

[PLATE XII—GEOLOGICAL MAP.]

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The physiography of the district and the features due to ice-action have recently been described by Dr. Marr & Mr. Fearnside¹: it will suffice, therefore, to mention here that the area is a very hilly one, the fells often rising steeply from the 600- to the 1750-foot contour-line. North-west of the Rawthey the hilltops are everywhere formed of hard grits of Ludlow age, while on the south-east intrusive igneous rocks occupy the highest ground.

¹ Q. J. G. S. vol. lxx (1909) pp. 587 *et seqq.*

The general structure of the district at the present day is complex. Originally, there was probably simple folding which was subsequently affected by faulting. Most of the Cautley area is occupied by the Wandale-Hill syncline with a north-by-east and south-by-west axis, and the Bluecaster syncline having a north-north-east and south-south-west axis; these are separated by the Murthwaite-Park anticline, which passes into the Sally-Beck fault close to Northwaite.

In both cases half only of the syncline remains. The Sally-Beck fault has cut out the north-western limb of the Bluecaster syncline, and the western part of the Wandale-Hill syncline has been faulted out by the Wandale-Hill fault, which has thrown down the Upper Wenlock and Ludlow Beds against the Stockdale and Coniston Limestone Series.

Numerous other small faults intersect the area, which are easily traced by zonal mapping.

Though exposures are well seen in many streams, yet no section shows the complete succession through the Salopian. Throughout the area the Wenlock and Ludlow strata differ markedly in their lithological characters: the former may be described as banded argillaceous flags, while the Ludlow rocks are tough, micaceous, sandy flags interstratified with unfossiliferous bands of grit.

Literature.

The Salopian rocks of this district have been briefly described in 'The Geology of the Country around Kendal, Sedbergh, Bowness, & Tebay' Mem. Geol. Surv. 1888, in which a classification into two groups is made: (1) Coniston Flags, and (2) Coniston Grits.

'The Geology of the Country around Mallerstang,' Mem. Geol. Surv. 1891, deals more particularly with the Cautley and Howgill area. The conformable relation of the Coniston Flags and the Stockdale Shales and the lithological characters of the beds are described. *Monograptus priodon* and *M. colonus* are recorded from the Coniston Flags, and *M. colonus* from the Coniston Grits. Unidentified graptolites are said to occur in the Bannisdale Slates.

The most important paper from our point of view is by Dr. Marr,¹ on the Wenlock and Ludlow strata of the Lake District, in which he divides the rocks into the following zones:—

LOWER LUDLOW.	{	Bannisdale Slates.	Zone of <i>Monograptus leintwardinensis</i> .
		Coniston Grits.	Zone of <i>Monograptus bohemicus</i> .
		Upper Coldwell Beds.	
		Middle Coldwell Beds.	Zone of <i>Phacops obtusicaudatus</i> .
WENLOCK.	{	Lower Coldwell Beds.	Zone of <i>Monograptus nilssoni</i> (?).
		Brathay Flags.	Zone of ? <i>Cyrtograptus carruthersi</i> .
			Zone of <i>Cyrtograptus murchisoni</i> .

¹ Geol. Mag. dec. 3, vol. ix (1892) p. 534.

We have recognized the following zones in the Salopian rocks of Cautley and Ravenstonedale:—

LOWER LUDLOW.	{	D ₂ Zone of <i>Monograptus leintwardinensis</i> Hopk.
		D ₁ Zone of <i>Monograptus nilssonii</i> Barr.
<i>Phacops-obtusicaudatus</i> Bed.		
WENLOCK	{	C ₄ Zone of <i>Cyrtograptus lundgreni</i> Tullb.
		C ₃ Zone of <i>Cyrtograptus rigidus</i> Tullb.
		C ₂ Zone of <i>Monograptus riccartonensis</i> Lapw.
		C ₁ Zone of <i>Cyrtograptus murchisoni</i> Carr.

II. THE WENLOCK BEDS.

The Wenlock Series is well exposed in three distinct areas in the Cautley district: namely, in the neighbourhood of the Rawthey, Wandale Hill, and Harter Fell. The rocks present three fairly distinct lithological types: (1) blue flags, (2) yellow sandy beds, and (3) red flags and grits; but in each case the same zones occur. The whole thickness of the Wenlock Series exposed in this area does not exceed 900 feet.

It has been possible to work out the approximate thickness of the zones in the Rawthey area as follows:

	<i>Thickness in feet.</i>
Zone of <i>Cyrtograptus lundgreni</i>	300 to 400
Zone of <i>Cyrtograptus rigidus</i>	178
Zone of <i>Monograptus riccartonensis</i>	160
Zone of <i>Cyrtograptus murchisoni</i>	100

(a) The Rawthey and the Western Slope of Bluecaster.

We have obtained our most complete sections through the Wenlock Series in the neighbourhood of the Rawthey. We therefore propose to describe the Wenlock Beds of this area in detail, and to give only general descriptions of the confirmatory sections elsewhere. Near the Rawthey each zone is exposed, and a conformable succession is obtained downwards into the Browgill Beds, and upwards into the *Phacops-obtusicaudatus* Bed, which here, as elsewhere in the Lake District, separates the strata of Wenlock from those of Ludlow age.¹

The Wenlock Series occupies a narrow strip of country, from Birks Field Beck north-eastwards to the mouth of Wandale Beck. There is uniformity in the character of the beds throughout this area. They are massive jointed flags, finely banded, blue-grey when unweathered, and becoming brown on exposure to weathering agencies.

As has been noticed elsewhere,² the argillaceous character of the rocks has so greatly favoured cleavage that it is always difficult to obtain a good surface along the bedding-planes; even when such

¹ J. E. Marr, *Geol. Mag.* dec. 3, vol. ix (1892) p. 540.

² 'Geology of the Country around Mallerstang' (Expl. of Quarter Sheet 97 N.W.) *Mem. Geol. Surv.* 1891, p. 34.

a surface is obtained, the fossils in places are almost unrecognizable. The complicated system of faulting shows that movements have considerably affected the area; the presence of felsite and lamprophyre dykes is also of interest.

We have observed that the lowest Wenlock Beds invariably have their fossils preserved in relief, and this is a distinctive feature of these beds throughout the whole of the Cautley area.

An ascending section shows a greater tendency towards flagginess in the rock, and the introduction of pyrite in the form of abundant tiny cubes causes the strata to weather to an ochreous colour. The highest beds are characterized by irregular calcareous concretions, varying from a few inches to a foot in diameter; the banding is very marked, and the rocks weather to a light brown.

On the north and west the Sally Beck and other faults bring the Wenlock Beds against strata of their own age, or against the Browgill and Ludlow; but on the Bluecaster side there is a conformable passage downwards into the Browgill Group. The general dip of the beds is 30° north-north-westwards: they strike, therefore, across the gills which run in a north-westerly and westerly direction; but, although sections are numerous, they are, with the exceptions of those in Middle and Near Gills, never complete. As a rule, the fossils occur in bands in the rock, or even along definite bedding-planes. There seems to be no means, however, of distinguishing between the fossiliferous and the unfossiliferous bands.

It is from a study of the exposures in the Bluecaster gills and their fauna that we have become convinced that the Wenlock Beds of this area are divisible into four zones, namely:—

- (1) Zone of *Cyrtograptus lundgreni*. C_4 .
- (2) Zone of *Cyrtograptus rigidus*. C_3 .
- (3) Zone of *Monograptus riccartonensis*. C_2 .
- (4) Zone of *Cyrtograptus murchisoni*. C_1 .

Bluecaster Gills: (i) Far Gill.

The exposures in Far Gill are large and fairly fossiliferous; but the rocks are so highly cleaved that the fossils are almost obliterated, or seen only as smudged impressions. The highly cleaved state of the rocks may be due to the proximity of a fault on the north of the gill.

Cyrtograptus-murchisoni Zone (C_1).—Just above the old road splintered blue flags crop out in the gill-bed, dipping at 36° north-west by north. The fossils found were typical of the zone: *Cyrtograptus murchisoni*, *Monograptus priodon*, and *Orthoceras* occur in abundance. Below the old road two felsite-dykes cross the gill; the rocks are baked by these, and for a distance of 100 yards no fossil is to be found. These beds presumably belong to the zone of *Monograptus riccartonensis*.

The rocks in the higher part of the gill break with greater ease along the bedding-planes, and are ochre-stained.

Cyrtograptus-rigidus Zone (C_3).—At the bend of the stream the lithological character of the rock changes once more to blue-grey banded flags, much affected by cleavage. Along one bedding-plane *Monograptus flexilis* is abundant, and it is the only fossil that is easily recognizable. As we have found throughout the Cautley area that *M. flexilis* is common only in the *C.-rigidus* Zone, it may be taken as an index of that zone.

A characteristic feature of this zone is the introduction of secondary calcite along the joints and bedding-planes of the rock.

Cyrtograptus-lundgreni Zone (C_4).—100 yards down stream the beds dip 20° north of north-west at 24° , and maintain their dark coloration and cleaved character. They yield many specimens of *Monograptus vomerinus*. Some 30 yards from the upper field-wall, however, the beds change; they become tougher, and weather to a light brown. *M. flemingii* var. δ and *M. dubius* were found here. The presence of the former fossil and lithological change in the rocks indicate the *C.-lundgreni* Zone.

(ii) Middle Gill.

Cyrtograptus-murchisoni Zone (C_1).—The felsite-dyke of the old road has baked the *Murchisoni* Beds of Middle Gill; but just below the road a small exposure yields good specimens of *C. murchisoni*, *Monograptus priodon*, *M. vomerinus*, and *Retiolites geinitzianus*.

The zone extends down the gill for a distance of about 60 yards, and other small exposures indicate that *Cardiola* and *Retiolites geinitzianus* are abundant in the higher parts of the zone.

Monograptus-riccartonensis Zone (C_2).—The passage into this zone is marked by a complete change in the fauna. The name-fossil becomes very abundant; indeed, slabs of rock are often covered by it, to the exclusion of any other. The fossils are, on the whole, badly preserved, as the result of cleavage. A list of the forms found is enumerated in Table I (p. 222). The beds dip at 35° north-westwards.

Cyrtograptus-rigidus Zone (C_3).—This zone is well exposed on the right bank of the gill, and extends down stream for 60 yards below the little waterfall.

The rocks dip at 34° north-north-westwards; they are highly cleaved, and contain abundant cubes of pyrite, which cause them to weather to a bright orange colour. The higher part of the zone is characterized by the blackness of the fresh rock, and by the abundant development of secondary calcite. *Monograptus flexilis* is crowded along definite bands in association with *C. rigidus*, *M. vomerinus*, *M. hisingeri*, *M. dubius*, and *M. flemingii* var. δ ; this last fossil becomes more abundant in the highest part of the zone.

Cyrtograptus-lundgreni Zone (C_1).—The lower part of Middle Gill is largely covered by drift, and the few exposures are poor. They yield *M. flemingii* var. δ and *M. dubius*, and dip at 41° north-north-westwards.

A large quarry between Middle and Near Gills on the Sedbergh road yields the associates *C. lundgreni*, *M. flemingii* var. δ , and *M. dubius*. The rock is a very massive blue flag.

(iii) Near Gill.

In Near Gill the exposures are smaller than in either of the gills already described, but the fossils are in a better state of preservation, and all four zones are well seen.

Cyrtograptus-murchisoni Zone (C_1).—Some 30 yards below the old road, a small exposure on the left bank of the gill yields *C. murchisoni* and the forms associated with that fossil. The beds are much affected by the 'old road dyke,' and have been converted into pale, flinty, unbedded rock.

Monograptus-riccartonensis Zone (C_2).—For the next 100 yards the only exposures are very small ones in the gill-bed. It is difficult to identify the fossils, but, from their crowded occurrence and general form, they can be recognized as *M. riccartonensis*.

Cyrtograptus-rigidus Zone (C_3).—At the bend of the stream ochre-stained beds form a small cliff on the right bank, and a scree-slope on the left bank; their dip is 32° north-westwards.

A richly fossiliferous band occurs in the cliff, containing many examples of *C. rigidus* and *Monograptus flexilis*; on the opposite bank *C. linnarssoni*, *C. rigidus*, and *M. flexilis* occur abundantly. *Retiolites spinosus* is also common—this fossil has hitherto been recorded in Britain from the Lower Ludlow rocks only. About 25 yards lower down, an exposure in the left bank yields *C. rigidus* and *Monograptus flemingii* var. α .

The higher part of this zone occupies two scree-slopes 100 yards down stream; here the rocks are characteristically pyritous, and contain *M. flemingii* var. α in abundance.

A small lamprophyre-dyke occurs in the left bank of the gill just below the screes: its trend is north-west by west.

Cyrtograptus-lundgreni Zone (C_4).—Below the dyke pyrite is no longer seen in the rock, which assumes the normal cleaved appearance. The most common species is *M. flemingii* var. γ , here, as usual, characteristic of the lower part of the zone. Some yards farther down *C. lundgreni* occurs in the left bank. Down stream the rocks become less massive, and show a greater tendency to break along the bedding-planes.

The beds throughout the zone dip at 26° north-westwards. Near the Sedbergh road they become lighter in colour and more sandy.

M. flemingii var. γ , *C. lundgreni*, and *M. dubius* are all contained in these highest beds.

Apart from the three gills mentioned previously, numerous small streams which run from Bluecaster into the Rawthey are, with a few exceptions, nameless. We have, therefore, for the sake of convenience, named them alphabetically (see map, Pl. XII).

One or more of the Wenlock zones crop out in each of these gills, and, as the results of our work in them are summarized in Table II (p. 222), it is only necessary here to mention a few points of interest.

(iv) West Gill.

This gill, which flows into the Rawthey below Low Haygarth, is of importance, not only because three of the zones are exposed in its banks, but on account of the conformable succession into the Browgill Beds which can be traced in the southern branch of the gill. *Cyrtograptus murchisoni* occurs in the bed of the gill 20 yards below a cowshed; at the same distance above the shed the Browgill Beds crop out.

The *Riccartonensis* Zone (C_2) comes on 6 yards below *C. murchisoni*. Its beds are almost black, veined with calcite, and speckled with cubes of pyrite; their dip is 5° west of north-west at 55° . The lower part of West Gill is largely occupied by two felsite-dykes, the lower of which is continuous with the 'old road dyke' of Near, Middle, and Far Gills.

Exactly 52 yards from the Sedbergh road, and just below a small lamprophyre-dyke, the rocks dip at 21° north by west, and yield the fauna of the *C. lundgreni* Zone (C_3).

The only other exposures that show the succession from the Browgill into the Wenlock Beds occur—

- (1) In a small dry valley running westwards in continuation of the head of Gill H; and
- (2) 20 yards below Ecker Secker Bridge.

Both these sections show the marked lithological and faunal changes which take place between the beds.

In Ecker Secker Beck the *Cyrtograptus-murchisoni* and *Monograptus-riccartonensis* Zones occur, but the *Cyrtograptus-rigidus* Zone seems to be cut out by faulting. At the hedge on the right bank of the beck there is evidence of faulting; the dip of the beds changes suddenly from 35° to 75° north-north-westwards, and there is considerable local development of secondary calcite in ramifying threads and veins. Some yards lower down the rock becomes concretionary, and *Monograptus flemingii* var. δ occurs. The presence of another fault at the mouth of the beck is proved by a fault-breccia seen in the left bank, accompanied by large veins and bands of calcite.

TABLE II.—GRAPTOLITES FROM BLUECASTER GILLS.

[illegible]

The River Rawthey.

The part of the Rawthey under consideration lies between the mouth of Wandale Beck and Cock's Dub. The Wenlock zones exposed on the western slope of Bluecaster should in turn appear in the banks of the Rawthey; but, as the result of faulting, the succession of zones is irregular.

Above Handley's Bridge the three lowest zones strike across the Rawthey in a south-easterly direction, but they are cut off at the bridge by a fault trending north-west and south-east.

Both the *Cyrtograptus-murchisoni* (C_1) and *Monograptus-riccartonensis* Zones (C_2) near the mouth of Wandale Beck have yielded the characteristic graptolites enumerated in Table I (p. 222).

The zone of *Cyrtograptus rigidus* (C_3) which conformably succeeds them down stream yields few fossil remains; and those which do occur, *Monograptus flexilis* and *M. flemingii* var. *a*, are poorly preserved, owing to movement in the rock close to Handley's Bridge, where there is evidence of both folding and faulting on a considerable scale. At Handley's Bridge the beds change their dips from south-south-west to west by north, and they are seen to strike across the river, and then to bend round towards the right bank.

Although exposures are good below Handley's Bridge, there is a scarcity of palæontological evidence; two zones only are found. The *Cyrtograptus-lundgreni* Zone (C_4) extends from Handley's Bridge to Cautley Thwaite, with the exception of some yards below the mouth of Backside Beck, and is conformably succeeded by the zone of *C. rigidus* (C_3). Below the fault at Low Wardses the *C. lundgreni* Zone (C_4) again appears.

The general dip of the rocks throughout is in a north-north-westerly direction, although variations occur in different parts of the river where it is crossed by faults, as, for example, at the mouth of Backside Beck, where the dip changes to south-west by south, and above High Wardses Bridge, where it is 50° east of north.

The evidence for the establishment of the succession lies below the mouth of Backside Beck. The beds dipping 22° west-north-westwards are yellowish and sandy when fresh, and yield *Phacops obtusicaudatus* in abundance. It will be shown elsewhere that beds containing that trilobite are immediately overlain by the lowest Ludlow, Zone of *Monograptus nilssoni* (D_1); hence in this part we have the completion of the Wenlock succession.

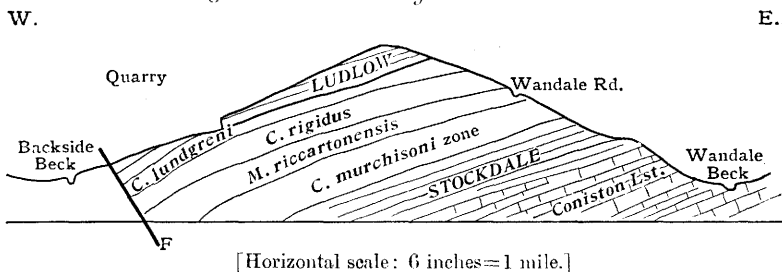
The four Wenlock zones are exposed in the Bluecaster Gills, and are conformably overlain by the *Phacops-obtusicaudatus* Bed as seen in the Rawthey.

(b) Wandale Hill.

The Wenlock and Ludlow rocks form the greater part of the top and the eastern slope of Wandale Hill. These beds are limited on the west by the Wandale-Hill fault, which runs in a north-north-

easterly and south-south-westerly direction, and brings them abruptly against the Stockdale Shales and the Coniston Limestone Series. On the south the Sally-Beck fault forms the boundary of the Wenlock Beds; this runs close to, and almost parallel with, the Rawthey.

Fig. 1.—Section through Wandale Hill.



The eastern slope of the hill shows a conformable passage downwards from the Wenlock into the Stockdale Shales and the Coniston Limestone Series. All these beds sweep round from a north-easterly to an easterly direction below Adamthwaite, and join the rocks exposed in Harter Fell.

Adamthwaite Sike, which forms the northern limit of Wandale Hill, runs through drift, and it is therefore impossible to determine the trend of the beds near the northern limit of the Wandale-Hill fault.

The Ludlow rocks occur as an oval outcrop capping Wandale Hill, and a section showing the Ludlow resting upon the highest Wenlock Beds is seen on the west side of the hill; but on the east side, in the gills near Wandale Farm (which we have named W_1 and W_2) only the three lowest Wenlock zones are exposed. The Wenlock strata of this area are yellow, banded, sandy flags, passing up into the blue banded flags typical of the Rawthey area.

Cyrtograptus-murchisoni Zone (C_1).—The boundary between the Browgill and the Wenlock Beds occurs 40 yards below the Fell wall on East Wandale.

The lowest Wenlock Beds strike parallel to, and are well exposed in many small sections along, the Wandale road. The conformable relation of these *C.-murchisoni* Beds to the Browgill Beds below is well seen in three small gills north of the Northwaite larch wood and in the numerous gills near Wandale. Their passage upwards into the *Monograptus-riccartonensis* and *Cyrtograptus-rigidus* Zones is best shown in two small gills north of Wandale Farm.

In one of these, W_1 , the base of the *Cyrtograptus-murchisoni* Zone is exposed 20 yards below the road, and its upper limit occurs at the road. The rocks, dipping at an angle of 40° north-west by west, are massive, banded, grey and yellow, sandy flags. The

fossils, as elsewhere in this zone, are preserved in relief. Table III (p. 226) shows that the characteristic faunal assemblage of the *Murchisoni* Zone occurs here, *Cyrtograptus murchisoni* and *Retiolites geinitzianus* being especially abundant. *Orthoceras primævum* is also of common occurrence.

Farther north is Gill W₂, in which good exposures of this zone again occur. The zone has been traced to a distance of 30 yards above and 25 yards below the road. The rocks here are roughly cleaved, and dip at an angle of 32° north-north-westwards.

onograptus-riccartonensis Zone (C₂).—Good exposures of this zone are found in Gills W₁ & W₂, and isolated exposures yielding the type-fossil occur farther north in the hillside.

South of Gill W₁ no exposures of this zone are found, but the outcrop of beds evidently narrows towards the Sally-Beck fault, as is indicated by the close proximity of the *Murchisoni* and the *Lundgreni* Zones in the larch-wood.

In Gill W₁ the transition between the *Murchisoni* and the *Riccartonensis* Zones is abrupt, and marked by both a lithological and a palæontological change. On the lower side of the Wandale road the grey banded rocks containing the *Murchisoni* fauna occur; while on the upper side these are replaced by pale-yellow sandy rocks, in which the bedding-planes are crowded with *Monograptus riccartonensis*. The zone extends 48 yards up the gill, the rocks dipping at an angle of 17° north-west by west.

Gill W₂ also gives a good section through the *Riccartonensis* Zone, but only the lower part yields many fossils. The rocks dip at 31° north-westwards, and retain their sandy character; they pass, however, occasionally into a darker and more banded type, as in the hillside exposures towards Adamthwaite, and in Wandale Beck 300 yards below Adamthwaite.

Cyrtograptus-rigidus Zone (C₃).—This zone is well exposed in Gills W₁ and W₂, and in an old quarry-road towards Adamthwaite. Southwards also it has been possible to trace the zone in a small exposure in Wandale slope.

The lower part has the same yellow sandy character as the *Monograptus-riccartonensis* Zone; but, when traced upwards, it gradually passes into a tough, blue, banded rock, which weathers brown.

Characteristic fossils are abundant. In Gill W₁ the beds dip at 42° west-north-westwards, and extend to the top of the gill; but numerous loose blocks on the hillside above, containing fossils common to the zone, indicate that only the lower part is exposed in the gill.

Gill W₂ extends higher up the hillside, and it has therefore been possible to trace the upper parts of the *Cyrtograptus-rigidus* Zone here. The transition between the *C. lundgreni* and the *C. rigidus* Zones is, however, hidden.

Cyrtograptus-lundgreni Zone (C_1).—This zone is best exposed in a small stream-section occurring in a larch-wood above Handley's Bridge. The rocks dip at 25° west by south, and are massive, blue, banded flags containing the characteristic zonal graptolites.

There are no other exposures of this zone on the eastern slope of Wandale Hill, but the fossils may be picked up in abundance at the gathering-grounds of the gills.

A massive grey-green grit occurs near the top of Wandale Hill: it is unfossiliferous, and probably forms part of the Lower Ludlow Series, since nowhere in the area does a grit appear in the Upper Wenlock.

TABLE III.—WANDALE-HILL WENLOCK GRAPTOLITES (GILLS W_1 & W_2).

Species and Varieties. C = very common. c = common. r = rare.	Zone of <i>Cyrtograptus</i> <i>murchisoni</i> . C_1		Zone of <i>Monograptus</i> <i>riccartonensis</i> . C_2		Zone of <i>Cyrtograptus</i> <i>rigidus</i> . C_3		Zone of <i>Cyrtograptus</i> <i>lundgreni</i> . C_4	
	W_1 .	W_2 .	W_1 .	W_2 .	W_1 .	W_2 .	W_1 .	W_2 .
<i>Cyrtograptus linnarssoni</i> Lapw. ....	...	...	...	...	...	c	...	...
<i>Cyrtograptus murchisoni</i> Carr.	C	C	...	...	...	...	...	...
<i>Cyrtograptus rigidus</i> Tullb. ....	...	...	...	...	c	c	...	...
<i>Monograptus capillaceus</i> Tullb. ....	...	...	r	r	...	...	...	...
<i>Monograptus dubius</i> Suess ....	...	...	...	...	C	...	...	...
<i>Monograptus flemingii</i> Salt. var. δ Elles.	...	...	...	...	...	...	C	C
" " " " β "	...	...	...	...	...	...	...	c
" " " " α "	...	...	...	...	...	C	...	...
<i>Monograptus flexilis</i> Elles ....	...	...	...	...	c	C	...	...
<i>Monograptus hisingeri</i> Carr. var.	C	...	C	...	C	...	...	...
<i>Monograptus priodon</i> Brom	C	C	...	...	...	...	...	...
<i>Monograptus riccartonensis</i> Lapw. ....	...	...	C	C	...	...	...	...
<i>Monograptus vomerinus</i> Nich. var. α Elles	C	C	...	C	...	...	...	...
" " " " β "	...	...	...	...	c	...	...	...
<i>Retiolites geinitzianus</i> Barr.	C	C	...	...	...	...	...	...
<i>Retiolites spinosus</i> Wood ....	...	...	...	...	C	C	...	...

West Wandale.

On the west side of Wandale Hill the Wenlock again crops out, and the *Lundgreni* Zone (C_1) is found overlain by the *Monograptus-nilssoni* Zone (D_1) of the Lower Ludlow. The Lower Wenlock zones are cut out by the Wandale-Hill fault, which has let down the Upper Wenlock and Ludlow Beds against the Browgill Beds and the Coniston Limestone Series.

The only exposures occur in a small gill, which flows down from the site of an old quarry above Northwaite to join Backside Beck. Where the gill crosses the Mountain-View Road, the Coniston-Limestone Beds are faulted against the Wenlock strata. These appear as blue finely-banded flags, with many concretions. The dip

is at 59° south-west by south, and cleavage has been induced in the beds. *C. lundgreni* and *Monograptus flemingii* vars. γ & δ were found a few yards above the road. Yellow sandy beds yielding small brachiopods and *M. dubius* overlie the *C. lundgreni* Zone (C_4), and above follow darker gritty beds containing graptolites of the *M. nilssoni* Zone.

(c) Harter Fell.

The top of Harter Fell is occupied by Lower Ludlow rocks, and, on passing down its southern and south-eastern slopes, we traverse the Wenlock, Browgill, and Llandovery Beds in turn.

Numerous little gills, making deep gashes in the hillside, afford the best exposures of the Wenlock Beds. The fossils of the lowest Wenlock are preserved in the typical solid form, and the beds themselves are blue-grey banded flags. A lithological change comes in with the appearance of *Monograptus riccartonensis*; the rocks weather with a red stain, and are gritty. The red coloration becomes accentuated as the beds are traced upwards into the red Ludlow grits.

The Wenlock zones sweep round Harter Fell in a semicircle, and are cut off abruptly on the east by the Sally-Beck fault. They all crop out within the short distance of 230 yards. Their prevailing angle of dip is a high one, and the direction varies between north and north-north-west. The Browgill Beds are exposed below the Wenlock in Five Gills; elsewhere the strata are hidden by grass and drift.

Each individual zone differs little from those previously described. Therefore only a list of places is given, where each zone is exposed:—

<i>C. murchisoni</i> Zone (C_1)	Gill 2 (Five Gills).
<i>M. riccartonensis</i> Zone (C_2)	Gills 2, 3, 4, 5 (Five Gills). Odd Gill, and at the waterfall in Wan- dale Beck below Adamthwaite.
<i>C. rigidus</i> Zone (C_3)	Gills 3, 4, 5 (Five Gills).
<i>C. lundgreni</i> Zone (C_4)	Gills 2, 3, 4, 5 (Five Gills). Gills 1 & 2 (Three Gills).

West of Harter Fell the Wenlock Beds are covered by drift, the only exposures being those mentioned in Odd Gill and Wandale Beck. They reappear, however, in Spen Gill. Here the Browgill Beds pass up conformably into blue banded flags containing *Monograptus priodon*, *Cyrtograptus murchisoni*, and *Retiolites geinitzianus*. Higher in the gill the rocks have suffered much from cleavage, and the only fossil fragments found were unrecognizable.

At the waterfall calcareous concretions appear, and with them *Monograptus flemingii* var. δ and *M. irfonensis*. *Phacops obtusicaudatus* was found in a yellow sandy bed occurring between the top of the *C. lundgreni* Zone and the base of the *M. nilssoni* Zone.

III. THE LUDLOW BEDS.

The Lower Ludlow rocks occupy the greater part of the high ground of the Howgill Fells; the lower beds pass up conformably into the Bannisdale Slates, which in their turn pass beneath the Carboniferous rocks of Ravenstonedale. An outlier of Ludlow rock, which is not indicated on the Geological Survey map, occupies the summit of Wandale Hill.

The Ludlow rocks of the Howgill area consist largely of banded, micaceous, sandy beds alternating with grit-bands; these serve to distinguish the Ludlow rocks from the argillaceous flags of the Wenlock Series. Graptolites are fairly abundant in the lowest Ludlow Beds, but usually they are poorly preserved owing to the coarse nature of the rock; exceptions are found in those bands where the fossils occur in relief.

Dr. Marr¹ has shown that the Ludlow rocks of the Lake District may be divided into two main zones, those of *Monograptus bohemicus* at the base and *M. leintwardinensis* at the upper limit. Our work in this area supports this earlier classification.

In addition to the graptolite fauna, lamellibranchs and brachiopods occur in much greater abundance here than in the Wenlock Flags.

The Ludlow Beds are most fully developed in the Ravenstonedale Common area; but, since the watershed occurs in the Ludlow rocks, no complete section is found, and hence it has not been possible to trace the passage between the *Nilssoni* and the *Leintwardinensis* Zones. There is evidence of considerable folding on both sides of the watershed, and this is further complicated by two sets of fault-lines which run at right angles to one another, and the great shatter-belt described by Dr. Marr & Mr. Fearnside.² Traced upwards from the yellow *Phacops-obtusicaudatus* Bed, the rocks may be divided into two groups:—

- (1) Blue-grey banded flags alternating with unfossiliferous blue micaceous beds which are cleaved and silky in appearance, succeeded by red micaceous grits and flags, with few fossils.

Throughout this group fossils belonging to the *Monograptus-nilssoni* Zone are found.

- (2) Grey banded flags, red grits, and blue slaty beds (the Bannisdale Slates) in which *M. leintwardinensis* is common.

The outcrop of the greater part of the *M. leintwardinensis* Zone is not inserted in the accompanying map (Pl. XII), as it occurs farther north, and agrees practically with the line between the Coniston Grit and the Bannisdale Slate on the Geological Survey map. The most fossiliferous development of the lowest Ludlow occurs on Wandale Hill.

¹ Geol. Mag. dec. 3, vol. ix (1892) p. 541.

² Q. J. G. S. vol. lxx (1909) pp. 589 *at seqq.*

(a) The Ludlow Beds of Wandale Hill.

The summit and the north-western slope of Wandale Hill are formed of Lower Ludlow strata, the outcrop being semi-elliptical; on the east and south-west the lowest beds pass conformably downwards into the Wenlock Series. On the west, however, they are faulted against the Browgill Beds, and farther north along the Spengill Road are faulted out. Only the *Monograptus-nilssoni* Zone is found on Wandale Hill.

The exposures occur in an old quarry above Northwaite, just below the Spengill Road; and in the heads of three gills which cross the same road farther north.

Northwaite Quarry.—The lowest beds crop out immediately below the west side of the quarry-wall; they are tough, blue, banded flags, rather coarse and sandy in texture, yielding *Monograptus dubius* in association with *M. colonus*.

Above the wall fossils typical of the *M.-nilssoni* Zone are abundant. They occur in relief in a band of blue flags, above which sandy and minutely banded blue flags dipping at 36° south-west by south are exposed; the fossils in these are preserved as impressions only. *M. colonus*, *M. bohemicus*, and *Cardiola interrupta* are met with most frequently.

The higher beds in the quarry are grey-green, slaty, unfossiliferous flags.

TABLE IV.—WANDALE-HILL LUDLOW GRAPTOLITES.

Species and Varieties. C = very common. c = common. r = rare.	Zone of <i>Monograptus nilssoni</i> .			
	Northwaite Quarry.	Gill 1.	Gill 2.	Gill 3.
<i>Monograptus bohemicus</i> Barr.	C	..	..	..
<i>Monograptus chimæra</i> Barr.	C	..	C	C
" " var. <i>salwegi</i> Hopk. ....	..	C	..	c
<i>Monograptus colonus</i> Barr.	C	C	C	C
<i>Monograptus comis</i> Wood	C	..	..	..
<i>Monograptus dubius</i> Suess	c	..	..	c
<i>Monograptus nilssoni</i> Barr.	r	..	r	..
<i>Monograptus ræmæri</i> Barr. ....	..	..	..	c
<i>Monograptus varians</i> var. <i>pumilus</i> Wood	C	..	..	c
<i>Monograptus wandaleensis</i> , sp. nov.	C	..	..	..
<i>Retiolites nassa</i> Holm .....	..	..	c	..

Spengill Road Gills.—The Ludlow strata in these three gills are sandy, banded flags of a higher horizon than those exposed in Northwaite Quarry; when weathered the rocks assume an

ochreous colour. The heads of all three gills rise in the *M.-nilssoni* Zone, as will be seen from an examination of Table IV (p. 229). Fossils are fewer than in the Northwaite-Quarry beds; but in the third and largest gill they are well preserved and fairly abundant.

Two exposures of a fine grey-green grit—one in the site of an overgrown quarry near the summit of the hill overlooking Adamthwaite, and the other in the hillside above Northwaite, probably represent a higher horizon of the *M.-nilssoni* Zone.

(b) The Ludlow Beds of Ravenstonedale Common.

The beds, dipping in a general north-north-easterly direction, are exposed in numerous streams flowing northwards and southwards from the watershed, and in small quarries occurring in the hill-sides.

Spen Gill and Dale Gill.—The Lower Ludlow rocks are well exposed in the higher part of Spen Gill, which flows southwards from the Howgill watershed, and in Dale Gill flowing northwards.

At the source of Spen Gill good specimens of *Monograptus bohemicus* and *M. colonus* were obtained in some abundance, from a micaceous band of rock which weathered red; and throughout the upper part of the gill occasional fossiliferous bands are found in the blue banded grits, yielding *M. colonus* and *M. roemeri*.

Across the watershed small scree-slopes occur in the hillside of Green Bell; palæontological evidence still points to the continuation of the *M.-nilssoni* Zone (D_1), for graptolites of the *colonus* type preserved in relief are common.

At the source of Dale Gill similar rock crops out; but the fossils are poor, and only preserved as impressions. The head of Stwarth Gill has yielded *Cardiola*, *Orthis*, and *Pterinea*; and a few badly preserved graptolites occur in a red grit which alternates with red micaceous flags.

Lower down the gill the rocks again change to blue-grey grits, sandy beds with lamellibranchs and trilobites (*Acidaspis*), and smooth unfossiliferous flags. No graptolites were found until 50 yards below the junction of Stwarth and Dale Gills, where a highly fossiliferous blue band crops out at the bend of the river, containing *Monograptus leintwardinensis* with many lamellibranchs and trilobites. The beds dip at 36° east-north-eastwards.

Gais Gill and Adamthwaite Road.—A small quarry situated in Adamthwaite Bank, overlooking the right tributary of Gais Gill, has yielded abundant specimens of *Monograptus leintwardinensis*, which tend to be preserved in relief in a hard, banded, blue-grey flag. No further exposures occur until this tributary joins with Long Gill, forming Gais Gill. Here the rock dips at 37° north-north-eastwards; it consists of coarse and fine red grits alternating with flags in which *M. bohemicus*, *M. colonus*, and

Cardiola interrupta are common. These fossils all indicate the *M.-nilssoni* Zone.

The gill flows practically on the strike of these rocks as far as the footbridge on the Adamthwaite Road. A small exposure of typical hard, blue, banded Wenlock rock occurs here in the left bank of the stream, and has yielded specimens of *M. flemingii* var. α , which is a typical fossil of the *C.-rigidus* Zone. Beyond this point, for a distance of 170 yards, no good exposure occurs until a quarry on the Adamthwaite Road is reached, in which fossils characteristic of the *M.-nilssoni* Zone are fairly numerous. The rock is similar to that previously described in the upper part of Gais Gill, and dips at an angle of 26° north-north-eastwards. Beyond this quarry the surface is again hidden by vegetation, until exposed in a cutting in the roadside, opposite a shed south of Banks Farm, which again yielded *M. leintwardinensis*. The rocks dip 39° north-north-eastwards. This succession of zones, with the rocks all dipping in a general north-north-easterly direction, seems to point to isoclinal folding in this region.

Isolated exposures.—The zones of *Monograptus nilssoni* and *M. leintwardinensis* are seen in numerous other stream-sections, but only a few present fresh features of interest.

Stonely Gill and Two Gills rise in Harter Fell, and show large exposures of Lower Ludlow rocks, which only differ from those previously described in their red coloration. *M. bohemicus*, *M. colonus*, and *M. remeri* were found, in addition to *Cardiola interrupta* and *Orthoceras*; these fossils clearly indicate the zone of *M. nilssoni* (D_1). The *M.-leintwardinensis* Zone (D_2) was met with in Bowderdale Beck and in Pinskey Gill, just north of Pinskey Bottom: the latter locality yielded *M. leintwardinensis* and its variety *incipiens*; these two varieties have so far not been found together.

IV. CORRELATION.

(1) The Wenlock Beds.

A glance at Table V (p. 233) will serve to show that there is abundant evidence in the Cautley area for a zonal classification of the Wenlock Beds. Each of the four zones is clearly marked off from the other three by a distinctive fauna; also the fossils which give their names to the zones are strictly limited to one zone, and, with the exception of *Cyrtograptus lundgreni*, range through the entire zone.

We have preferred to retain *C. lundgreni* as the zone-fossil of the highest Wenlock Beds, as Miss Elles has already chosen it for beds of the same age in the Welsh Borderland. For purposes of identification of the zone, however, the varieties of *Monograptus flemingii* γ & δ have been most useful to us.

As *Cyrtograptus linnarssoni* is found only in association with *C. rigidus* at Cautley, we have correlated our *Rigidus* Zone with the zones of *C. linnarssoni* and *C. rigidus* of Builth.

The assemblage of forms below the *C.-rigidus* Zone do not justify the interpolation of another zone in Cautley between this and *Monograptus riccartonensis*. We have recognized four zones only (see Table V, p. 233).

TABLE V.—DISTRIBUTION OF THE GRAPTOLITES IN THE SALOPIAN ROCKS OF WALES AND THE WELSH BORDERLAND, AND IN THOSE OF CAUTLEY AND RAVENSTONEDALE.

Species and Varieties.	WALES and the WELSH BORDERLAND.					CAUTLEY and RAVENSTONEDALE	
	Ludlow.					Ludlow.	
	Zone of <i>Monograptus</i> <i>vulgaris</i> .	Zone of <i>Monograptus</i> <i>nilssonii</i> .	Zone of <i>Monograptus</i> <i>scanicus</i> .	Zone of <i>Monograptus</i> <i>tumescens</i> .	Zone of <i>Monograptus</i> <i>leintwardinensis</i> .	Zone of <i>Monograptus</i> <i>nilssonii</i> .	Zone of <i>Monograptus</i> <i>leintwardinensis</i> .
C = very common.							
c = common.							
R = very rare.							
r = rare.							
<i>Monograptus bohemicus</i> Barr.	C	c	r	...	...	C	...
<i>Monograptus chimæra</i> Barr.	c	C	r	...	...	C	...
" " var. <i>a</i>	c	c	...	...	...	...	...
" " var. <i>salweeni</i> Hopk.	c	...	...	...	...	C	...
<i>Monograptus colonus</i> Barr.	C	...	...	...	...	C	...
" " var. <i>compactus</i> Wood	r	...	...	...	...	...	...
<i>Monograptus comis</i> Wood	r	...	...	...	...	c	...
<i>Monograptus crinitus</i> Wood	r	...	...	...	...	...	...
<i>Monograptus dubius</i> Suess	C	c	c	...	...	c	...
<i>Monograptus gotlandicus</i> Perner	c	...	...	...	...	...	...
<i>Monograptus leintwardinensis</i> Hopk.	r	...	...	...	c	...	C
" " var. <i>incipiens</i> Wood ....	...	...	...	c	...	...	c
<i>Monograptus nilssonii</i> Barr.	C	...	...	...	...	R	...
<i>Monograptus ræmeri</i> Barr.	r	c	...	...	c	c	...
<i>Monograptus scanicus</i> Tullb.	c	c	c	...	...	...	...
<i>Monograptus tumescens</i> Wood ....	...	c	c	c	...	...	...
" " var. <i>minor</i> M'Coy ....	...	c	c	...	...	...	...
<i>Monograptus ultimus</i> Perner ....	...	...	...	r	...	...	...
<i>Monograptus uncinatus</i> var. <i>micropoma</i> Jækel	r	...	...	...	...	R	...
<i>Monograptus uncinatus</i> var. <i>orbatus</i> Wood	r	...	...	...	...	...	...
<i>Monograptus varians</i> Wood	c	...	...	...	...	...	...
" " var. <i>a</i> Wood	r	...	...	...	...	...	...
" " " <i>β</i> Wood	c	...	...	...	...	...	...
" " var. <i>pumilus</i> Wood	C	C	...	...	...	c	...
<i>Monograptus vulgaris</i> Wood	C	...	...	...	...	...	...
" " var. <i>a</i> Wood	c	...	...	...	...	...	...
" " " <i>β</i> Wood	r	...	...	...	...	...	...
<i>Monograptus wandalensis</i> , sp. nov.	C	...
<i>Retiolites nassa</i> Holm	r	c	...
<i>Retiolites spinosus</i> Wood	C

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(2) The Ludlow Beds.

We have been able to distinguish two zones only in the Howgill Fells, those of *Monograptus nilssoni* and *M. leintwardinensis*: the watershed of the Howgill area is occupied by rocks which are so unfossiliferous that the evidence obtained from that region is insufficient to permit the establishment of any zone. We have, therefore, included it in the upper part of the *M. nilssoni* Zone. It may possibly represent the *M. scanicus* and *M. tumescens* Zones found by Mrs. Shakespear in Wales and the Welsh Borderland. It is of interest to note that *M. bohemicus* is a far more characteristic fossil of the first zone than *M. nilssoni*. The similarity between this area and the Lake District has already been pointed out (p. 228).

TABLE VI.—CORRELATION OF THE SALOPIAN ROCKS.

Cantley.	Welsh Borders.	Southern Sweden.
Zone of <i>Monograptus leintwardinensis</i> .	Zone of <i>M. leintwardinensis</i> .	
Grits and flags { ? =	Zone of <i>M. tumescens</i> . Zone of <i>M. scanicus</i> .	
Zone of <i>Monograptus nilssoni</i> .	Zone of <i>M. nilssoni</i> .	
Zone of <i>Phacops obtusicaudatus</i> . (?) =	Zone of <i>M. vulgaris</i> .	
Zone of <i>Cyrtograptus lundgreni</i> .	Zone of <i>C. lundgreni</i> .	Zone of <i>C. carruthersi</i> .
Zone of <i>Cyrtograptus rigidus</i> .	{ Zone of <i>C. rigidus</i> . Zone of <i>C. linnarssoni</i> . Zone of <i>C. symmetricus</i> .	{ Zone of <i>C. rigidus</i> .
Zone of <i>Monograptus riccartonensis</i> .	Zone of <i>M. riccartonensis</i> .	Zone of <i>M. riccartonensis</i> .
Zone of <i>Cyrtograptus murchisoni</i> .	Zone of <i>C. murchisoni</i> .	Zone of <i>C. murchisoni</i> .

V. PALEONTOLOGY.

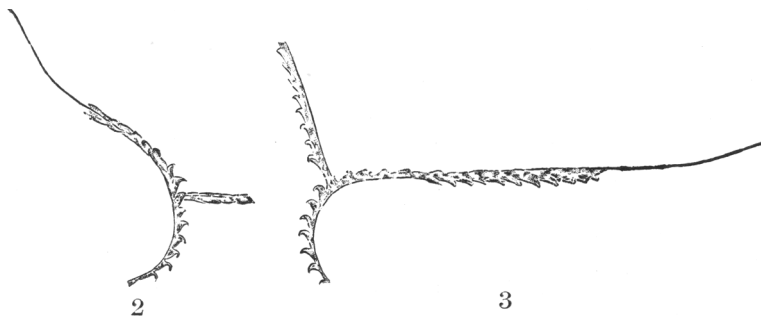
CYRTOGRAPTUS RIGIDUS, Tullb. (figs. 2 & 3, p. 235).

Our specimens of this Cyrtograptid are intermediate in form between *C. rigidus* and *C. symmetricus*; we find that the branching almost invariably occurs at the seventh or eighth theca, and that the first nine thecae are of the proximal type: these characters constitute a slight divergence from both *C. rigidus* and *C. symmetricus*.

Several specimens show prolongation of the virgula in both branches. It has seemed best, however, to adhere to the name first given by Tullberg, since in general form our specimens agree

with the one most completely figured by him in 'Skånes Graptoliter' pt. ii, 1883, pl. iv, fig. 12. Previously¹ we have called this species *C. symmetricus*, Elles.

Figs. 2 & 3.—*Cyrtograptus rigidus*, Tullb. $\times 2$.

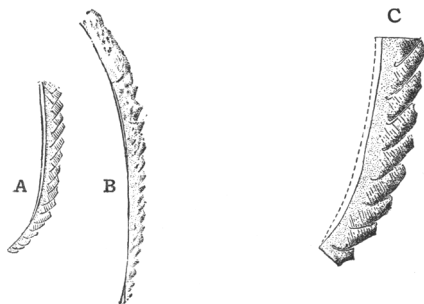


[2, coll. J. E. Marr; 3, from Near Gill.]

MONOGRAPTUS WANDALENSIS, sp. nov. (fig. 4).

Polypary.—Maximum length observed = 2.5 mm.; width at proximal extremity = 0.5 mm., increasing to a maximum of 1.5 mm. at the distal end. Curvature dorsal, variable in amount, in some specimens much marked at the proximal end.

Fig. 4.—*Monograptus wandalensis*, sp. nov., from Wandale Hill.



[A=Proximal extremity, $\times 2$; B=Proximal extremity, showing part of sícula, $\times 2$; C=distal thecæ, showing growth-lines, $\times 5$.]

Thecæ.—Thirteen in 1 cm.; inclined to the axis at an angle of 35° . The thecæ show a tendency to narrow towards the aperture. Apertural margin concave. Overlap of thecæ a half to two-thirds of their length.

This form may be readily distinguished from all other Ludlow

¹ Geol. Mag. dec. 5, vol. vii (1910) p. 473.

graptolites by the marked dorsal curvature conspicuous throughout its length.

Locality, etc.—Wandale Hill, zone of *M. nilssoni*; associated with *M. bohemicus*, *M. nilssoni*, and *M. colonus*.

In conclusion, we wish to express our gratitude to Dr. Marr for all the advice and encouragement which he has given us throughout. We also wish to thank Prof. Charles Lapworth for the interest which he has shown in our work; Mrs. Shakespear for help in the identification of fossils and for the drawings of the graptolites figured in this paper; and Miss G. L. Efles, D.Sc., for much help in the past.

EXPLANATION OF PLATE XII.

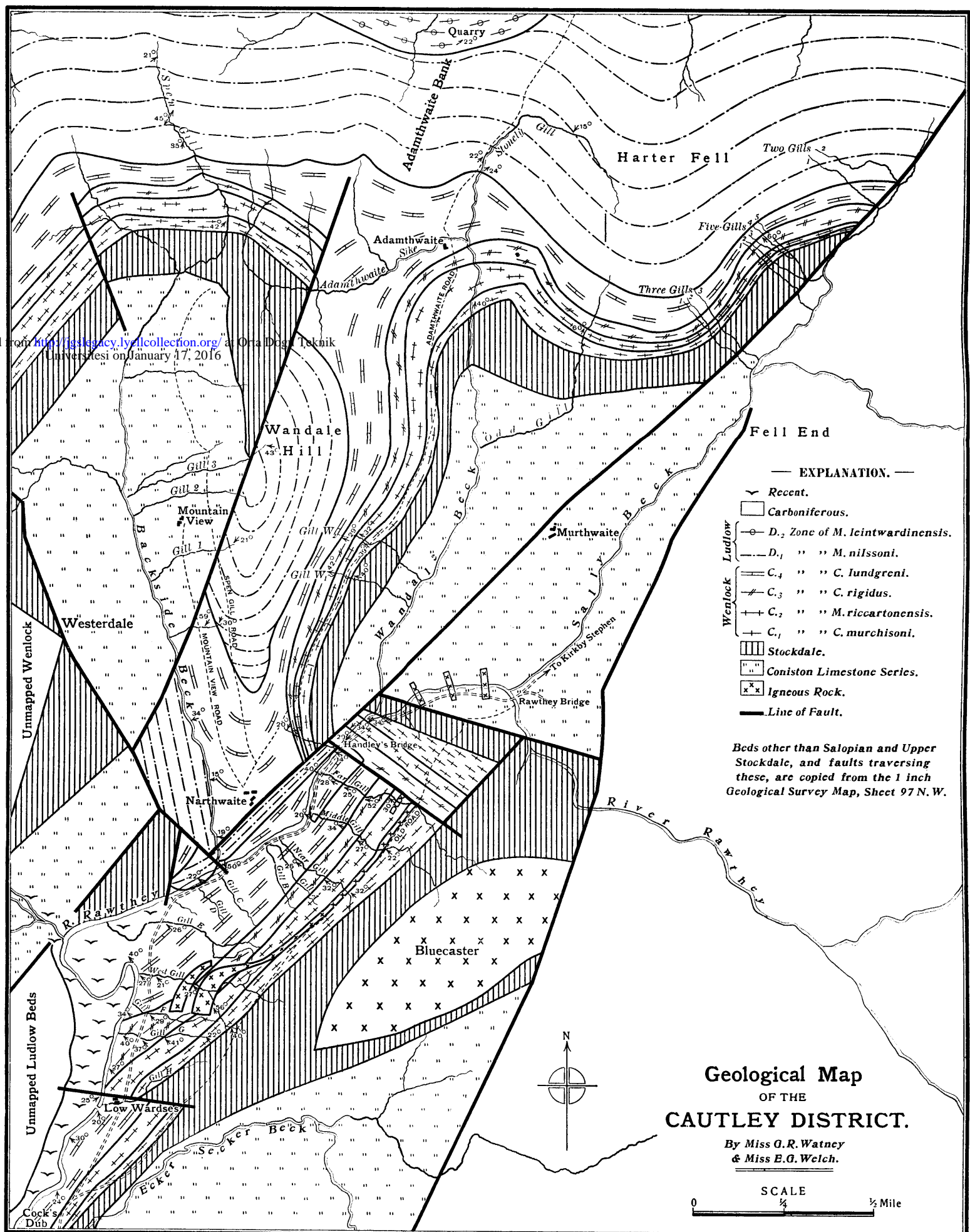
Geological map of the Cautley and Ravenstonedale area,
on the scale of 3 inches to the mile, or 1 : 21,120.

DISCUSSION.

Prof. T. McKENNY HUGHES thought that the Fellows of the Society would be best able to realize the difficulties with which the Authors had been confronted, if they were to imagine that the Eastern Counties had been upheaved some 2000 feet, and that deep valleys and bays and inlets had been cut through the newer rocks, exposing the floor of older rocks below, which had been folded and faulted and altered; and that the parts under observation consisted of rocks differing little in detail of lithological character through great thicknesses, while fossils were scarce and badly preserved. Such represented very fairly the problem which the Authors had attempted to solve when they undertook to determine the sequence and distinguish the zones in the Silurian rocks exposed by denudation in the deep valleys cut through the Carboniferous rocks of West Yorkshire.

Edward Forbes had explained the importance of taking representative forms in classifying strata by their fossil contents, pointing out that percentages of fossils in common did not furnish a basis for correlation, unless the forms were identical or representative—that was, if nothing but trilobites had been found in the one, and nothing but brachiopods in the other, and there were not a species in common, still the beds might not be remote in age. The Authors, as might be seen in their tabular synopsis, had recognized the importance of this as far as was possible in the circumstances, and had taken various species of graptolites as characteristic of zones. It was obviously not a pedigree, and it remained to be found out where the variations arose and why new forms took the place of the old. Here again the speaker wished to call attention to the difficulties of the work. Graptolites were hard to find, especially when the beds had been cleaved and altered, and the sheen of rain was on the rock.

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Universitesi on January 17, 2016



The index to the map began with the Coniston Limestone Series. The speaker had cut off the upper part of this under the name of Fairy Gill Shale, which was the equivalent of that so well described by Dr. Marr in the adjoining Lake District as Ashgillian. There was a troublesome fossil at this horizon, the difficulty in respect of which Davidson left unsolved. This was *Strophomena siluriana*, which had not yet been satisfactorily distinguished from the *Orthis hirsutensis* of the upper or proper Hirnant Limestone, which the speaker would regard as the equivalent of the very variable base of the next division in the Authors' index—namely, the Stockdale Shale, which forms the basement-bed of the Silurian.

The Authors had attacked principally the enormous overlying series of rocks, which, sometimes more sometimes less sandy, but rarely justifying the name of grit, appeared to be the Northern Type corresponding to the Wenlock and Ludlow of South Wales. They had not here, as in the case of the Southern Type, well-marked limestones (the Woolhope, the Wenlock, and the Aymestry Limestones) to help them to run lines across an obscure country; but, by working out the graptolitic fauna of every available exposure, they had succeeded in correlating the sequence with that of other better-known areas, especially with that of Scandinavia. Such a work required great knowledge, care, and staying power, qualities by which the Authors had made a notable advance in geological research.

Dr. MARR, replying, in the absence of the Authors, remarked that there was nothing to answer, but that he wished, as one who knew the district, to express his satisfaction with the detailed and accurate results obtained in an area where, owing to the somewhat monotonous uniformity of lithological characters, separation of the zones by such characters was almost impossible until the fossil horizons had been determined in the manner pursued by the Authors.