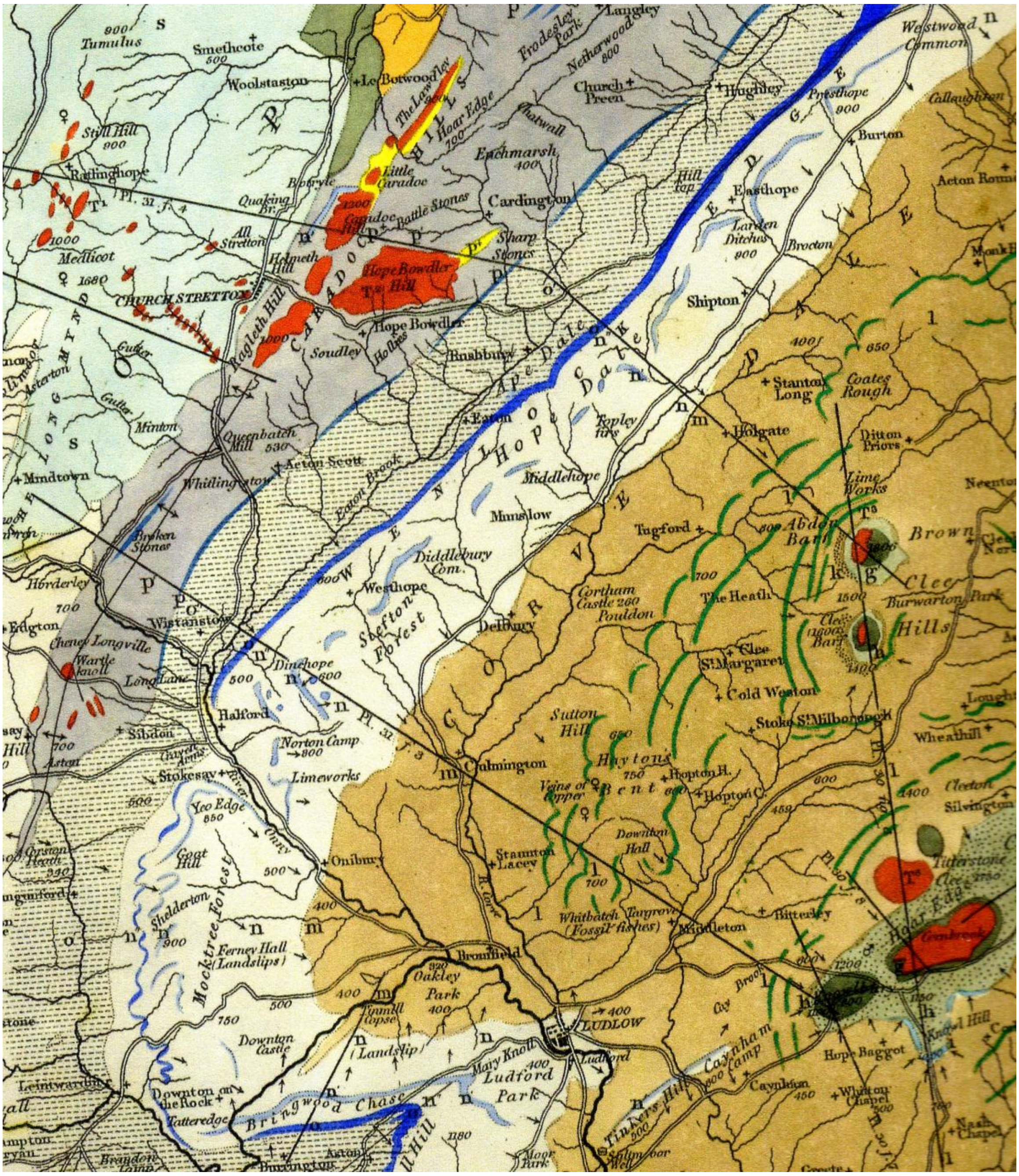
We drive down to the town of **Ludlow** (famous for its mediaeval castle and well-preserved 18th-century town centre) and visit the Ludlow Museum, where the museum's geologist Daniel Lockett will show us its fine display of 'characteristic fossils' from all the formations that outcrop in south Shropshire – better specimens than any we are likely to find in the field! – and also a historical display about Murchison. We then walk down to the river Teme to see outcrops of highest 'Silurian' and basal Old Red Sandstone (the subsequently famous 'Ludlow Bone Bed' is no longer visible).

We drive back to the town of **Craven Arms** and then northeast up **Corve Dale**, along the strike of the formations, with the Old Red Sandstone of the Clee Hills on one side and the dip slope of the highest Silurian formations (Murchison's 'Ludlow') on the other; we hope to visit a quarry in the Aymestry Limestone near the village of **Diddlebury**. Turning into the dip direction (northwest) at the village of **Brockton**, we traverse uphill but down the sequence, through the discontinuous line of hills marking the scarp of the Aymestry Limestone, and on to the long unbroken ridge of **Wenlock Edge**. This marks the scarp of the Wenlock Limestone, which we hope to see in a quarry near the town of **Much Wenlock**.

Returning along Wenlock Edge we descend into **Ape Dale**, underlain by Wenlock Shales (also in Murchison's 'Wenlock'), and continue to traverse down the sequence into Murchison's 'Caradoc' formations, named after the nearby prominent hill of **Caer Caradoc** (topped by an Iron Age fort). The more resistant of the 'Caradoc' rocks, which generally dip much more steeply than the 'Wenlock' and 'Ludlow', form scarps such as **Hoar Edge**. Finally we stop at the foot of **The Lawley**, the northern end of the conspicuous line of hills composed of igneous rocks (Caer Caradoc being another) that mark the base of the sequence on this eastern side of the deep valley in which Church Stretton lies.



SECTION FOR DAY ONE: Part of one of Murchison's sections, from his *Silurian System* (1839). It extends from the Old Red Sandstone of Brown Clee (right) down across Corve Dale to the scarps of 'Ludlow' and 'Wenlock' with Hope Dale between them; across Ape Dale and up on to 'Caradoc' strata with basal 'Quartz Rock' resting on the 'Trap' or igneous rock of Cardington Hill and Caer Caradoc (left). The Stretton valley is immediately beyond this point in the section.



MAP FOR DAY ONE: Part of Murchison's map of "The Silurian Region", published with his *Silurian System* (1839), from Church Stretton (top left) to Ludlow (near bottom edge). This portion shows Old Red Sandstone (*l*) and *m*) with outliers of Carboniferous and igneous 'Trap' rocks above (on Clee Hills, lower right); resting successively on 'Ludlow' (*n*) with discontinuous Aymestry Limestone (pale blue); Wenlock Limestone (bright blue) and underlying Wenlock Shale (*o*); 'Caradoc' (*p*) with thin bands of limestone and its basal 'Quartz Rock' (yellow); the 'Trap' of Caer Caradoc and nearby hills; and the 'Cambrian' (*s*) of the Long Mynd.

DAY TWO (Saturday 20 July): see **Section** and **Map for Day Two**.

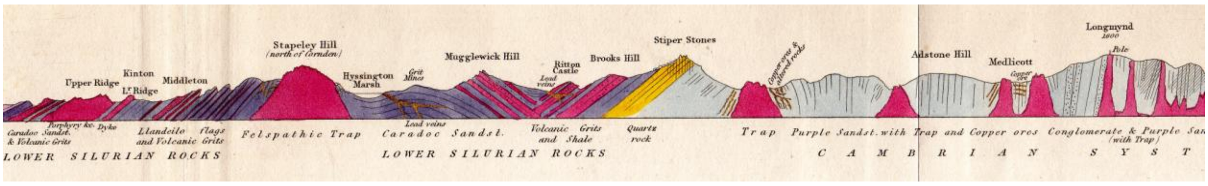
Our hotel in Church Stretton is on the eastern slope of the **Long Mynd**, a broad steep-sided plateau which dominates the western side of the Stretton valley. From the village of **Little Stretton** we walk into **Ashes Hollow**, one of several deep valleys cut into the Long Mynd, to see exposures of the immensely thick, almost vertical Longmynd formations, which Murchison treated as pre-'Silurian' and accepted as part of Sedgwick's 'Cambrian'; having only rare, obscure and dubious traces of fossils, they were controversial throughout the 19th century, but were agreed to be the oldest sedimentary rocks in the area.

We then drive south. Near the village of **Wistanstow** we walk to the little river **Onny** to see an exposure of the (here) very slight unconformity between the lowest 'Wenlock' and highest 'Caradoc' strata, i.e. between Murchison's 'Upper' and 'Lower Silurian'. We walk up the Onny valley to see, near the village of **Horderley**, an exposure of the unconformity between the basal 'Lower Silurian' (as on Hoar Edge) and the underlying 'Cambrian' Longmynd rocks.

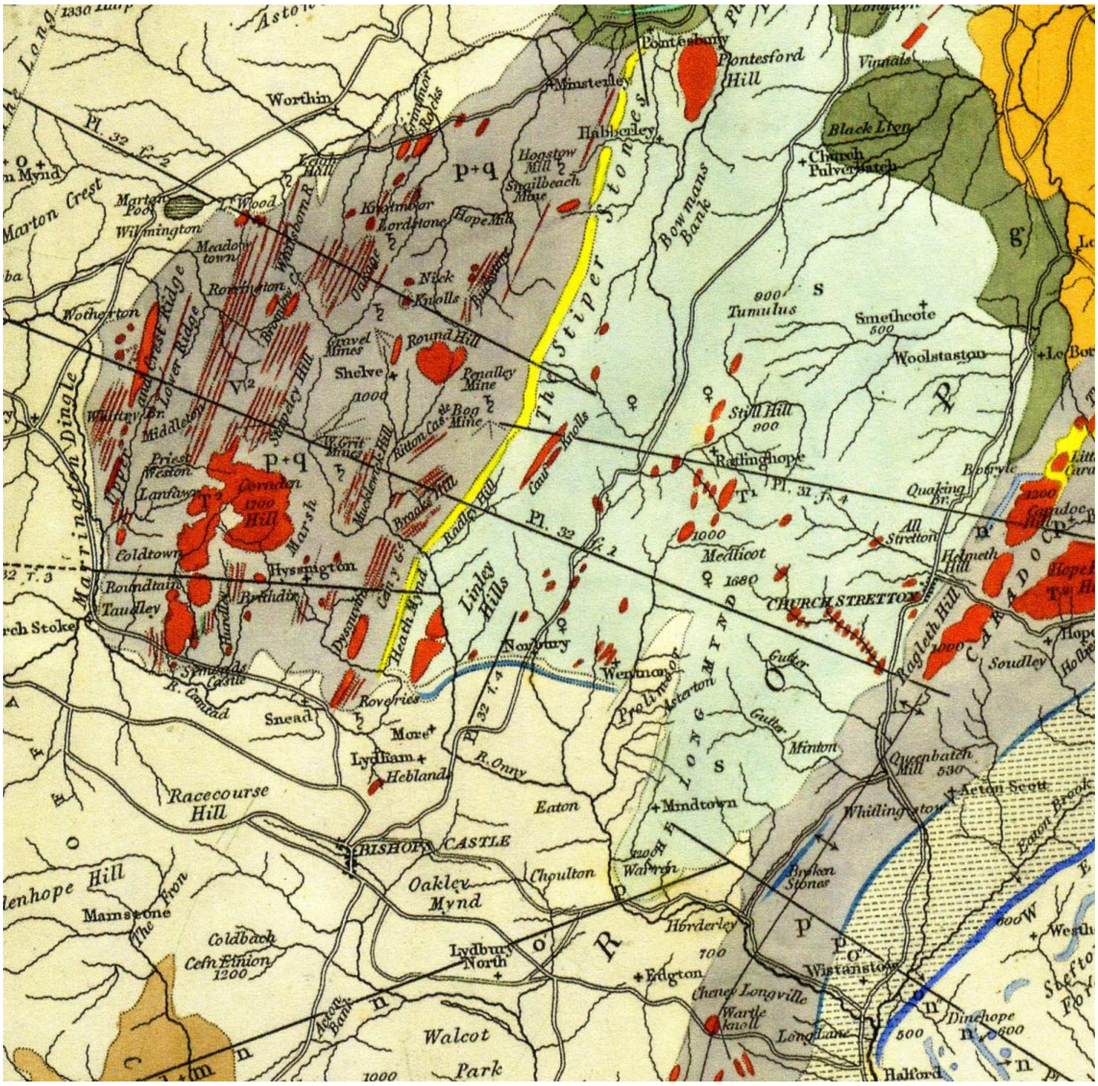
We drive west round the southern tip of the Long Mynd itself and north into the 'Shelve inlier' of 'Lower Silurian' and 'Cambrian' rocks. We walk on to the flank of **Stapeley Hill**, from which, at the prehistoric stone circle of Mitchell's Fold, there are extensive views into Wales to the west (if the weather is clear), towards the Berwyn Hills, where Sedgwick found huge thicknesses of his 'Cambrian' greywacke (the town of Bala, and the thin but important Bala Limestone that he assigned to his 'Middle Cambrian', is on the far side of these hills).

We drive east through the former mining area around the village of **Shelve**: the mineral veins (of lead ore) that penetrate the greywacke were thought to be confined to Sedgwick's 'Upper Cambrian' – Murchison's 'Lower Silurian' – in contrast to the 'Upper Silurian' without such veins. At the former mining village of Stiperstones we see exposures of the very thick and steeply-dipping greywacke strata. We walk up to the **Stiperstones** themselves, a line of natural outcrops of steeply-dipping quartzite representing the base of Murchison's 'Lower Silurian' on this western side of the 'Cambrian' Longmynd rocks. There are extensive views west to the Berwyn Hills and east to the Long Mynd itself.

We drive east across a broad area underlain by Longmynd rocks and then south to the small border town of **Bishop's Castle**, for tea at Martin's 17th-century house, where he and Hugh will show some relevant primary sources from their collections. Finally we drive back to Church Stretton.



SECTION FOR DAY TWO: Part of one of Murchison's sections, from his *Silurian System* (1839). It extends across the Shelve area, from 'Lower Silurian' on both sides of the 'Trap' rock on Stapeley Hill to its basal 'Quartz Rock' at the Stiperstones, which rests on the 'Cambrian System' of the Long Mynd, the 'axis' of the Shropshire rocks.



MAP FOR DAY TWO: Part of Murchison's map of "The Silurian Region", published with his *Silurian System* (1839): from Church Stretton (right) to the Shelve area (left). This portion shows the 'Cambrian' of the Long Mynd (s), the Stiperstones quartzite (bright yellow), and the rest of the 'Lower Silurian' (*p* + *q*) with many patches of igneous rock.

A SHORT HISTORY

Martin Rudwick

The defining of the Silurian and Cambrian 'systems' (and periods) has often been told simply as a heroic story of personal conflict between Roderick **Murchison** and Adam **Sedgwick**, who at the outset were friends and collaborators but who became unreconciled opponents, and whose rival definitions were only resolved by the much later irenical insertion of an 'Ordovician' system between the Cambrian and the Silurian. This account is not wholly untrue or merely mythical, but it does over-simplify the historical record of what was at stake in the exploration of the oldest fossil-bearing rocks then known. The brief summary that follows is based mainly on the invaluable historical research – utilising a mass of manuscript and printed primary sources – incorporated in James A. Secord's *Controversy in Victorian Geology: The Cambrian-Silurian Dispute* (Princeton University Press, 1986). Jim Secord's work remains the definitive narrative and analysis of this lengthy affair.

Two preliminary points – which should be emphasised, but often are not, by those who write about the history of geology in the 19th century – must be cleared out of the way. Firstly, what was *not* at issue in the arguments among geologists about these ancient rocks was any concern about the timescale of the Earth's history. They all took it for granted that the total pile of rock formations – of which the Silurian and Cambrian formations were just a part – represented many millions of years, at the very least, and perhaps even billions; but their inability to quantify the timescale, even approximately, was *in practice* unimportant to them. In contrast, they had nothing but scorn for those popular writers (largely confined to anglophone countries) who asserted that the whole history of the Earth could be squeezed into a few millennia and who claimed to derive this from the Bible. Among geologists there was no conflict on this point between 'Science' and 'Religion' (which are in any case highly questionable historical categories). Many of the leading geologists, particularly in Britain, were in public life ordained clergymen and in private life devout Christians: Sedgwick was a prominent example.

Secondly, these same arguments among geologists were *not* closely related to concurrent debates about the possible '*transmutation*' of animals and plants [in modern terms, their *evolution*] in the course of time. To most geologists it seemed clear that the history of life, as preserved in the fossil record, was turning out to be broadly a history of *progression*, in the sense that new and more 'advanced' forms had made their appearance successively during the history of the Earth (fish before reptiles, reptiles before mammals; flowerless before flowering plants). But how this might have happened was a separate issue, on which there was lively debate: 'special creation' by divine intervention was *not* the only alternative to Lamarck's (and later, Darwin's) concept of imperceptibly gradual change. Again, *in practice* it was unimportant to geologists how the apparent progression of life had come about: Sedgwick is a good example of those who interpreted the fossil record in 'progressionist' terms yet were strongly critical of contemporary concepts of evolution.

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An Outline of the Geology of England and Wales (1822), revised and expanded by William **Conybeare** from an earlier book by William Phillips [no relation of John Phillips], described the sequence of sedimentary rock formations in the usual order from the top downwards, with a focus on the *Secondary* formations – often with plenty of fossils – from the Chalk down to the Old Red Sandstone. These formations had been mapped by the mineral surveyor William **Smith** (1815) and by George **Greenough** and his collaborators at the Geological Society in London (1819); they were relatively well understood. 'Conybeare-and-Phillips', as it was often known, became an international standard of reference for stratigraphical sequences in other parts of Europe and even beyond it. [**FIG. 1**]

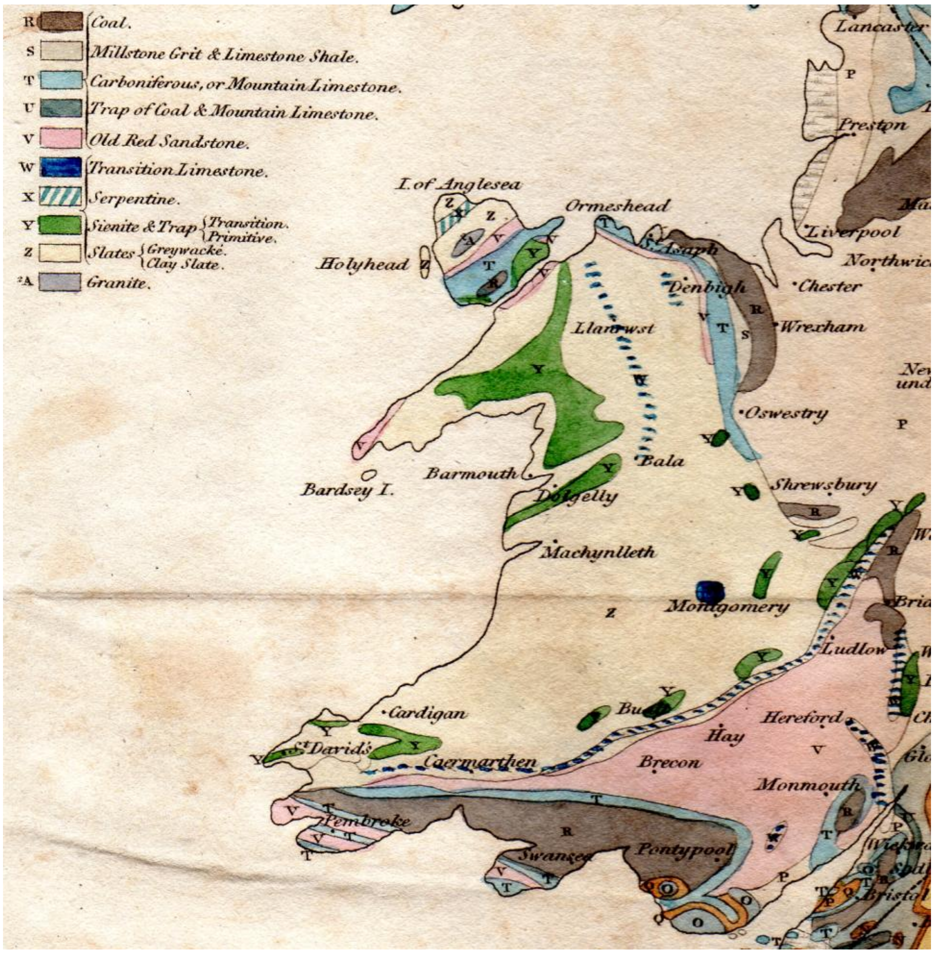


FIG. 1 Part of the geological map in *Outlines of the Geology of England and Wales* (1822) by William Conybeare and William Phillips, which was reduced and much simplified from the large geological maps by William Smith (1815) and George Greenough (1819). The sequence down to the 'Coal' (R), 'Carboniferous or Mountain Limestone' (T) and 'Old Red Sandstone' (V) was clear and well understood. The underlying 'Transition Limestone' (W), especially the long narrow band (striped) extending from near Shrewsbury (right) into southwest Wales, was the area on which Murchison later based his 'Silurian System'. Still lower in the sequence, the vast area of 'Greywacke and Clay Slate' (Z) in Wales, with its included igneous rocks of 'Syenite and Trap' (Y), was tackled by Sedgwick. Among other places mentioned in the text, this map also marks the towns of Ludlow, Bala and St Davids, and the island of Anglesea.

When Phillips died in 1828, Conybeare asked Sedgwick, the professor of geology at Cambridge, to help him prepare the planned 'Volume 2' on the formations still lower in the sequence (below the Old Red Sandstone), which were much less well understood. They were generally called *Transition* formations – with only a few fossils, usually poorly preserved –

and below them the *Primary* or *Primitive* rocks (granites, gneisses, schists etc.) with no fossils at all, which were regarded as products of the Earth's earliest history or even as relics of its incandescent origin as a planet (some, but not all, granites were recognised as being later igneous *intrusions*) [**FIG. 2**].

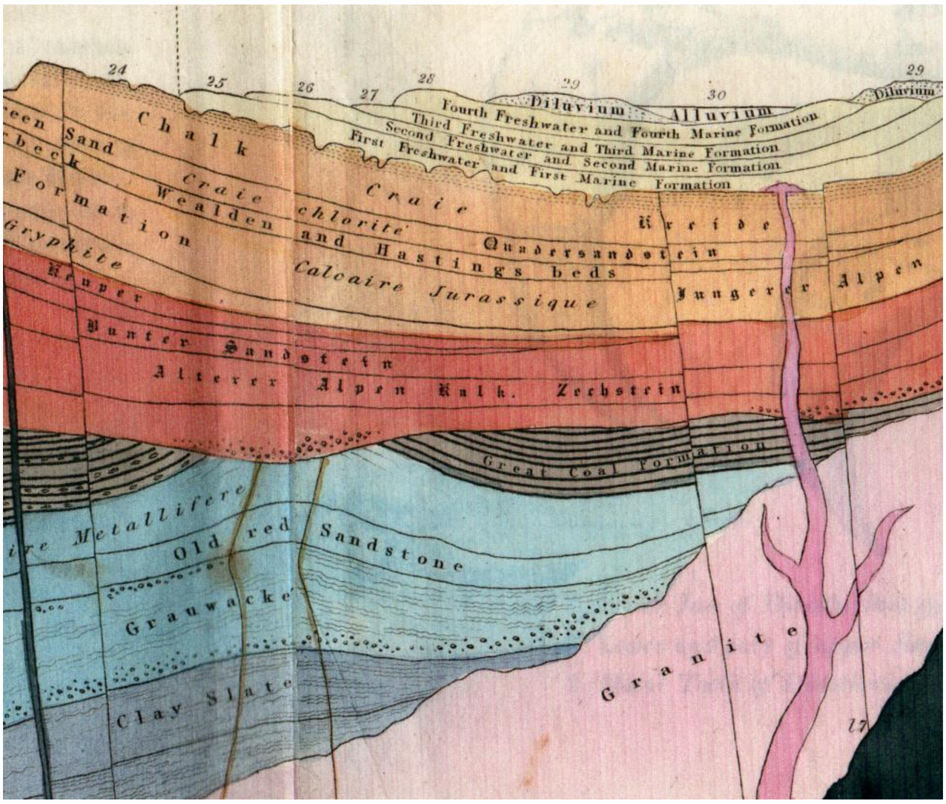


FIG. 2 A small part of the great ideal section through the Earth's crust published in William Buckland's 'Bridgewater Treatise' on *Geology and Mineralogy* (1836). It shows diagrammatically the whole pile of formations from *Tertiaries* at the top, through *Secondaries* – including the 'Great Coal Formation', Mountain [Carboniferous] Limestone and Old Red Sandstone – into the then poorly-known *Transition* formations of 'Grauwacke' and 'Clay Slate', overlying a basement of *Primary* or *Primitive* granite (elsewhere in the section, other granites were shown as intrusive and much younger). The trilingual names given to the formations reflect the highly international character of stratigraphical research at this time. The section was designed by Thomas Webster in 1833, just before Murchison and Sedgwick described the Transition formations of Wales and the Marches and named them Silurian and Cambrian.

Sedgwick first undertook fieldwork towards this internationally important project when in 1831 he tackled the rocks of north Wales, a large region about which the geology was poorly known (for a part of the time he had as his companion and trainee the young Cambridge student Charles Darwin). He made an effective reconnaisance survey and traced an upward sequence: from Primary rocks on the island of Anglesea in the northwest, through a very thick pile of the slaty rocks known as *greywacke* (half-anglicised from the German *Grauwacke*) in the Snowdon area and much of north Wales, to the overlying Carboniferous formations in northeast Wales. His focus was on the structure and solid geometry of the rocks; he adopted many of Léonce **Élie de Beaumont**'s recent ideas about [in modern terms] *tectonic* geology. In particular he was looking out for *unconformities* that could be taken as evidence for the occasional *révolutions du globe*: these tectonic events might define the *natural* divisions of the Earth's history. Unravelling these ancient rocks was made more difficult because their strata were often obscured and confused by what Sedgwick later defined as their *slaty cleavage*; clarifying this was of the utmost importance for interpreting them [**FIG. 3**].

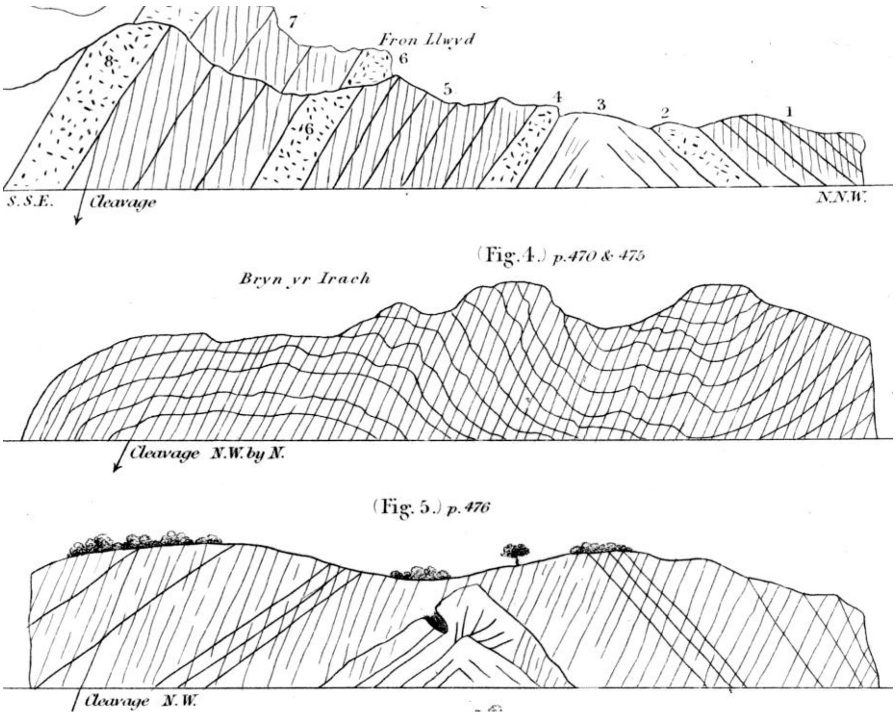


FIG. 3 Slaty cleavage affecting folded 'Cambrian' strata in Wales: three sections from Sedgwick's classic paper (1835) on slaty cleavage, showing how it could obscure the structure, be confused with stratification, and make it difficult to split the rock along the original bedding and find any fossils (unless, locally, the two planes coincided).

In the same year, 1831, Murchison, a wealthy ex-soldier and amateur geologist based in London, undertook a much longer tour around England, but it was much less focussed in its objectives. One part of his chosen route took him through the Welsh Marches, but simply to check and correct Greenough's map along the boundary between the Old Red Sandstone and the underlying Transition rocks, and to clarify the relation between the sedimentary rocks and the igneous ones. He saw for himself what was already well known from an earlier survey by Arthur **Aikin** (1810) and from later fieldwork by Conybeare, William **Buckland** (Sedgwick's counterpart at Oxford) and other geologists: namely, that in this region the Old Red Sandstone was underlain by a sequence of formations as undisturbed as many Secondary formations, and as full of well-preserved fossils [**FIG. 4**].

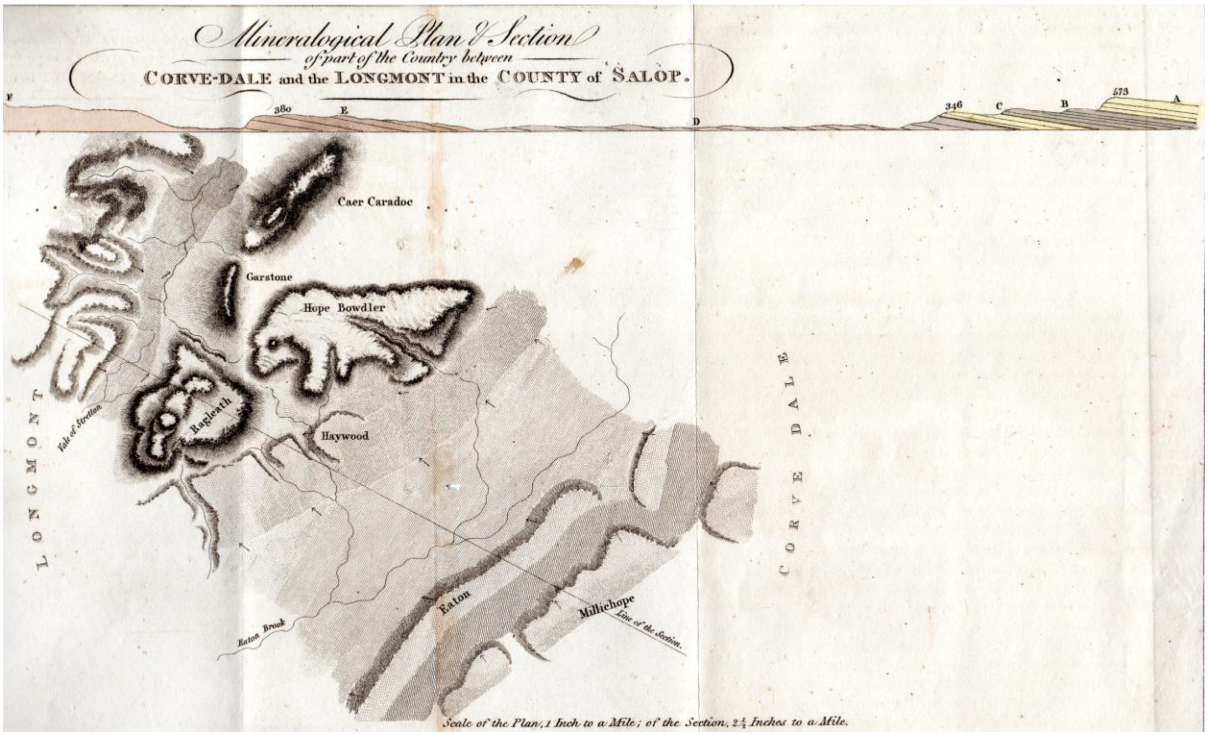


FIG. 4 Arthur Aikin's 'Mineralogical Plan and Section' through part of the 'County of Salop' [Shropshire], published in 1810. His map and section extended from the double scarp of limestones (A, C) at Wenlock Edge (right), across the broad Ape Dale (D) and a further scarp of lower formations (E) to the line of hills (F, including Caer Caradoc, top of map) on the east side of the Stretton valley (G), beyond which are the rocks lowest in position on 'Longmont' [Long Mynd] (left). Aikin's work, although limited to this small area, gave later geologists the crucial key: that in south Shropshire these 'Transition' formations were as straightforward in structure as the 'Secondary' ones that William Smith was mapping elsewhere in England.

These rocks and fossils were shown to him in the field by the highly competent local geologist Thomas **Lewis** (whose vital input he later minimised, accentuating his own originality). Murchison then adopted the geology of this decisive area as his own new research project, abandoning an earlier alternative plan – to work on the *Tertiary* [Cenozoic] formations of East Anglia – that would have kept him in the shadow of the prominent London geologist Charles **Lyell**. He returned to the Marches in 1832 and subsequent years, adopting Smith's emphasis on 'characteristic fossils' as his main criterion for identifying different formations and tracing them across country [**FIG. 5**]. In contrast, Sedgwick's emphasis was on clarifying the tectonic structure of the rocks. So Sedgwick and Murchison initially tackled separate regions with different methods and objectives; it was *not* initially a joint research project.

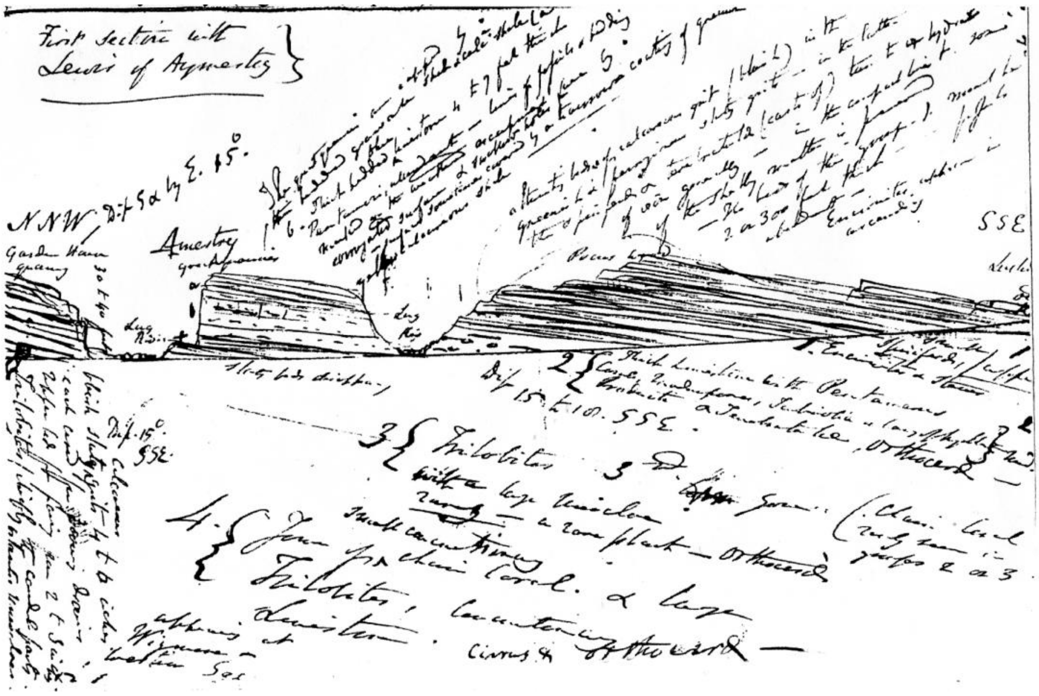


FIG. 5 Murchison's manuscript section (1832) of the strata forming the hills between the village of Aymestry (left) and the town of Ludlow (right), with his copious notes on the rocks and fossils. Some time later he added the note "First section with Lewis of Aymestry" (top left). In 1834 he defined these strata as part of the 'Ludlow' group of his 'Upper Silurian'. This page from one of his field notebooks is characteristic of their style.

In 1832 Sedgwick, while continuing to unravel the structure of north Wales, found that he could trace a thin *Bala limestone* and its fossils for some 30 miles across country. This gave him an invaluable reference 'horizon' in the middle of what – with some exasperation – he privately called the "interminable greywacke". His traverse from Bala eastwards over the Berwyn Hills into Shropshire convinced him that this band of limestone was separated by thousands of feet of greywacke from Murchison's formations, which were therefore far younger [**FIG. 6**].

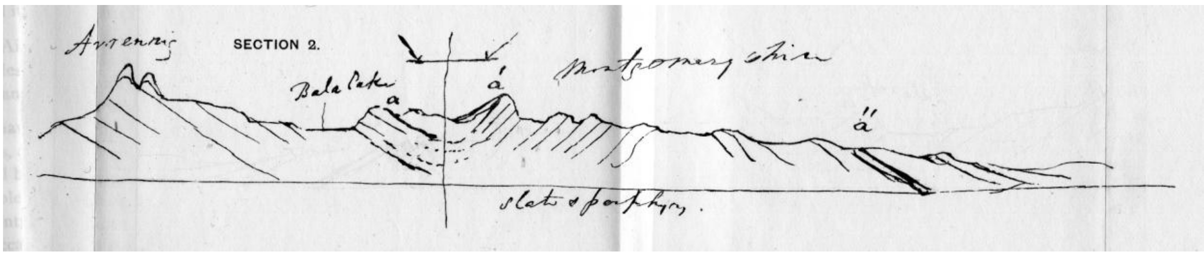


FIG. 6 Sedgwick's sketch field section (1832) through part of north Wales, showing the huge thickness of formations of 'slate & porphyry' that he later called 'Cambrian', all lying below Murchison's formations (beyond the section to the right). The thin Bala limestone (*a, a', a''*) was folded into a trough or *syncline* in the Berwyn Hills (centre) and an arch or *anticline* further east. Murchison later claimed that this and similar limestones properly belonged, by their fossils, in his 'Lower Silurian', thus eliminating a large part of Sedgwick's 'Cambrian'.

Murchison agreed, in the light of their similar traverse (in the other direction) in 1834; this was their one and only joint fieldwork tour. In 1835 Murchison summarised his sequence of younger formations – in order downwards below the Old Red Sandstone – as: I. ***Ludlow*** / II. ***Wenlock*** / III. ***Caradoc*** / IV. ***Llandeilo***. Below all these were still older rocks (V. ***Longmynd***), which he described as being very thick, with few fossils, but still above and younger than Sedgwick's Bala limestone and other Welsh rocks (all these formations, except Llandeilo, were named after localities in the Marches) [**FIG. 7**].

	Formations.	Maximum approximate thickness.	Subdivisions.	Lithological Characters.
	Carboniferous Limestone.	Feet. 500 ?	Limestone. Shale.	
	Old Red Sandstone.	10,000.	a. Red conglomerate and sandstone.	a. Quartzose conglomerate overlying thick-bedded sandstones.
			b. Cornstone and argillaceous marls.	b. Red and green, concretionary limestones, with spotted argillaceous marls and beds of sandstone.
			c. Tile stones, &c.	c. Flaggy, highly micaceous, hard, red and green sandstone.
UPPER GREYWACKE SERIES.	I. Ludlow Rocks.	2000.	d. Upper Ludlow rock.	d. Slightly micaceous, grey-coloured, thin-bedded sandstone.
			e. Aymestry and Sedgeley limestone.	e. Subcrystalline or grey and blue argillaceous limestone.
			f. Lower Ludlow rock.	f. Sandy, liver, and dark-coloured shale and flag, with concretions of earthy limestone.
	II. Wenlock and Dudley Rocks.	1800.	g. Wenlock and Dudley limestone.	g. Highly concretionary grey and blue subcrystalline limestone.
			h. Wenlock and Dudley shale.	h. Argillaceous shale, liver and dark gray-coloured, rarely micaceous, with nodules of earthy limestone.
	III. Horderley and May Hill Rocks.	2500.	i. Flags.	i. Thin-bedded, impure, shelly limestone, and finely laminated, slightly micaceous greenish sandstone.
			k. Sandstones, grits, and limestones.	k.* Thin-bedded, red, purple, green, and white freestones. Conglomeritic quartzose grits. Sandy and gritty limestones.
	IV. Builth and Llandeilo flags.	1200.		l. Dark-coloured flags, mostly calcareous, with some sandstone and schist.
	V. Longmynd and Gwastaden Rocks.	Many thousand feet.	Comprising all the slaty system of South Wales.	m. Hard, close-grained, gray greenish and purple sandstone. Red and gray quartzose conglomerate. Slate-coloured and purple schists. Coarse slates: little or no calcareous matter.

FIG. 7 Murchison's table of formations in Wales and the Marches (1834), shortly before he renamed the 'Upper Greywacke Series' as '*Silurian*' (the 'Lower Greywacke' became Sedgwick's 'Cambrian'). Of its constituent 'Formations' below the Old Red Sandstone, 'I. *Ludlow'* and 'II. *Wenlock'* retained their names (Dudley is an inlier of Wenlock rocks near Birmingham); 'III. Horderley' was renamed '*Caradoc'* (May Hill is much further south); 'IV' was later named just '*Llandeilo'*. 'V. *Longmynd'*, with a thickness of 'many thousand feet', was clearly excluded from the future Silurian.

In 1835, primarily on Murchison's initiative, he and Sedgwick publicly named their respective sets of formations *Silurian* and *Cambrian*. There was no obvious reason for any conflict between them: the Cambrian formations seemed unambiguously lower and therefore older than the Silurian. The Cambrian included Murchison's 'Longmynd' rocks and Sedgwick's thick greywacke with its thin Bala limestone, down to his oldest rocks; the Silurian comprised all the formations from 'Ludlow' down to 'Llandeilo'[**FIG. 8**].

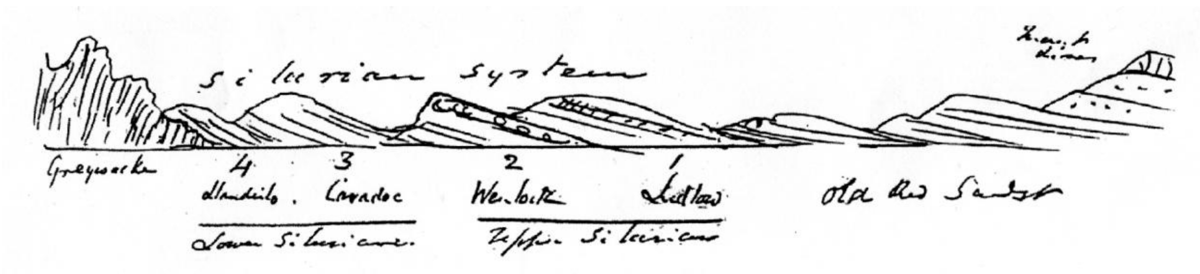


FIG. 8 Murchison's first use of '*Silurian System'*, in a letter to Buckland (1835). The section was based mainly on his fieldwork in south Shropshire: in descending order, right to left, 'Mount[ain] Limes[tone]' (Carboniferous) as on the summits of the Clee Hills; 'Old Red Sandst[one]' as in Corve Dale; 'Upper Silurian' divided into '1 / *Ludlow*' with the scarp-forming Aymestry Limestone, and '2 / *Wenlock*' with the scarp of Wenlock Limestone on Wenlock Edge; 'Lower Silurian' divided into '3 / *Caradoc*' as in the Caer Caradoc area, and '4 / *Llandeilo*' (named after an area far to the southwest); resting with an inferred major unconformity on 'Greywacke', elsewhere assigned to Sedgwick's 'Cambrian'.

Murchison's 'Silurian' name involved a possible historical fudge, since antiquarians did not think that the territory of the Silures had ever extended as far north as Shropshire (Murchison thought they were mistaken). 'Cambrian' was more appropriate historically, since it referred simply to Wales itself; but it was far from having its modern geological meaning. Sedgwick assigned its upper parts, above the level of the Bala limestone, to his 'Upper Cambrian'; Murchison agreed at this point that they were lower than any of his Silurian formations. Sedgwick assigned the greywacke of the Snowdon area and much of north Wales, with the Bala and other thin bands of limestone with fossils, to his 'Middle Cambrian'; and the obviously even more ancient Primary rocks of Anglesea to his 'Lower Cambrian' [it is important to note that at this time there was no clear concept of *Precambrian* rocks]. Sedgwick's main criteria for working out this stratigraphical sequence were those of structure and superposition, so he was not disconcerted at being unable to define his Cambrian by its fossils. For Murchison, however, following Smith's model of stratigraphy, fossils were essential. He claimed that his Silurian deserved recognition as a major natural '*system*' because its fossils were distinct from those in the Old Red Sandstone immediately above the Silurian, just as, in turn, those in the Old Red Sandstone were distinct from the fossils in the Carboniferous formations above them [**FIG. 9**].

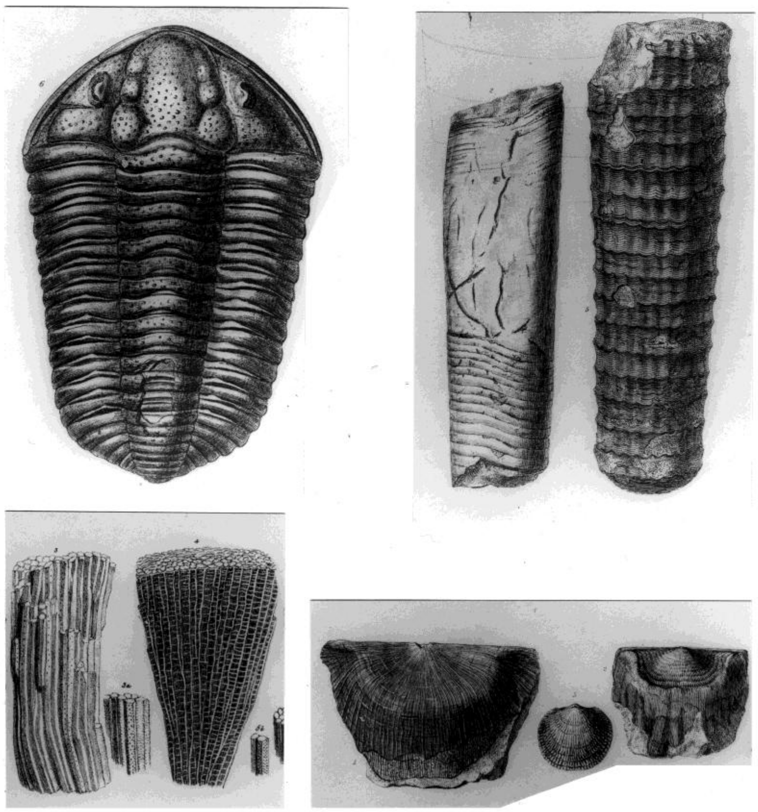


FIG. 9 Some 'characteristic' fossils from Murchison's 'Upper Silurian' formations, as illustrated in his *Silurian System* (1839): the trilobite *Calymene* (upper left), the cephalopod mollusc *Orthoceratites* (upper right), the coral *Favosites* (lower left) and the brachiopods *Leptaena* and *Orthis* (lower right).

In Murchison's opinion no separate system could or should be defined *below* his Silurian, unless it could be shown to have an equally distinct set of fossils. His huge book on *The Silurian System* (1839) was a description of the geology of the 'Silurian' *region* and its rocks of *all* ages from youngest down to oldest; but most of the book set out his detailed evidence for defining his Silurian '*system*' in terms of its formations and their distinctive fossils [**FIG. 10**].

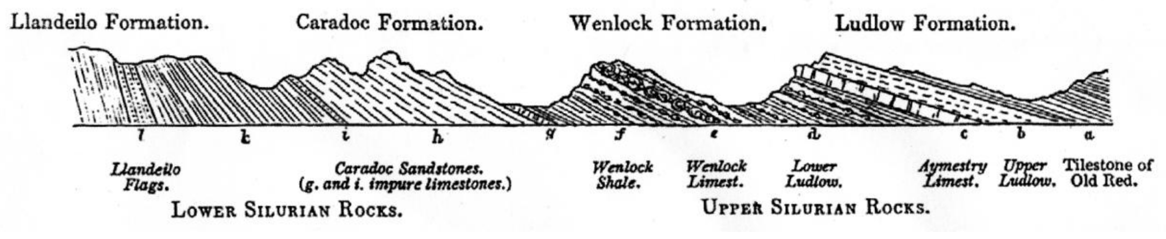
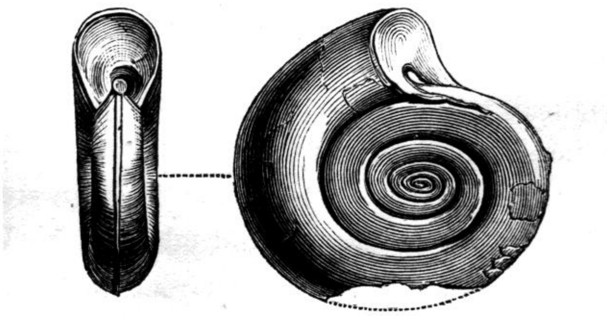


FIG. 10 Murchison's summary section through his 'Silurian' formations, as published in *The Silurian System* (1839). It shows the sequence found in south Shropshire, from basal 'Old Red [Sandstone]' down through the 'Upper Silurian' of 'Ludlow' and 'Wenlock' and the 'Lower Silurian' of 'Caradoc' and 'Llandeilo'. The problematic relation between these 'Silurian' formations and Sedgwick's 'Cambrian' was here discreetly omitted altogether.

However, the relatively few fossils in Sedgwick's Upper and Middle Cambrian turned out to be similar to some of those in the lower parts of Murchison's Silurian (his 'Caradoc' and 'Llandeilo' formations). In Murchison's eyes this implied that there was a significant *overlap* between 'Silurian' and 'Cambrian'. He therefore thought it right and proper to reclassify these 'Cambrian' formations *as Silurian*. Further fossil collecting reinforced this point, so more and more of Sedgwick's 'Cambrian' was transferred by Murchison into his 'Silurian'. Sedgwick objected to this bold annexation of 'his' formations, but not just because it diminished his own scientific achievement (and heightened Murchison's). It was also objectionable because his progressionist concept of the overall history of life led him to expect that the 'Silurian' organisms would have made their appearance *gradually* in the course of the immense span of time represented by the huge thickness of 'Cambrian' formations. In Sedgwick's opinion a distinctive set of Cambrian fossils was therefore *not* essential for establishing the validity of his Cambrian system. So the growing rift between the two geologists was much more than a matter of wounded pride or vaunting ambition: there was a major *theoretical* and methodological difference between them.

These issues were complicated by what Greenough and others called the "great Devonian controversy", which was developing – during just the same years – among leading geologists in Britain and, increasingly, in the rest of Europe. Large areas of Devonshire (in southwest England) had just been mapped as 'greywacke' by Henry **De la Beche** (it was the forerunner of the government-funded Geological Survey). Most geologists, including both Sedgwick and Murchison, agreed with him at first that these rocks were probably *pre-Silurian*, as in Wales. So when some of their fossils were found to be distinctive, and definitely not Silurian, they were interpreted as Cambrian forms; Sedgwick was confident that similar fossils would be found in his Cambrian rocks in Wales itself [**FIG. 11**].



Endosiphonites carinatus, Ansted.† Cambrian strata, Cornwall.

FIG. 11 A distinctive cephalopod mollusc found in the 'greywacke' of Devonshire (and the adjacent county of Cornwall), but not in Murchison's 'Silurian' formations further north. It was therefore assigned to Sedgwick's 'Cambrian'; Lyell chose it here for his *Elements of Geology* (1838), to exemplify the fauna of the Cambrian period. But soon afterwards Sedgwick and Murchison jointly proposed a radical revision of Devonshire geology, as a result of which this fossil (and many others) were reassigned to a new 'Devonian' system *younger* than the Silurian. The Cambrian was therefore left without *any* set of distinctive fossils. (The name given to this fossil by Sedgwick's young colleague David Ansted was soon recognised as a synonym of what the Prussian geologist Ernst Beyrich had already called *Clymenia*, which is the name by which it was subsequently known.)

In 1839, however, Sedgwick and Murchison jointly proposed a radical revision of Devonshire geology. To cut a long and complex story short, they reinterpreted most of the older Devonshire rocks as being of the same age as the Old Red Sandstone, although unexpectedly quite different in appearance and totally unlike in fossils (it was an early example of the recognition of contrasting *facies*, which required a major modification of Smith's methods in stratigraphy). On this new interpretation, the rocks were attributed to a '*Devonian*' system, intermediate in age between the Silurian and the Carboniferous: they were *younger* than the Silurian, not older. In the early 1840s this solution to the Devonian controversy rapidly attracted a consensus of almost all the geologists with first-hand knowledge of the problem. It had the unexpected side-effect of completely eliminating the supposed Cambrian fossils of Devonshire, though Sedgwick expected that some distinctive Cambrian fossils would eventually be found in Wales.

The identification of a Devonian system intermediate between the Silurian and the Carboniferous, with fossils that were similarly intermediate in character, might have been expected to weaken Murchison's insistence on defining his Silurian in terms of a sharply distinct set of fossils, while reinforcing Sedgwick's concept – which he shared with other leading geologists such as Lyell – of a much more gradual process of change. But in fact Murchison's position hardened: he asserted with increasing forcefulness that *all* formations with the fossils he had found in his original Silurian should be absorbed into that system. This extended what *counted* as 'Silurian' downwards in the stratigraphical pile, and back in the Earth's history, almost all the way to the obviously ancient Primary rocks with no fossils at all. The 'Silurian' fossils – including animals of highly complex structure such as trilobites – then became the oldest organisms known (apart from a few rare, obscure and dubious traces of still earlier life). Murchison believed that this interpretation was supported by the sequence in the Baltic provinces [now the Baltic states] – undisturbed and with plenty of fossils – which he saw for himself on his long fieldwork tour of Russia in 1840; and by reports from Sweden, where similar formations directly overlay Primary rocks. On the other hand, Sedgwick argued that Murchison's 'Lower Silurian' (the 'Llandeilo' and 'Caradoc' in Wales and the Marches) was truly Cambrian and separated from the 'Upper Silurian' ('Wenlock' and 'Ludlow') by an unconformity – implying a natural boundary – but this failed to convince other geologists. So while 'Silurian' went from strength to strength, recognised by geologists internationally, 'Cambrian' was eclipsed and almost dropped out of use.

In 1846, however, Sedgwick confirmed a local geologist's report that a formation in north Wales that was called '*Lingula Flags*' ('flagstones' used for paving, with fossil shells of the brachiopod *Lingula*) also contained other distinctive fossils, including trilobites, unlike those in the Silurian; it was well down in his 'Cambrian' sequence but still far above any ancient Primary rocks. He and some other geologists thought that these fossils might count towards a distinctive Cambrian fauna, and thereby support a revival of the concept of a Cambrian period in the early history of life. But Murchison rejected this and continued to insist that a much greater contrast with his Silurian fossils would be needed to define a distinct Cambrian fauna and justify a distinct Cambrian period.

Also (by coincidence) in 1846, Joachim **Barrande** began publishing descriptions of superbly preserved trilobites and other fossils from Bohemia [now in the Czech Republic]. With extravagant praise for Murchison, who had already visited him, he confidently identified them all as Silurian. Many were indeed similar or even identical to Murchison's species from the Welsh Marches. But one of Barrande's lowest and oldest formations, directly overlying Primary rocks, yielded a distinctly different set of fossils (mostly trilobites). He included this formation in the Silurian but defined it as '*Primordial*', implying that it marked the very beginnings of life [**FIG. 12**].

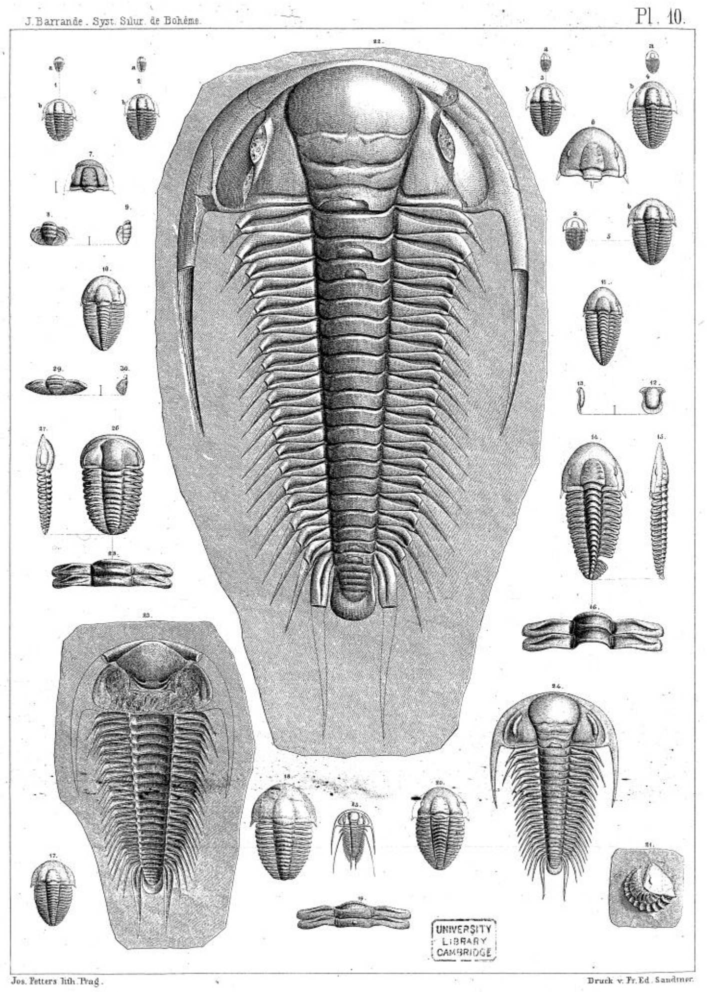


FIG. 12 Barrande's illustrations (1852) of some of the trilobites (and their juvenile growth stages) from his '*Primordial*' formation in Bohemia, assigned by him to the lowest and oldest Silurian but subsequently treated as typical of the Cambrian. In either case these fossils represented the earliest unambiguous organisms then known, yet they were surprisingly large and complex (the largest specimen shown here was 18cm / 7in long, and others were even larger).

In 1851 Barrande visited Britain. On the basis of the fossils he was shown in museum collections, he correlated his Primordial formation with the Lingula Flags. This prompted British geologists to make a further search, in the field, for fossils in all the older Welsh rocks; enough were found to convince them that this correlation was valid. In particular, John **Salter**, who was professionally indebted to both Sedgwick and Murchison, hoped that Barrande's Primordial fauna could lead to a reconciliation between them, if they would agree to define these fossils as representing a distinctive Cambrian fauna. But neither of the now elderly combatants accepted this solution.

Yet Barrande's success in Bohemia prompted more thorough studies elsewhere, and from the 1850s onwards his Primordial fossils were recognised very widely, for example in Sweden, Norway, Canada and the United States. In the 1860s they were also found in Welsh rocks, including famously a two-foot giant trilobite from near St Davids (in southwest Wales). Eventually they became the basis for a revived [and modern] definition of the Cambrian period as that in which animals were first diverse, large in size, and relatively well preserved as fossils. This made it more difficult to support Murchison's persistent claim to have discovered – in his original 'Silurian' of the Welsh Marches – the *earliest* diverse fauna in the history of life, though it was indeed more diverse than the Cambrian fauna. Formations that were still older or pre-Cambrian [later termed *Precambrian*], including Murchison's lowest or 'Longmynd' formations in the Marches, continued – until the mid-20th century – to yield nothing but rare, obscure and controversial traces of still earlier forms of life.

The persistence and vehemence of the *Cambrian-Silurian dispute* – which to modern eyes may look petty – can be seen in retrospect to have been underlain by the widespread belief among 19th-century geologists that 'systems' of rock formations (and the 'periods' of time that they represent) were real *natural* divisions of the geological and fossil record. Only gradually did they come to recognise that its named divisions, while being indeed the record of real events in the Earth's history, are necessarily *conventional* and therefore matters to be settled by negotiation and agreement. One sign of this was that in 1879, after both Sedgwick and Murchison had died, the conflict between 'Cambrian' and 'Silurian' was finally resolved when Charles **Lapworth** proposed '*Ordovician'* (after the Ordovices, a tribe that lived in Wales in Roman times, not far from the Silures) to denote the rock formations and the period of time represented by the contentious overlap.

In conclusion, this argument about the naming of the older rocks of Wales and the Marches – which this historical field-trip will explore by 're-treading' some of the relevant fieldwork – deserves to be put in the wider context of the entire history of the Earth and of life. In 1841, John **Phillips** (William Smith's nephew), whose expert study of the Devonshire fossils had just helped to resolve the Devonian controversy, proposed a threefold division of the record of the history of life into *Cenozoic*, *Mesozoic* and *Palaeozoic* eras. The earliest of these, the *Palaeozoic* era of '*ancient life*', extended from Murchison's then newly defined *Permian*, back in time (or downwards in the pile of formations) through the Carboniferous, the then newly defined Devonian and Murchison's Silurian, all the way to Sedgwick's Cambrian and the very beginnings of the fossil record. Phillips, however, wanted to replace names such as these – derived from the specific rocks found in specific regions – with terms based on the global history of life itself. His three great eras were soon adopted by geologists everywhere. In 1860 he publicly criticised Darwin's claim (in *On the Origin of Species*, 1859) that the fossil record was far too fragmentary to be used as evidence against Darwin's own concept of very slow and gradual evolutionary change. Phillips argued on the contrary that the fossil record, although certainly imperfect, was already known well enough in broad outline to show, among other things, its overall increase in diversity through time. Traced back through the Palaeozoic era, it was eventually reduced almost to zero (in the oldest Cambrian formations). This suggested that the origin of life itself could not be much further back. There was no trace of the immensely long pre-Cambrian fossil record that was expected – not least by Darwin himself – if the already complex organisms of Murchison's Silurian period and Sedgwick's Cambrian had evolved as slowly and gradually as Darwin's kind of evolutionary theorising demanded. This was an enigma that was left to geologists in the 20th century to resolve, as they did in quite unexpected ways.