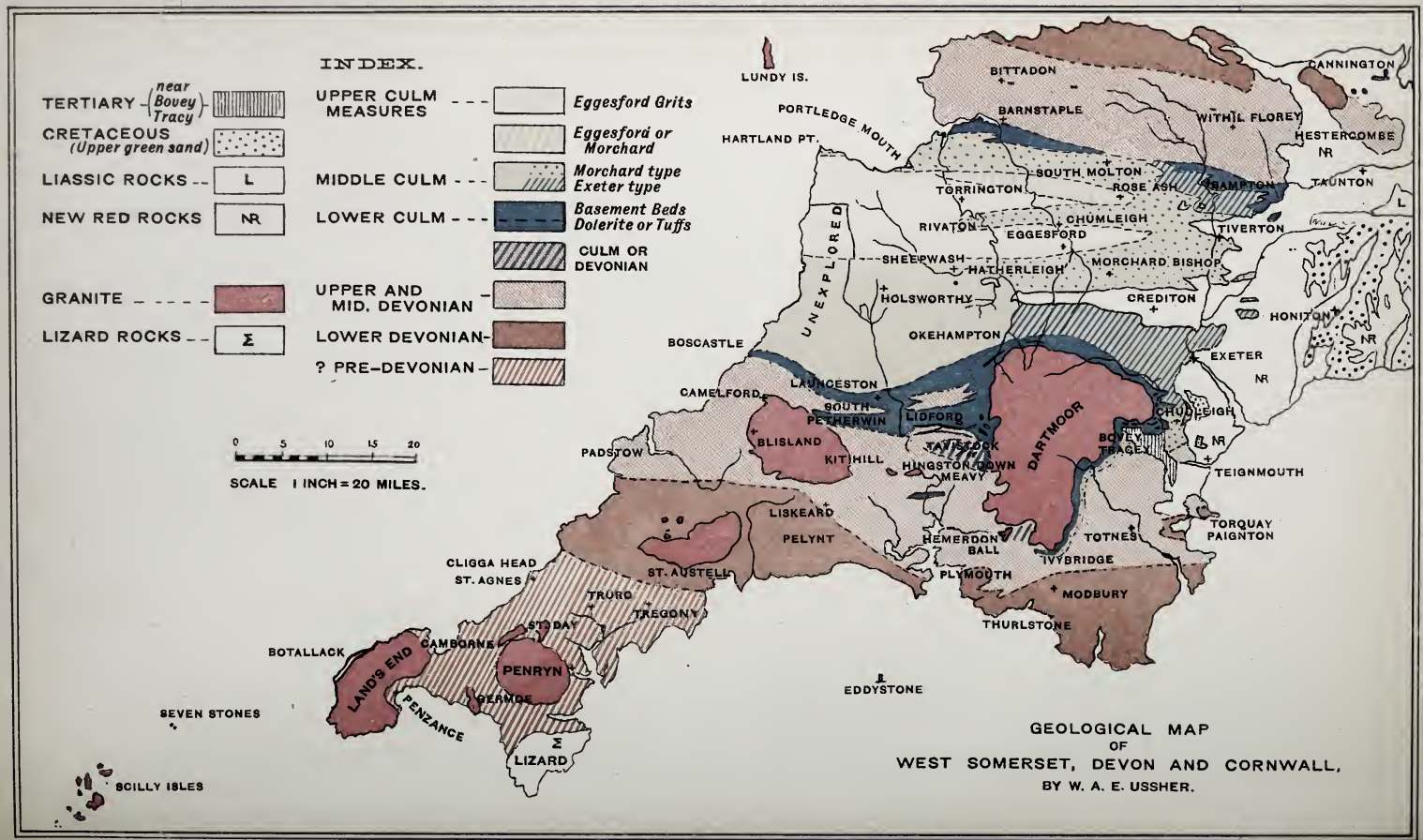
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CULM OR DEVONIAN
UPPER AND MID. DEVONIAN
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? PRE-DEVONIAN
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SCALE 1 INCH = 20 MILES.
LUNDY IS.
HARTLAND PT.
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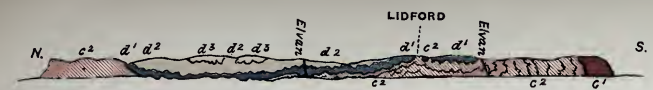

N. & S. SECTION THROUGH LIDFORD ON THE WEST SIDE OF DARTMOOR.
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- STRIKES

0 5 10 15 20

SCALE 1 INCH = 20 MILES.

Theoretical subterranean connection of Granite masses indicated by a pale pink wash.

SCILLY ISLES

LUNDY ISD

BITTADON

Felsite occasionally visible along the Line

BARNSTAPLE

PORTLEDGE MOUTH

HARTLAND PT.

WITHIL FLOREY

CANNINGTON

ADSCOMBE

HESTERCOMBE

SOUTH MOLTON

ROSE ASH

BAMPTON

TAUNTON

TORRINGTON

RIVATON

CHUMLEIGH

EGGESFORD

TIVERTON

SHEEPWASH

HATHERLEIGH

MORCHARD BISHOP

HOLSWORTHY

CREDITON

HONITON

OKEHAMPTON

EXE MOOR

EXETER

BOSCASTLE

LAUNCESTON

CAMELFORD

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LIDFORD

CHUDLEIGH

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BOVEY TRACEY

Normal line of outcrop of Basement Culm Measures at Junction with Upper Devonian

PADSTOW

HUDSTON DOWN

WATERGATE BAY

LISKEARD

ST AUSTELL

PELYNT

HEMERDON BALL

TOTNES

PAIGNTON

CLIGGA H.D

ST. AGNES

IVYBRIDGE

PLYMOUTH

TRURO

TREGONY

MODBURY

THURLSTONE

ST. DAY

CAMBORNE

BOTALLACK

LANDS END

PENRYN

GERNOE

ST MICHAELS MOUNT

LIZARD

EDDYSTONE

MAP SHOWING THE DISTRIBUTION OF THE GRANITES AND ELVANS
WITH REFERENCE TO THE GENERAL STRIKES,

BY W. A. E. USSHER.

The British Culm Measures.

BY W. A. E. USSHER.

By permission of the
Director General of Her Majesty's Geological Survey.

PART I.

INTRODUCTION.

IN a paper "On the probable nature and distribution of the Palæozoic strata beneath the Secondary rocks of the South Western Counties," which appeared in the Proceedings of the Somersetshire Arch. & Nat. Hist. Soc. for 1890, the relations of the Devonshire Culm Measures were briefly discussed. In the present communication I propose to consider, specially, the Culm Measures of the South Western Counties; amplifying in many important particulars the brief accounts published in the Geological Magazine for January, 1887, and discussing in a separate section the effects on the structure of the Culm Measures produced by the Granite.

An admirable *resumé* of the early literature of the Culm Measures will be found in Dr. H. Woodward's invaluable paper.* The general structure of the Culm Measures has long been known† : it is admirably sketched in De la Beche's section‡ from Marsh, near Swimbridge, on the north, to Cawsand Beacon, Dartmoor, on the south, where the distribution of the beds in a shallow synclinal, complicated by many lesser folds, is shown. The correspondence of the lower

* Geol. Mag. for 1884, p. 534.

† Sedgwick and Murchison Rep. Brit. Ass. Vol. 5, p. 95, 1836. Rev. D. Williams, Rep. Proc. Brit. Ass. *Athenæum*, Oct. 7. 1837.

‡ Rep. on. Geol. of Cornwall, Devon and Somerset, p. 116 and Plate 2, fig, 1.

horizons of the Culm in North and South Devon is shown—in the indication of "carbonaceous limestone" patches at intervals from Fremington to Bampton and in the vicinity of Westleigh and Holcombe Rogus near the northern boundary, and along a curved strike deflected by the Dartmoor Granite, from Drewsteignton by Bridestow to Launceston—in De la Beche's maps and in his Report.* De la Beche also pointed out the presence of igneous rocks partly contemporaneous in the lower Culm Measures of South Devon and their absence in the north. He draws a distinction between the junction of the carbonaceous rocks with the Grauwacke (Devonian) on the north, which displays "a passage of the one system into the other,† and the irregularity of the evidence in the southern district; the boundary being "a marked line" conformable but without signs of passage near Boscastle, and very indefinite through intercalation of volcanic rocks near Tavistock. He figures‡ a thrust-fault junction near Landue Mill between Launceston and Callington as a sign of unconformable position, though recognizing the overthrusting, and mentions§ appearances of discordance between the faulted Culm outlier above Conator quarry, near Newton Abbot, and the Devonian limestone pointed out to him by Godwin-Austen, without however committing himself to a definite opinion.

Dr. Harvey Holl regarded the relations of the Culm and Devonian as completely unconformable, from the absence of correspondence in the Devonian rocks in North and South Devon underlying corresponding Culm horizons, and considered the Devonian slates bounding Hingston Down to be the oldest members of that series.

* Ordnance Geol. Sur. Maps, sheets 21, 26 and 25. Report, pp. 117, 118, and Map. H. Ibid, pp. 119 to 123.

† Report, p. 102.

‡ *Ibid*, p. 107.

§ *Ibid*, p. 111.

|| Quart. Journ. Geol. Soc. for April, 1868 p. 441, &c.

In studying chapters iv. and v. of De la Beche's Report it is necessary to bear in mind the fact that reversed dips are not allowed for; hence the discussion of abnormal relations in the southern area where reversed dips are the rule. Dr. Holl advanced the methods of the study of the South Devon stratigraphy by insistence on reversed dips and overfolding, and in applying this method Mr. Champernowne most materially advanced our knowledge of the relations of the Devonian rocks.

CLASSIFICATIONS.

The Rev. D. Williams divided the Palæozoic strata of North and Central Devon and of West Somerset into nine groups in 1837. Mr. Weaver gave eight subdivisions in 1838. These classifications are as follows :—

WILLIAMS.	WEAVER.
9. Culmiferous and floriferous shales and sandstones.	8. Culmiferous shales.
8. Wavellite Schistus and black limestones, passing into 7.	7. Wavellite Schistus and limestones.
7. Trilobite slates.	6. Trilobite slates
6. Woolacombe flags and sandstones including Baggy Pt. sandstones.	5. Woolacombe sandstones, flags and slates.
5. Limestones of Combe Martin and Ilfracombe.	4. Morte slates.
4. Red slates and laminated sandstones of Trentishoe and the Great Hangman.	3. Trentishoe quartzy slates and sandstones, including the Combe Martin limestone.
3. Calcareous slates of Lynton.	2. Lynton Calcareous slates.
2. Sandstones of the Foreland.	1. Foreland sandstones.
1. Limestone of Cannington Park.	

The succession is accurately shown in both these groupings with the exception of the misplacement of the Carboniferous limestone of Cannington Park by Williams: in both, the Culm Measures are represented by two subdivisions, Nos. 9 and 8 respectively representing the main mass of the formation, Nos. 8 and 7 denoting the Coddon Hill beds in which Wavellite has been found, and the Posidonomya limestones. Professor J. Phillips's classification* gives four subdivisions, obtained by

* Figs. and Descriptns. Pal. Foss., Dev. Corn., &c.. 1841.

splitting up the Wavellite Schistus and limestones of Williams and Weaver into three. This classification, in a condensed form, is as follows :—

NORTH DEVON.	SOUTH DEVON.
4. Gritstone series, Anthracitiferous containing ironstone and coal plants.	4. Gritstone group of Central Devon.
3. Coddon Hill Cherts, &c. (1,500 to 2,000 feet according to the Rev. D. Williams).	3. Upper Shale group, dark shales, carbonaceous grits and shales, the lowest part being the Coddon Hill Chert series.
2. Posidonia limestone and black shale.	2. Calcareous group, Posidonia limestones and shales.
1. Black shale group.	1. Lower Shale group (few fossils), black argillaceous plate, not cleaved.

The value of this classification consists in the attention it attracts to the basement beds : but as denoting structure it is no advance on the earlier classifications of Williams and Weaver. The estimate of thickness assigned to three could only be obtained by adding an unknown amount of the overlying shales and sandstones to the Basement beds. The general succession of the Basement beds is possibly correctly shown by groups 1, 2, 3, but the groups are only recognizable by impersistent lithological characteristics, and there is reason to think that they are occasionally blended or transposed.

From an extensive series of detailed observations in the area between Okehampton and the North Devon Devonian area, made in 1876 and 1877, I communicated a new classification of the Culm Measures to the British Association, subsequently published *in extenso* in the Geological Magazine.* In it I pointed out certain lithological distinctions also having a stratigraphical value in those parts of the Culm Measure area which had before been included in one group (Phillips No. 4, Williams No. 9, Weaver No. 8.) These distinctions, although not susceptible of separation by actual boundary lines, seemed to me to justify the following classification, which sup-

* Geol. Mag. for Janry., 1887, pp. 10—17.

plies the want of an upper group to define the position of the axis, or axes, of the main synclinal structure :—

Upper Culm Measures.	Eggesford type. Hard rather thick even bedded grey grits, slaty beds and shales.
Middle Culm Measures.	Morchard type. Thick bedded grey greenish and reddish sandy grits associated with marly splitting shales irregular grits, slates and shales.
Lower Culm Measures.	Exeter type. Dark grey shales with grit beds, seldom thick and generally even, and slates and splintery shales. Even bedded cherty shales and grits (of Coddon Hill type) limestones and dark grey shales.

Since this classification was published, detailed observations in South Devon and traverses in the districts west of Dartmoor have supplied me with materials for carrying the subject much further. The west coast from Hartland Point to Boscastle has not been explored, nor has any part of the districts west of Dartmoor been surveyed in detail : until this has been done, no communication can be regarded as final, as it is to be hoped that future investigations in the unexplored districts may supply the solution to problems here left unsolved.

AREA, GENERAL STRUCTURE, AND GENERAL RELATIONS.

The Culm Measures of Devon and Cornwall occupy an area of about 1200 square miles. Throughout this area the strata are repeated by a vast number of small contortions obscuring the great curves by the repetition of junction beds of successive horizons and rendering the absolute delimitation of the various divisions an impossible task. The main synclinal structure as shown by the distribution of the Eggesford grits or Upper Culm Measures is very shallow, and made up of a series of undulations, so that the axis of the syncline is merely a generalized line not necessarily running along a synclinal but in a part of the distance being seemingly along a gentle anticlinal with synclinals on either side of it. As a consequence of this complex structure, the distinctions, which could easily be traced out in beds thrown into broad curves only, become lost

through appearances of intercalation produced by the numberless small contortions. From this structure it will be seen that no valid estimates of the thickness of the Culm Measures can be put forward, any estimates which are based on superficial extension, or apparent breadth of outcrop, being liable to exaggeration.

In speaking of the northern and southern boundaries of the Culm Measures, it must be borne in mind that these boundaries, as shown on De la Beche's maps and the small map accompanying this paper, are mere generalized lines, implying the main delimitation of the Culm and Devonian rocks, not showing the irregularity which, where unfaulted, the boundaries must necessarily exhibit, and ignoring on either side the repetition, by anticlinals or synclinals, of the older or newer strata.

The relations of the Culm Measures to the Devonian where unfaulted, both in North and in South Devon, are rendered obscure by the seeming absence of any marked lithological difference or absolute junction, although in mass or in large exposures their appearance is perfectly distinct. In the Tavistock country the lavas from Brentor appear to have locally formed either the actual base of the Culm or the uppermost horizon of the Devonian. The Upper Devonian emerging from beneath the basement Culm beds of North Devon is of the slate and psammite type of the Ardennes, whilst that occupying a similar position in South Devon is of the German type—Cypridinen Schiefer—and contains no sandstones and very few fossils, such beds as those of South Petherwin being most exceptional.

Owing to the absence of sections and presence of faults the North Devon Culm boundary is often very obscure: in the vicinity of Clayhanger, near Castle Hill, and other places, it is probably irregular from plication; but on the whole it may be regarded as a fairly regular line. In South Devon, on the contrary, Upper Devonian slates or shales occur near

Lydford and Mary Tavy, and detailed mapping would no doubt prove their further extension and repetition in other places to the north of the main boundary which is very irregular, and according to Holl's sections does not exclude the plicated repetition of Culm Measures to the south of it. The alteration of the strata on the west side of Dartmoor renders the distinction between Culm Measures and Devonian very difficult : from Horrabridge southward the rocks appear to be Upper Devonian, although near Shaugh Bridge Tunnel there may be a mass of Culm Measures. As far as lithological aspect can be relied on, I think Culm rocks extend on the West of Dartmoor as far south as Walkhampton, whilst they are present at Ivybridge and probably also at Cornwood. The general absence of fossils accentuates the difficulties of distinguishing the junction rocks on the West of Dartmoor.

The relations of the Basement beds of the Culm to the rocks of the Exeter type with which they were bracketed in the 1887 classification are doubtful, as, where the Basement beds do not display marked lithological types such as chert beds or limestones, their presence can only be distinguished from the shales of this series by the accidental discovery of fossils.

The relations of the beds of the Exeter type to the conglomeratic sandstones of Ugbrooke Park, etc., and to the sandstones (anthracitiferous) and shales of the Morchard type, are the main obstacle in forming any absolute classification of the Culm Measures. As the Basement beds are directly succeeded by the Ugbrooke Park sandstones in that locality, and apparently directly or almost directly by the rocks of the Morchard type west of South Molton in North Devon, it becomes questionable whether the rocks of the Exeter type which prevail from Chudleigh northward possess more than a local stratigraphical value, and pass laterally westward and southward into the Morchard and Ugbrooke Park types, whether they belong to the Basement beds, or whether they

are a distinct series overlying them, but uncomformably overlapped, proceeding westward from Chudleigh and Bampton by the more arenaceous groups. In either case the correlation of the Ugbrooke Park and Morchard beds seems justifiable. The Eggesford grits form a lithologically distinct series ; yet, in proceeding outward from their central developments, as at Torrington and Eggesford, it becomes impossible to trace any definite boundary between them and the rocks of the Morchard type through the plicated repetition of junction beds.

In speaking therefore of the respective areas occupied by the several types of the Culm Measures, or in referring to the map, the probability of faulted or folded inliers or outliers of lower or higher types must always be entertained, as in the relations of the Basement beds and Upper Devonian.

The subject will be treated under the following heads :— Basement beds, Exeter type, Ugbrooke Park beds, Morchard type, Eggesford grits, Inliers and easterly prolongation, Outliers, Fossils, Volcanic Rocks.

In a second part, to avoid confusion, the effects of the Granite on the structure of the Culm Measures will be treated of.

BASEMENT BEDS.

From their locally marked lithological characters and distinctive fossils the Basement Beds form the most important horizon in the Culm Measures. Professor J. Phillips wrote : " In the centre of this great district no limestone occurs, and there are no other fossils than obscure marks of plants or mere carbonacoeus stains ; but on the southern border the limestone bands reappear almost exactly as on the northern side, with similar mineral characters and accompaniments and similar or identical organic remains ; for example, at Trescott near Launceston, Lew Trenchard, Bridestow and Okehampton." Again, with reference to the range of hills south of Barnstaple, the most conspicuous of which is Coddon Hill on the east side of the River Taw, " the beds which in this range of

hills overlie the shales and limestones of Swimbridge and Venn are a whitish or grey or black chert in thin striped beds. With these lie white arenaceous and argillaceous layers mostly very soft and sometimes cleavable. Other parts show black and reddish shales. In these laminated beds lie *Goniatites*, *Orthoceratites*, *Terebratulæ and Posidoniæ*. The debituminized condition of these white shales parallel to the black bituminous shales of Swimbridge is remarkable, and it is a fact repeated not only on the northern range near Bampton but also on the southern range near Launceston and Lew Trenchard."* The beds described in this classic passage are the Coddon Hill beds of Phillips with all, or almost all, their local modifications. All these characters are very seldom displayed in any one line of section, but the horizon is represented by one or more of these types, wherever the characteristic fossils occur. The Chert beds are the Kieselschiefer type of Germany, the Franco-Belgian Phtanites. The white arenaceous and argillaceous type is locally the characteristic of the horizon, as at Brimley Farm south of Bovey Tracey; perhaps also at Cornwood, which, for type distinction and comparison in the field, I distinguish by the local name Brimley beds. The black and reddish shales occur often with the limestones, sometimes with the Brimley type as at Hestow Farm near Chudleigh and many other places. The celebrated Waddon Barton beds belong to this horizon. In South Devon the beds of this series are much faulted, and in North Devon contorted, so that a definite sequence is not obtainable in any general section, and the types are so variable and impersistent that it is unsafe to formulate a general succession of the Basement beds of the Culm from local relations. Nor is it possible to separate the Basement beds from the overlying thin bedded grits and shales which are their normal concomitants. In localities where abnormal beds such as those of Ugbrooke

* Figures and Descriptions of the Palæozoic Fossils of Cornwall, Devon, &c., 1841, p. 194.

Park succeed them the distinction is much more marked. No attempt has been yet made to trace the limestones and cherty beds, etc., of this series along their strikes continuously, but from the numerous observations made at intervals along the Culm and Devonian junction in North Devon, and from detailed mapping in South Devon, it appears to me that the lithological characteristics are not permanent but recurrent on the same or nearly the same horizons; that the whole series is not very thick, and is everywhere so much disturbed by faults and contortions that in the present state of our knowledge it is safer to group the Basement beds in one series than to subdivide them as in Phillips's Classification. Owing to the impersistence of the limestones and the variable characters of the Coddon Hill group it would be necessary either to arrive at the succession of the Basement beds from distinct consecutive exposures showing the relative positions of the components of the whole series both in the northern and southern area, or so to piece together the evidences obtained from junction sections of the different types by detailed mapping that the sequence of the whole could be established. Faults and disturbances render the first and easier method, I fear, hardly practicable.

The northern Culm boundary is to a great extent concealed by alluvial deposits,* and where this is not the case faults are frequent, whilst in the southern area faulted junctions with the Devonian are of very common occurrence. At Barnstaple, where the junction is apparently unfaulted, the lowest beds of the Culm are blackish rather irregular shales with calcareous stone nodules and lenticles, similar beds occur at Fremington station. In the railway cutting west of Morebath† similar shales contain nodular films and thin lenticles of crinoidal limestone, and are probably a kind of connecting link between the limestone patches to the east and west.

* Phillips—Figs. and Descriptions of Pal. fossils, &c., p. 189.

† Ussher Proc. Som. Arc. and Nat. Hist. Soc. 1879.

LIMESTONES.

The distribution of the limestone patches of Venn, Swimbridge, Bampton, etc., in the lower part of the Culm, on a large scale, is strictly analogous to the distribution of lenticles of limestone in the dark shales on a small scale. In the case of the limestones and dark shales, their economic importance has been recognized long before geological investigations were thought of, so that wherever limestone appeared at the surface, in sufficient thickness to pay for working, quarries have been opened, and thereby we are enabled to ascertain structure; but where these masses die out in dark shales with calcareous lenticles, of no economic value, sections are accidental, such as are displayed by road or railway cuttings; so that the absolute thinning out of the limestones is rather matter for inference than actual observation. It is very possible that Phillips may be correct as to the Coddon Hill beds overlying the shales and limestones, but the manner in which they are related cannot always be inferred from the relative positions of the strata on apparent strike lines as I shall show.

At Venn near Barnstaple * even bedded dark grey limestones with shaly partings in places covered with impressions of *Posidonomya lateralis*, *P. Becheri* and *P. tuberculata* † are exposed in quarries showing considerable disturbance and some faulting. If these limestones are beneath the Coddon Hill beds, which occupy the range immediately on the south of them, they would appear to be not an actual outcrop but an inverted anticlinal axis, as "they appear to overlie beds of the Coddon hill type." In that case, as they do not re-appear to the north, they would seem to have passed out northward in the dark shales. At Bampton we have exposures of the Coddon hill beds and limestones.

* Geol. Mag., January, 1887, p. 14.

† De la Beche (Report p. 118) records *Goniatites truncatus* and a form allied to *G. sphæricus*, Sow. from Venn quarry and from Swimbridge.

The Bampton limestones in an old quarry west of the town, consist of even beds of dark blue grey limestone varying from 3 inches to 1 foot in thickness and intercalated with thin bands apparently not nearly so calcareous: the thicker beds weather into nest-like hollows whilst the thinner bands stand out in relief; both are intersected by veins of Calc Spar; the limestones are overlain by rather irregular dark grey shales, in places mottled with white, in this respect only being suggestive of the remarkable mottled even shales of Coddon Hill. In a larger quarry near Westbrook Farm, west of the above, similar limestones are well exposed. The thin intercalated seams in this quarry are suggestive of some Coddon Hill shales (or Phtanites). The overlying beds are grey shales. The structure of the limestone is here a complicated anticlinal, (*fig.* 1). On the north side of the limestone, both at West-

Fig. 1.

Culm Limestone. Westbrook Farm Quarry, near Bampton.

brook and in the railway cutting at Bampton Station, pink and white shales—sometimes forming even stone bands, sometimes soft (Brimley beds), with traces of crinoids—represent the Coddon Hill types, and recall at the same time the shales at Brimley near Bovey Tracey and the *Goniatites spiralis* beds between Chudleigh and Kingsteignton* Further north, cuttings by the Exe Valley railway show intercalated grits and shales. We then encounter in the Taunton and Barnstaple railway, south of Morebath, the dark shales before mentioned, and further north, typical Coddon Hill beds occur at Morebath

*Phillips. Figs and Descripts. Pal. Foss, &c. p. 190. records discovery of many Posidoniæ in shales beneath the south band of Bampton limestone and speaks of Coddon Hill grits which underlie the lowest limestone.

where they are faulted against the Upper Devonian. This series of consecutive observations seem to show the northward passage of the Bampton limestone into dark partly calcareous shales, and, as the Coddon Hill characteristics are not displayed in the Exe valley railway cuttings, to the south of the Bampton limestone anticlinal, we must either account for their absence by a very doubtful fault, or admit that they have lost their distinctive characters, unless indeed we suppose them blended or interbanded in the local development of limestone.* The Bampton limestones may be 30 to 40 feet thick; from the contortions it is difficult to tell, they appear to be very unfossiliferous. Although De la Beche's boundary in the Bampton district is by no means correct, there appears to be no reason to dispute his general conclusion as to the passage between the Culm and Upper Devonian.

The greatest development of limestone in the British Culm Measures occurs on the margin of the New Red Rocks between the Devon and Somerset County boundary near Ashbrittle, on the north, and Burlescombe on the south. There are here no less than twelve irregular limestone masses: some of these are very small, but the West Leigh mass, those near Holcombe Rogus and Binnager Bridge on the north of it and two contiguous masses near Kitton Barton, further north, are of considerable size. These limestones are well exposed in numerous quarries, displaying a great variety of folding and contortion, which, by repeating the rock, has given the appearance of three successive horizons. The late Rev. W. Downes† records the occurrence of *Goniatites* in these limestones as also 'of Corals' *Michelinea favosa* Goldf and *Zaphrentis cylindrica* (?) (Scouler); also Brachiopods *Orthis resupinata* Martin, a Spirifer, *Chonetes Hardrensis* from Crinoidal limestone beds, in which he noticed cuplike nodules suggestive of

* See De la Beche's Report. p. 104, as to siliceous interbanding in Bampton limestones.

†Trans. Dev. Assoc., 1878.

crinoidal calices. The identification of the *Goniatites* with *G. spirorbis*, Phill. and *G. crenistria* appear to be doubtful. Phillips figures *Posidonomya Becheri* and *P. lateralis* from these beds. The limestones are rather evenly bedded and in places intercalated with shales in which the *Posidonomya* and apparently also the *Goniatites* have been found. De la Beche * notices the occurrence of the *Goniatites* at Westleigh, which occur in the Culm limestone at Swimbridge, but comments on the absence of *Posidonomya* in the West Leigh limestones; they were, however, found in comparative abundance by the Rev. W. Downes, both in the shales and parts of the limestone; imperfect plant traces have also been found, and a *Calamite* is said to have been found by Mr. Champernowne at Holcombe. Mr. Vicary of Collaton Crescent, Exeter, has in his collection a series of Culm Measure fossils, which have not however been authoritatively identified: amongst these he kindly informs me, with the above caution, are *Posidonomya*, *Productus*, *Strophalosia*, *Pterinea*, *Goniatites*, two corals and a Gasteropod from West Leigh. Mr. Whidborne is, I believe, in possession of Mr. Vicary's *Goniatites* with a view to identification. Mr. Vicary's collection is worthy of the attention of Geologists well acquainted with the fossils of the Culm; during the many years that I have had the pleasure of his acquaintance, I can testify from personal experience to the kind way in which he is ever ready to place his collection at the service of any student of Geology.

To revert to the stratigraphy of the West Leigh, &c. limestones. Their complicated and often faulted folds suggest a subterranean connection between all the patches, in one mass probably attaining to as much as 100 feet in maximum thickness, but thinning out westward, beneath the surface, as the terminations of the limestone hills westward are due not so much to decrease in thickness as to a lowering of the anticlinal axes, or to westerly terminal dips. On the east the behaviour

* Report p. 105.

of the limestone is not visible owing to concealment by New Red rocks, beneath which it may develop and finally pass into the Carboniferous Limestone; or thin out, as there are neither inliers of the Older Rocks nor borings or sinkings of sufficient depth in the Secondary area south of the Quantocks, to afford any clue. As these limestones do not reappear between their most northerly exposures near Kitton Barton and the Upper Devonian rocks which pass under the Culm Measures at a mile further north, north of Ashbrittle, and as there is no suggestion of their absence being due to fault, we must either suppose that they overlie the Culm strata on the north, which their structure seems to forbid, or else conclude, as in the case of the Bampton limestones, that they are anticlinals, and pass out into dark shales northward in which condition the horizon ultimately crops out.

"The village of Ashbrittle is situated on dark bluish... thick shaly beds of the Coddon Hill type, and exhibiting its characteristic features in adjacent hill summits to the west of the village. The Culm beds are exposed near Trace Bridge, dipping S.E., at 45°. A line south of Coalmans Mill, passing between Chequeridge and Pitt Farms, divides the Culm shales (which near Pitt Farm are nearly horizontal), from the light grey slates of the Pilton series. Near Coalman's Mill, *Spirifer Urei** occurs in bluish-grey slates which dip S.E." †

From these observations—made with the late A. Champernowne in 1878—it would appear that the limestones pass under representatives of the Coddon Hill beds, and that their horizon merges into shales to the northward. In many places in North and South Devon the Coddon Hill characteristic hard and cherty shale types, seem to have given place to softer materials in which the cherty character is not recognizable.

* Compare —Ussher, Geol. of Tavistock. Trans. Dev. Assoc. for 1889, pp. 442 and 450—on slates with Sp. Urei at West Litton.

† Champernowne and Ussher. Q.J.G.S. for Aug. 1879, p. 542, under head of Tone Valley. Torre is a misprint.

We will now turn to South Devon and Cornwall, where the limestones form a series of patches ranging from Drewsteignton to Launceston. Their distribution within this restricted range is irregular owing to deflection of strike by the northern boundary of the Dartmoor granite, but there is absolutely no reason to suppose that they occupy a different horizon in the Culm from the series on its northern boundary. De la Beche, it is true,* regarded the parallel distribution of the limestone patches between Launceston and Bridestow as successive outcrops rather than repetitions by plication, but this view is untenable. The limestone patch at Bridestow is in strike with that of Lifton, but the Bridestow limestone is ten miles to the north of the main Devonian boundary, whilst the Lifton limestone is only about three-and-a-half miles north of it. This might be explained by the effects of the forces which produced the east and west strike acting simultaneously on the Granites of Dartmoor and Brown Willy and the stratified rocks surrounding them, which will be discussed further on in a separate part of this paper. The limestone of Drewsteignton occupies a similar relative position to the northern boundary of the Granite of Dartmoor that the Venn and Swimbridge limestones occupy with reference to the North Devon Devonian boundary. Assuming that the contact Culm Measures on the north of Dartmoor are the Basement beds of the Culm, which there is no reason to doubt, the great interval between the Bridestow limestone and the Culm boundary at Tavistock can only be explained by the lenticular nature of this and of all the other limestone patches, by their replacement by dark shales and other materials, and by the constant repetition of these materials by folds in an area where they were relieved from the constriction of an inlying Granite mass which had near Drewsteignton, checked their expansion. In commenting on the curved strike of the limestone patches between Lifton and Okehampton, De la Beche observes, "Though calcareous

* Report, p. 118.

matter in sufficient quantity to form limestone thus recedes from the extreme edge of the whole system in this direction, calcareous matter is not absent from that edge. It occurs among the shales on the east side of the Tamar, near Grayston Bridge, and in the cutting for the high road from Tavistock to Launceston, through the Trappean Ash near Longford, ... which ... not only contains calcareous matter but also nodules of limestone." As De la Beche * observed, the characteristic difference between the Culm Measures near their northern boundary and near their southern boundary consists in the occurrence in the latter of igneous rocks, many of which are of distinctly contemporaneous origin. This is the case in the Launceston and Tavistock areas on the West of Dartmoor and in the Chudleigh area on the east of Dartmoor, where I have worked out their boundaries in detail. In both these areas the limestones are practically absent, but the different varieties of the Coddon Hill series occur more or less frequently. For comparison with the limestones singled out in the northern area I select the following examples from the southern district. The Lew Trenchard section is thus described by Phillips.† "Argillaceous and arenaceous laminar beds, white or colored by oxide of manganese which correspond to those of Coddon Hill...contain *Calamites*, *Asterophyllites*, and a *Goniatite*— below are quarries of black limestone," in which no *Goniatites* were found, with "shaly partings rich in *Posidoniæ*" in the upper part. I have thus described ‡ the Lifton limestones which occur between Lew Trenchard and Launceston :— Near Lifton station a quarry exposes dark grey limestone with calc spar veins, under dark bluish grey shales, which are overlain by buff and grey papery shales apparently, along a thrust fault, breaking an inverted synclinal. Near Woolaton, west of Lifton, a long quarry affords a fine section of dark

* Report p. 119.

† Phillips, Figs. and Descrips., &c. p. 195.

‡ Trans. Dev. Assoc. for 1889—p. 443.

bluish grey distinctly bedded limestones under buff and whitish papery shales * in places associated with thin hard beds. The dip is N. 10° W. at 25°. In the westernmost part of the quarry the buff shales pass into blackish shales in which traces of *Posidonomya Becheri* were observed. The limestone beds are intercalated with these dark shales, in which they occur impersistently. They are veined with calc spar and afforded no traces of fossils. The beds present a zig-zag appearance from small folds, probably accompanied by small thrust faults. In the wood between Park Town and Lifton, midway between the afore-mentioned quarries, the characteristic Chert beds (Coddon Hill beds) are exposed in a small quarry. They consist of thin even beds of chert with grey and buff surfaces and dip S. 35, E. at 25°. They are overlain by yellowish brown conglomeratic beds intersected by numerous horizontal joints and resembling rocks in the Culm series at Ramsleigh near Newton Abbot.

At Trescott,† west of Launceston, Phillips describes the section as follows:—"Soft and hard white pink stained and black layers, the equivalent of the Coddon Hill grits, with quartz veins. Below are laminated grey grits and shales. Then thick dark grey or black limestone covered by black shales resting on trap." *Goniatites* were found in the limestone, crinoidal joints and *Posidoniæ; Neuropteris* and *Lepidostrobi* are also recorded from this section. Taking these three sections together and assuming that those quoted from Phillips are actual junction exposures and not inferentially connected from contiguous exposures, the succession given is as follows in descending order.

3 Conglomeratic sandstones.

2 Cherty beds and laminated grits and shales (Coddon Hill series).

1 { Buff, whitish and dark grey shales on
{ Dark grey shales with impersistent masses of limestone.

* Compare Shales overlying Bampton limestones.

† Phillips, Figs. and Descrips., &c. p. 195.

Compare this with the section given in my paper on the Tavistock district.*

a Shales with grits and sandstones locally conglomeratic.
b Thin even cherty beds (Phtanites).
c Dark slaty shales containing limestone, succeeded by, and
locally giving place to *d* Shales and thin even hard beds (fine grit or mudstone), with *Goniatites spiralis*, *Posidonomya* and *Orthoceras*.
Upper Devonian *e* Dark grey slates with *Spirifer Urei*.

The relations of *c* and *d* were inferred, and I now think that although the inference may be generally correct as regards passage replacement, that on the whole these thin hard *Goniatites spiralis* beds may be above the limestone horizon in this neighbourhood, and correspond to the laminated grey grits and shales of the Trescott section. If this is the case the dark grey slates with *Spirifer Urei* occurring at West Litton in the Culm Measure area, may not belong to the Devonian, but constitute the basement beds of 1 and *c* in the above successions. Similarly the shales with *Spirifer Urei* at Coalman's Mill, near Ashbrittle, in West Somerset, would be referred to the actual basement beds of the Culm.

In suggesting the above order of succession it must be borne in mind that the boundary between the Culm and Petherwin (Upper Devonian) beds is merely a generalized line, and that no inference as to the position of horizons in the Culm can be based on their relative proximity to that boundary —as thin horizons are very quickly disposed of by faults or folds in this country. Between Launceston and South Petherwin "a large slate quarry south of Tresmarrow exhibits dark grey . . . shales in places quarried in great tabular masses sometimes five feet square, through the cohesion of the laminæ.

* Trans. Dev. Assoc. for 1889, p. 450. All through this paper read Phtanites for Pftanites and *Goniatites spiralis* for *Goniatites crenistria*.

A few hard even beds resembling the chert beds (Phtanite) occur in the slates. The only organic remains found were faint *Calamite* markings. The beds are nearly horizontal, and are exposed to a depth of about 60 feet." Rather arenaceous buff and grey shales with occasional faint traces of plants occur to the south of this quarry; dark grey shales coming to the surface at Does House, where the junction with Upper Devonian is shown on the maps. From contrary or cross dips the real junction seems to be a fault. "At Launceston Station, a quarry about 80 feet in height, shows irregular bluish slaty shale, the laminæ being often so closely welded as to permit the rock to be quarried in very large blocks. With these are associated grey brown weathered shales with buff sandy nodules (? decomposed limestone). The beds are much contorted. The cliff above the station consists mainly of buff and grey broken arenaceous shales with harder bands, apparently disturbed and affected by small thrust faults." *

The dark shales in the above-mentioned quarries may be the beds below the calcareous group, in Phillips's *South Devon Classification;* but if so, the buff and grey shales with sandy nodules, if they are not Devonian, would represent the calcareous group. But the caution as to proximity to Devonian being quite inconclusive, and owing to the plant traces in them, I am not sure that these dark shales may not be the same group as that locally calcareous, and that the overlying beds, if really overlying, may not be a local type development of the Coddon Hill series, occurring, on a much smaller scale apparently, in the Chudleigh district. Again it is possible that all these beds may be above the horizon of the Coddon Hill cherts, and so come with them under Phillips's South Devon Upper shale group. On the east of Dartmoor the horizon of the Culm limestone is occasionally identifiable. In a small quarry at Wooder near Doddiscombleigh, where a single bed of limestone, about two feet thick, as well as I remember, occurs

* Trans. Dev. Assoc. 1889, p. 444.

in an anticlinal, *Posidonomya Becheri* was found in this exposure, and in thin even stone bands in the Culm shales, *in situ* or in surface fragments: above the Baryta Mine, Bridford; near Bileing in the vicinity of a contemporaneous volcanic ash near Ashton Station, where thin bands of limestone occur in the shales apparently for 20 to 30 feet; near Cato Hall about a mile and a half north of Chudleigh Station where small calcareous lenticles seem to occur in the shales, not far from a contemporaneous band of volcanic ash. The strike of the Culm Measures as indicated by dips and by the run of volcanic ash bands connects these *Posidonomya Becheri* bands. From Cato Hall the strike runs S.S.E., to Bovey Tracey in which neighbourhood near Brimley the same kind of stone is met with, and good examples of the *Posidonomya Becheri* were obtained in it and in fragments of thick buff even shale, somewhat similar to even shales intercalated with the Westleigh limestones; on the east of Lurcombe, south of Bovey Heath a trace of limestone was noticed in Culm shales. It may, therefore, be safely inferred that the horizon of the Culm limestones is represented from the Tavistock country to Drewsteignton and from thence right round Dartmoor to Bovey Tracey. In this country also the Chert beds are represented, but owing to alteration in vicinity of Granite and to the absence of markedly distinctive characters away from it their relations cannot often be observed. Mr. Vicary has obtained *Posidonomya* and a coral from Doddiscombleigh.

CHERT BEDS.

The Coddon Hill beds, as we have seen embrace a variety of types. The typical Coddon Hill beds of Coddon Hill, are thick buff whitish and dark grey shales, fine shaly grits and cherty mudstones, with these colors often distributed in irregular patterns, the individual beds are intersected by numerous even joints separating them into small angular pieces somewhat like a Chinese puzzle. Owing to this circum-

stance in Tawstock park, and many other places near the northern boundary the rock has been quarried for coarse gravel as it does not require much breaking. This type as Phillips mentions, is sometimes associated with soft shaly beds and with black and reddish shales. It constitutes a marked series of conical, hogbacked, or ridgy hills, as near Swimbridge, Hulverton Hill near Dulverton, at Morebath, and at Castle Park near South Molton, where the hills are round and conical, Coddon Hill hog back, Tawstock Park ridge features. In south Devon this type is represented by hard thin even bedded fine grit, characterized by abundance of *Goniatites spiralis*, probably also the equivalent of the thin even *Goniatite* shales intercalated with the Westleigh limestones. The hard beds with *Posidonomya Becheri* in the Chudleigh district may belong to this type and take the place of the limestones.

The Waddon Barton beds are a mixture of softish shales and harder even jointed brown beds of this type containing numerous examples of *Goniatites spiralis*, *Orthoceras*, *Posidonomya*, etc. The *Posidonomyæ* in these beds are as a rule smaller than those occurring in the beds which in the Chudleigh and Bovey Tracey districts carry on the calcareous horizon.

The hard thin *Goniatites spiralis* beds are a wide spread type in South Devon and North Cornwall, we find them in many places between Chudleigh and Kingsteignton, underlying the coarse sandstones of this neighbourhood, as near Larcombe Bridge, Oldchard Well, south of Lewell House, etc., south of Bovey Tracey, near Pool Farm ; near Bad Ash, south of Launceston ; near Laburnick, south of Hardow Down, two miles east of South Petherwin. In all these places the characteristic *Goniatites spiralis* often accompanied by *Posidonomya* has been found. At a mile east from Petherwin Church Coddon Hill chert beds are quarried for road metal to the south of the most easterly patch of Petherwin limestone on

De la Beche's map. Dr. Holl's section * from Yealm Bridge through South Petherwin southward shows Culm Measures in two places, respectively about one and four miles south of South Petherwin, and in another section near Brown Willy south of Trewen; so that within the area colored as Devonian on the old one inch geological survey map, there are no doubt many faulted or folded extensions of the Culm Measures. South of Hardow Down thin even buff-brown and grey shales containing *Posidonomya Becheri* are probably faulted against shales with grit, and rest upon the hard thin *Goniatites spiralis* beds which here contain *Orthoceras*. The soft varieties of the Coddon Hill series, buff-red and blackish shales, are noticeable at Hestow Farm between Chudleigh and Bishopsteignton where I found in them *Phillipsia Leei*, *P. minor*, *Goniatites spiralis* and plant traces, at Brimley near Bovey Tracey; probably near Druid, Ashburton; south of Brentor, &c. Near Whiteway Farm, Culm Measures are faulted against the Upper Devonian, they are of an irregular shaly character with arenaceous buff matter in which *Phillipsia* was found. Arenaceous, or rather friable arenaceous, earthy nodules, are of course common in the Knollen Kalk type of Upper Devonian, and they are met with here and there in the Lower Culm, being probably the friable residuum of calcareous nodules, from which the lime had been filtered away. It is possible that the shales with patches of similar material above Launceston Station may also be a local development of this type. The Chert beds, or Kieselschiefer or Phtanites, are not so conspicuous in North as in South Devon where their layers are often welded together and porcelainized in the vicinity of Granite. In South Devon their local occurrence may be due to faults. Near Lewell Ho, Chudleigh, small patches of even chert beds occur in faulted association with their surroundings.

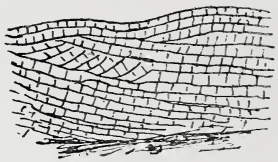
South of Bovey Tracey Upper Devonian slates are exposed

* Q.J.G.S. for 1868 p. 417.

in the valleys, their junction with the Culm being generally faulted. Chert beds are developed in this district on Ramshorn Down. In Livaton it is difficult to say whether the beds exposed belong to Culm Measures or Devonian.

The chert beds on Ramshorn Down are much broken by even bed joints, and are evenly bedded. False bedding is well shown in a quarry in the south corner of the Down *(fig. 2)*.

Fig. 2.



Quarry in Culm Chert Beds (Kiesel Schiefer) on Ramshorn Down.

Similar dovetailing is shown in a quarry in the north part of the Down. Veinstone masses occur in the Basement Culm Measures near Bridford, on Ramshorn Down, in the vicinity of Druid (Awsewell rock) near Ashburton, and in many other places on the borders of the Granite. The slates or shales between Cannonteign and Trusham are in lithological aspect somewhat suggestive of Devonian.

The hills about Ramshorn Down display contours recalling the Coddon Hill features of North Devon. The Chert beds forming them seem to pass beneath sandstones and shales with traces of plants and to rest on the Upper Devonian in the valleys; but as the steep slopes above the junction are either concealed by brushwood or grass land, one cannot say if Chert beds form the actual base of the Culm hereabout. There may be a few feet of intervening materials, as in this vicinity, north of Lenda Farm, dark bluish grey slates, apparently Devonian, seem to pass upward into the Chert beds through a few feet of pale grey shaly beds weathering whitish and exhibiting a vesicular appearance, probably through the dissolution of small crinoid ossicles, as crinoidal casts occur in them. It must be remarked, however, that the disturbed state of the

strata through frequent faults renders any deductions liable to suspicion. In a general way it may, I think, be asserted that Chert beds are here at the base of the Culm, and apparently below the shaly arenaceous beds and *Posidonomya* bands of Brimley type. The relations of the Chert beds on the east of South Petherwin are not clear. In the vicinity of Dartmoor the Chert beds, where present, seem to have been altered into hard flinty, often banded massive rock. This is noticeable in the S.W.R. cuttings between Okehampton and Tavistock; near Bridford, in the district north of Chudleigh; near Lenda, south of Bovey Tracey; and near the Granite margin from Kingsbridge Road Station northward toward Dean Church where De la Beche terminated the Culm. Respecting the last-named district, the late Mr. Champernowne noted on his map, close to the Granite boundary, north of South Brent "hornblendic rock altered," and further south at about half-a-mile from the Granite "Axinite" and "banded felspathic rock" dipping off the Granite to the south-east. At the Granite junction, near Kingsbridge Road Station, he noted "porcelainized felspathic rock," dipping S.E. off the Granite. This porcelainized rock is used for road metal near Kingsbridge Road and Ivybridge.

At Ivybridge, in a builder's yard opposite the Church, the basement Culm Measures are exposed in a quarry. They consist of hard Chert and rubbly buff and brown weathered-broken cherty shales with softer, somewhat arenaceous matter interbedded here and there: the dip is southward. On the north, apparently below these beds, even grey spotted shales (spilosit?) with a few hard dark grey bands resembling Culm limestone, are succeeded by even pale grey spotted shales exposed in the railway cutting. At Dennaton Railway Bridge, between the above and Cornwood, cherty rock is shown on whitish and buff soft shales of the Brimley type, with a few thin even shaly stone bands, perhaps representative of the *Goniatites spiralis* beds, upon soft even shales. At Cornwood

station the Culm Basement beds seem to be represented by soft even whitish and buff shales of the Brimley type, with harder shaly stone bands ; near the viaduct a mass of irregular dark rock occurs in irregular broken even-splitting shales or mudstones contorted and spotted in places.

Fossils were not obtained in any of these exposures, there being insufficient time for a careful search.

Beyond Cornwood, round the Granite to Yelverton and Horrabridge, the bordering rocks appear to be pale greenish grey Upper Devonian, generally exhibiting low dips. At Walkhampton, however, Culm Measures seem to be represented, their boundary with the Devonian being probably a prolongation of the faulted junction near Tavistock. In the vicinity of Dartmoor, through alteration generally of a spilositic character, the faulted or folded presence of even Culm shales of the Brimley type might easily escape recognition in the railway cuttings south of Horrabridge.

In the S.W.R. cuttings at Meldon Viaduct banded Chert rock and cherty shales are exposed ; in these, on the south side of the line is a remarkable band of igneous rock, and apparently below them limestones and dark indurated mudstones are exposed in Meldon quarry.

In the district on the north of Dartmoor stretching westward from Exeter, on the south of the tongue of New Red rocks, although, as a whole, the rocks belong to the shale and grit series above the Basement beds, yet there can be little doubt that the latter are here and there brought to the surface by the ubiquitous plications affecting the entire district ; but from their protean character it would be difficult, if not impossible, to trace such inliers of the Basement beds without an enormous expenditure of time in tracing out minute structure and lithological characters, and a very careful search for fossils. The recurrence of the Basement beds is evidenced as follows :—Near Lea Cross, between Bridford, Dunsford, and Doddiscombleigh, thin rather cherty beds suggest the presence

of the Cherty (Kieselschiefer) variety of the Coddon Hill series. At five miles west from Exeter a stream source depression marks an extension of dark shales, in which, south of Baldoak Farm, I obtained a few small, nearly circular *Goniatites*, too imperfect for specific identification. Mr. Vicary has *Goniatites** in his collection, obtained from the Culm in Bonhay Road, Exeter, and *Goniatites*† and *Calamites* from Pinhoe, near Exeter. In Phillips's List Exeter is given as the locality for *Goniatites serpentinus*. Mr. Vicary has also *Goniatites* in his collection from the Culm on the south border of the New Red rocks, at Cocktree Moor, near North Tawton, resembling those I obtained near Baldoak Farm, but larger. In the district west of Okehampton and south of Holsworthy and Bude similar recurrences of the Basement beds through plication may confidently be assumed Exeter type.

The Basement beds north of Chudleigh, as has already been mentioned, pass up into the shales and grits of the Exeter type.

THE EXETER TYPE.

The main characteristics of the Exeter type, as distinguished from the Morchard type and from the Eggesford grits, are as follows :—Comparatively regular intercalation of grit beds in shales; occurrence of grits in single beds as a rule; grits seldom sandy, generally compact, rather evenly bedded; grit beds average a few inches in thickness, but occasionally attain two or even three feet; shales frequently fracture irregularly in splintery flakes; shales predominate, but grit intercalations are generally abundant.

The Morchard type, on the other hand, is more variable and more irregular. The grits vary in colour, often occur in

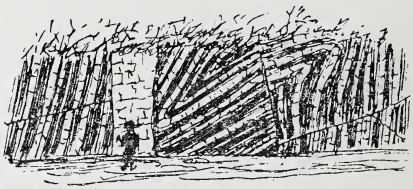
* These *Goniatites* are casts apparently identical with similar casts also associated with *Calamites*, in nodules, from Instow in N. Devon, collected by Mr. Townsend M. Hall, and now in the Natural History Museum, S. Kensington.

† Very like cast of Clymenia.

masses, and are frequently arenaceous, and the shales or mudstones locally exhibit slaty cleavage. In contra-distinction to the Exeter type the Eggesford grit series consists mainly of grits, the shales often occurring as thin partings. The grits are more regular, thicker, and of different grain.

The rocks of the Exeter type are very much contorted, as the accompanying sketch shows. It would be difficult to

Fig. 3.



Contorted Culm Measures. By the road from St. David's to St. Thomas' Station, Exeter.

obtain an undisturbed section for many feet either in North or South Devon. Owing to these disturbances it is impossible to distinguish any absolute junction between the rocks of the Exeter and Morchard types in North Devon, and the shales cease to be distinctive. The types are parted on their southern outcrop by the New Red valley of Crediton; to the west of that valley their relations have not been worked out.

Typical exposures of these strata are visible in Exeter and its environs. The sketch was taken from the cliff between St. David's and St. Thomas' Stations. The sections consist of irregular grey shales often divided into splintery flakes and containing nodular concretions in places irregularly intercalated with more or less even beds of brown weathered grit, the whole being thrown into a series of sharp frequently invested folds and broken by faults and thrusts.

Rocks of the Exeter type are visible toward Norwood, north of Chudleigh Station: they consist of hard generally thin bedded even grits intercalated in splintery shales, also exposed near Huxbere Barton on the east. About Lea Cross contorted shales, generally of a splintery character associated

with thin bedded grits, are well exposed; on one section north of Lea Cross, near the road to Great Oak, similar beds are associated with two thick grit beds, about 4 feet, exhibiting sharp flexures. Throughout the area from Exeter westward splintery shales associated with thin bedded grits form the normal type of the Culm Measures on the south of the New Red valley, with very local exceptions. One of these, the most notable, is presented by a mass of grit, much broken by joints and 10 feet in thickness, occurring in Fulford Park, N.N.W. of Dunsford: this may belong to the overlying Morchard type brought in by fault or fold.

The distribution of the Exeter Culm Measures is well shown by the Exe Valley Railway. This line, after traversing the tongue of Culm rocks of the Exeter type which projects eastward to Poltimore in the New Red rocks, traverses the New Red of the Crediton valley, emerging from it through a district composed of rocks of the Morchard type; traverses the New Red of the Tiverton district; the Junction of the Morchard and Exeter types being probably a fault in very much disturbed grits and shales and splintery shales in a cutting at about a mile-and-a-half north of the New Red boundary; from this cutting to within a half-mile of Bampton Station, where Coddon Hill beds are exposed, the cuttings and adjacent quarries display intercalations of hard even bedded grit in dark shales, partly splintery. In the Cove Cliff cutting the grit beds vary from six inches to a foot in thickness. From the evidence furnished by this line the rocks of the Exeter type on the north and south are separated by about $8\frac{1}{2}$ miles of newer Culm Measures.

It is difficult to trace the presence of the Exeter type in the neighbourhood of South Molton and farther west. At Bummer, near Molland, thin bedded grits intercalated with blue-black shales are exposed near the Devonian junction, which is probably a fault. It would be impossible to follow the rocks of the Exeter type further in North Devon without

entering into their relation to the Morchard type, which will be treated of further on.

The rocks of the Exeter type contain occasional imperfect traces of plants, including portions of *Calamites*, but in this respect they are not so fossiliferous as those of the Morchard type, to which the Anthracite beds belong.

UGBROOKE PARK BEDS.

The consideration of the nature of the junction between the Basement beds and the overlying shales and grits containing only plant remains, is perplexed by the occurrence of coarse, partially conglomeratic sandstones in Ugbrooke Park and near Oldchard where they rest on Coddon Hill beds of Brimley and Waddon Barton types; at Conator and Rydon Ball Hill, and at Two Mile Oak, between Newton Abbot and Ipplepen, where they are faulted down amongst Devonian rocks. Similar sandstones occur elsewhere in South Devon and also in North Devon in the strata overlying the Basement beds. The normal succession both in North-east Devon and in the districts north of Chudleigh from the Eggesford grits downward, as shown in my classification of 1887, would place the typical thick bedded sandstones of the Morchard type (Zeal Monachorum and Umberleigh), considerably above the Basement beds, the intervening rocks being the rocks of the Exeter type, a series of dark shales and mudstones, with constant intercalations of grey-brown weathered grit beds, generally thin bedded, occasionally sandy, but as a rule rather fine grained and compact. The general resemblance, or rather community of arenaceous characters, would have led me to correlate the Ugbrooke Park, &c. beds with Middle Culm Measures of the Morchard type, but I had no adequate opportunity of studying the Ugbrooke sandstones, until after the 1887 classification was published. Stratigraphically, there is no evidence of unconformity between the Basement beds and the conglomeratic sandstones, but, considering the faulted and flexured structure

of the Culm Measures, one could scarcely expect to find direct evidence. In the conglomerates of Ugbrooke Park and Rydon Ball small pebbles and subangular fragments of quartz are most abundant, but they also contain decomposed fragments, felspar (?) and dark cherty rock, suggesting the denudation of the cherty beds of the Basement Culm Measures. De la Beche says,* "In fact the Ugbrooke Park, Ogwell, Hestow Farm, and Kingsteignton carbonaceous rocks differ mineralogically in the coarseness of their beds from the great mass of the carbonaceous deposits on the north, part of the detritus of which they are formed being probably derived from that mass. Rounded pieces of black carbonaceous rocks, the origin of which may be more questionable, are also detected in these conglomerates." De la Beche notes † the occurrence of "remains of *Calamites*, and other plants and much carbonaceous matter" in these sandstones, shales, and conglomerates. Sedgewick and Murchison in 1840 also described the Ugbrooke Park sandstones, &c.—"Over it are some beds of more thin bedded grey sandstone not to be distinguished from a coal measure sandstone, and containing fine vegetable impressions, among which are well marked *Calamites*." ‡ The irregularly fissile character of the shales associated with these beds is also described.

These sandstones are exposed to a depth of about 30 feet in a quarry at the north end of Ugbrooke Park. They are greenish grey in colour, partly friable, partly hard and coarse, and finely conglomeratic in places; they contain a few lenticular bands and patches of shale. In the upper part of the quarry the rock is distinctly bedded, but in the lower part the bedding planes are only partially developed. These sandstones occur apparently directly over the fossiliferous Culm shales, on the east side of Waddon Barton Lane. The Conglomerate is

* Report, &c., pp. 111, 112.

† Ibid p. 110.

‡ Memoir on Physical Structure of Devon, etc., pp. 678, 679.

local, probably confined to the lower beds: it is well displayed in Ugbrooke Park, near Oldchard Well Farm, near Ponswine Farm and near Whiteway Farm, north of Kingsteignton. South of Oldchard Well Farm, near Whiteway Farm, and at Hamblecombe lane, between Oldchard Well Farm and Ideford, the conglomeratic sandstones seem to rest on Basement beds of the Waddon Barton and Brimley type, the former being hard even stone beds, with *Goniatites spiralis*. By Hamblecombe lane there is a small reddish limestone patch containing fossils, which have been submitted to several experts, without any result. If Devonian, this limestone would be overthrust on the Culm, and a shale breccia, with which some of its fragments are shod, would be thus explained.

In this neighbourhood, the only representation of the Chert beds proper seem to be confined to a small quarry by the path road to Lewell Ho, in vertical beds, either under or faulted against the sandstones; in an exposure by a hedge north of Lewell House; and in a small quarry north of Gappagh. By the high road, south of Chudleigh Station, at Bellamarsh Wood, disturbed black shales and greyish brown sandstones with plant traces are shown; their association is often very irregular and lenticular, and both grits and shales have a tendency to fracture in concentric flakes owing to spheroidal structure, a phenomenon common enough in the Culm Measures of the Morchard type.

From Chudleigh Station northward the Basement Culm beds seem to pass upward into shales and thin bedded grits, amongst which there does not appear to be any development of coarse micaceous sandstones until we reach the north border of the Crediton New Red rocks, about 14 miles to the north.

As to the easterly extension of the conglomeratic sandstones beneath the New Red rocks it is of course impossible to form an opinion. At Bishopsteignton dark shales occur which may belong to the Culm Measures. In the area south of Chudleigh,

and probably round Dartmoor by Tavistock and Lifton, arenaceous deposits with conglomeratic materials in places seem to have succeeded the Basement beds, but as these are largely associated with dark shales it is impossible to obtain any marked lines of junction.

Between Newton Abbot and Ipplepen there are two faulted Culm patches in the Devonian area. The largest extends for a mile from the Upper Bradley valley (W. of Newton Abbot) southward to beyond Rydonball Cross: its boundary is made by an irregular system of faults. In this outlier there are signs of the presence of Basement beds of the cherty and Brimley type adjoining the faulted Conator Hill Devonian limestone; greenish sandstones are exposed by Rydonball Plantation, and on the south of Rydonball Cross, where bean sized conglomerate is plentiful. By the road to East Ogwell shaly conglomerate, containing plant traces, seems to rest on Culm shales. Blackish shales are often met with, as between Rydonball Cross and Rydonball Plantation. Respecting this outlier, De la Beche observed,* "Mr. Austen pointed out to us the non-conformable position of shales, which probably form part of the neighbouring carbonaceous rocks, upon the limestones of the Conator Quarry Hill, a kind of conglomerate, chiefly composed of pieces of the subjacent limestone, some of large size, mixed with quartz, and loosely cemented by sand, occuring beneath the shales. How far this may be the general character of the lower part of this patch of carbonaceous rocks, it would be difficult to say, as the country is deficient in good natural sections of its base, and faults seem common."

In making a detailed map of the district, I was unable to verify the above passage, not having observed limestones in the conglomerate or any fragments much larger than a bean; consequently, it is possible that if the above quotation refers to an actual exposure, it may have been destroyed in subsequent

* Report p. 111.

quarrying operations, and denote either a very considerable unconformity or a thrust plane with shattered limestone ground into its sole.

At a half-a-mile south of this outlier there is another patch of Culm bounded by four faults. This is about half the extent of the former patch, and is chiefly composed of dark grey shales, but near its eastern border hard bluish and greenish sandstones crop out, and on the east of Two Mile Oak Inn, an irregular bed of small quartz pebble conglomerate occurs in the shales. In the district, south of Bovey Tracey, the Chert beds of Ramshorn Down are apparently overlaid by greenish sandstones and shales containing plant remains.

The faulted Culm Measures in the Goldstreet Farm cutting by the Devonport and Tavistock railway,* consist of Basement beds of the Brimley type with cherty bands apparently overlain by micaceous grey sandstones, partly shaly and irregularly associated with shales. In the Wood between Park Town and Lifton, as has already been pointed out, the Coddon Hill Chert beds "are overlain by yellowish-brown conglomeratic beds, intersected by numerous horizontal joints, and resembling rocks in the Culm series at Ramsleigh" (east of East Ogwell). As there is nothing in De la Beche to guide one in tracing these sandstones toward the Bude coast it is impossible to conjecture as to their extension in that direction. It is a noteworthy fact that this abnormal occurrence of sandstones and conglomerates in the southern area above the Basement beds is confined to a district in which igneous activity is evidenced by numerous intrusive dolerite patches and contemporaneous volcanic materials, which are almost absent in the northern area.

It will be seen that if these arenaceous rocks rest upon different horizons of the Basement beds, and contain fragments derived from them, a gap in time between their deposition and that of the underlying beds is indicated; and north of

* Ussher—Trans. Dev. Assoc. for 1889, p. 441.

Chudleigh, where the series is complete, if we search for similar arenaceous developments they are met with in the irregular grits and shales which constitute the Morchard type, and are separated from the Basement beds by a series of hard generally thin bedded grits, intercalated in dark shales frequently of a splintery character (the Exeter type). If then the correlation of the sandy grits of the Morchard type with the conglomeratic sandstones could be proved, the gap between the latter and the Basement beds would be bridged over by these intercalated grits and shales of the Exeter type, north of Chudleigh; but from local shoalings consequent upon the volcanic activity manifested during the earlier stages of Culm deposition on the east and west of Dartmoor, little or no deposition took place until after the Exeter type had been accumulated in the waters to the north. If the observation quoted from De la Beche as to Culm conglomerate with fragments of Devonian limestone occurring on Conator Quarry Hill can be depended upon, there would be a very strong reason for inferring an unconformity in the Culm, south of Chudleigh, of sufficient magnitude to account for the absence of the Exeter type in this part of the area. On the other hand, it is quite possible that these conglomeratic sandstones may be contemporaneous with rocks of the Exeter type, and owe their difference in character to a modification of conditions of deposit in some way connected with the prevalence of volcanic activity* in their vicinity. But in this case we must dismiss the Conator limestone-bearing conglomerate of De la Beche, as untrustworthy, or otherwise explainable.

On the hypothesis of an unconformity, the inclusion of the beds of the Exeter type with the Basement beds, as Lower Culm, and the separation from them of the rocks of the Morchard type as Middle Culm, would certainly be justified, and my classification of 1887 would be vindicated.

* Near East Ogwell, in Goldstreet Farm, Cutting, and near Lifton, the coarser materials may be partly of volcanic origin as tuffs or agglomerate.

THE MORCHARD TYPE.

The rocks of the Morchard type consist of grits, sandstones, shales and slates. The grits are often hard and fine grained, varying in colour from grey, greenish grey, to brown and lilac-brown. The sandstones are generally micaceous, often coarse, sometimes compact, sometimes friable, of whitish, greenish, reddish and grey colours. In bedding, this series displays great irregularity, its component grits, shales, and sandstones being partly even thin and thick bedded, partly very uneven, the grits occurring in irregular masses in the shales. As a consequence of this irregular association the constant contortions affecting these beds frequently exhibit a bizarre appearance. The shales are sometimes blackish and finely laminated, sometimes thick and irregularly laminated or intersected by slaty cleavage, sometimes breaking in concentric flakes, a structure simulating that of the Triassic marls of Devon and Somerset but more finely divided.

The village of Morchard Bishop is about half-way between Crediton and Chumleigh : most of the peculiarities mentioned above are exhibited by the Culm rocks in its vicinity, so I applied the term Morchard to this type, in contradistinction to the higher series of even grits typically exposed in the Railway cuttings near Eggesford Station on the S.W.R. in the same district, and hence called Eggesford grits. The Morchard type, often in plicated association with the Exeter type, occurs at Hartland Point, and occupies most of the coast from Westward Ho ! to beyond the New Red outlier of Portledge and Peppercombe : it extends thence through Bideford and the adjacent villages by South Molton toward Uploman in the New Red area. On the borders of the New Red rocks these beds have an extensive superficial outcrop which is probably due to the bifurcation of the main synclinal trough of Eggesford grits, bringing in an anticlinal from Witheridge and Cruwys Morchard, past Chumleigh, Burrington and Beaford westward. The villages of Bickleigh, Kenner-

leigh, Broadwoodkelly, Hatherleigh, and Sheepwash are surrounded by beds of the Morchard type. Beyond Sheepwash westward my researches do not extend. The Exe valley railway on emerging from the New Red rocks follows the Alluvium of the river for about four miles through a district furnishing numerous quarries of lilac-brown sandstones often thick bedded and associated with finely divided shales, and marly splitting shales or mudstones. At two-and-a-quarter miles from Bickleigh station, grits which may belong to the Eggesford series, are imperfectly exposed in a cutting for the most part walled up. Near Howden, at thirty chains further north, a cutting shows dark shales with beds of grey quartz-veined sandstones. The Tiverton cutting reveals irregular shales and marly splitting shale and mudstone, with intercalations of brownish sandstone.

In the first cutting, one-and-a-half miles beyond the New Red boundary at Bolham, there may be a faulted junction between rocks of the Morchard type, consisting of broken grits, lilac grits and shales, and hard grey grits and shales, and splintery shales of the Exeter type. The beds are very much contorted; further north the Exeter type prevails.

On the north of the New Red boundary about Honeychurch, Zeal Monachorum, &c.; thick-bedded sandstones, reddish and greenish, associated with shales, often of a marly structure, are met with. Thick-bedded sandstones occur in this series, notably, along the strike of the Anthracite bands, from Bideford, through Umberleigh, Chittlehampton, and South Molton. In Hawkridge Wood, near Umberleigh, the sandstones are coarse and whitish, and contain anthracitic plant traces. Near Bideford, at Higher Southcot Farm, white sandstone also occurs and a quarry shows greenish grey massive, rather imperfectly bedded, coarse sandstones, intersected by regular joints, also, a bed of soft sandstones, containing plant traces and thick, grey shales. In character this section assimilates nearly to the Ugbrooke Park

beds. By the Torridge, near Durrand, north of Bideford, greenish and grey sandstones are exposed, often flaking in thin flaggy pieces, sometimes with ripple-marked surfaces and shale films ; about Westward Ho buff and greenish, irregularly-jointed sandstones, with plant traces ; hard, red brown sandstones, in places, fissile, with micaceous surfaces ; shaley, grey grits in mudstones or shales, splitting in thick, irregular flakes. At the north end of Appledore, grey sandstones, containing plant remains, exhibit spheroidal and elliptical, concentric, concretionary structure. A somewhat similar structure is exhibited by massive, irregularly-jointed, anticlined grits at Beam, north-west of Torrington.

In the area from South Molton westward there is a strange absence of any proportionate representation of the rocks of the Exeter type, *en masse ;* and to the west of the Taw Valley it would seem as if the rocks of the Morchard type occupied pretty much the same position with reference to the Basement beds that the Ugbrooke Park beds occupy in South Devon. From Appledore to beyond the New Red outlier of Portledge Mouth the coast section is chiefly made up of rocks, referable to the Morchard type. It is only where we get developments of splintery shales and thin-bedded grits that we hesitate to aver that the Exeter type is absent from this part of the area ; but the contortions ever present throughout the area prevent our assigning a definite stratigraphical value to these shales.

Between Westward Ho ! Pier and Rock Nose greenish grey sandstones and shales and massive sandstones and slaty shales occur in the cliffs.

Between Rock Nose and Lake Nose, at from 16 to 89 chains from the former, the coast consists of shales and mudstones, with beds of grey grit here and there, massive grits occurring at from 24 to 34 chains ; these are interstratified with blackish shales, and bear up a complicated synclinal of grits, partly lilac, containing a thin impersistent conglomerate band at 34 chains, where they appear to be cut off by fault. At 45 to 48

chains concretionary dark grey mudstones occur; at 60 even flaggy grey broken grits. Dark grey splintery shales and mudstones occupy the coast, at from 65 to 87 chains; grey grits, 87 to 89 chains; whence to Lakes Nose dark grey shales prevail. With the exception of the complex grit synclinal above referred to, it is possible that these beds may be the representatives of the Exeter type. From Lakes Nose to Portledge Mouth the grits of the Morchard type and associated shales occupy the coast.

The section at Lakes Nose consists of dark grey splintery shales, thin alternations of sandstone and shales, coarse, hard and soft, white and buff, speckled sandstone, with anthracite seams, massive grit and sandstones, one of the beds being eight feet in thickness: these beds may be faulted against dark shales, with thin grit beds. From this point to Portledge Mouth grits and sandstones predominate; proceeding southward we encounter hard, course, grey grits, associated with dark shales, massive grey, quartz-veined grits and shales, thick grey, arenaceous, splintery-fractured shale or mudstone, whitish sandstone, irregular concretionary sandstones, grey grits and shales, massive grey grits, forming a fine inverted anticlinal; these latter, with overlying intercalated thin beds of grits and shales, are repeated by well-marked anticlines, and affected by numerous contortions consequent on the resistance of the harder massive beds, and on the yielding of the thinner grits and shales: two of these were figured by me.* For half-a-mile up to Portledge Mouth the cliffs show contorted grey grits and red-brown and lilac grits and sandstones, affected by a fault at about a quarter-of-a-mile from Portledge Mouth. From the New Red rocks of Portledge Mouth toward Clovelly, the Morchard type, through plicated repetition, gradually gives place to the Eggesford grits, which occupy the coast from near Buckish Mill to beyond Clovelly; the Morchard type reappearing in the Hartland

* "Geol. Mag.," Jan., 1887, p. 15.

Point Cliffs. From the Lighthouse at Hartland Point the following downward succession of beds is visible: pale greenish sandstones, dark shale with greenish sandstone beds, thick brown sandstone, lilac shale with grit beds, thick-bedded hard lilac grit and shale, dark blue shale, grey, brown weathered even grits, dark blue (slaty?) shales, grits, with dark grey tough shale partings, grey quartzveined grits, dark grey shale.

By the high road, south of Ford, near Bideford, vertical cleavage intersects shales, with grit beds, exhibiting a synclinal; but in other parts of the section slaty structure is not so apparent. By the high road, south of Lancross, thick and thin-bedded grey grits are intercalated with dark shales, often of a splintery character. As these shales occur apparently either high up in the Morchard group or at the base of the Eggesford grits, and similar shales occur in the vicinity of Chumleigh, seemingly on or about the same horizon, we must either cease to assign any definite stratigraphical value to the splintery type of shales, or ascribe their occurrence to faults or folds bringing up a lower series of the St. David's type in unexpected places. Red or lilac grits and shales occur at Littleham and near Lancross; south of Lancross Mill a well was sunk through 57 feet of red shales and grits. Similar red beds are plentiful in the Witheridge district, and in places on the north of the Crediton valley. In proximity to the New Red rocks the shales and grits of both the Exeter and Morchard types are often reddened, but in the Morchard type reddish or lilac hues occur in districts far removed from the New Red boundaries, which does not appear to be the case in districts occupied by the Exeter type.

The Anthracite beds are found in the vicinity of Chittlehampton, Tawstock, Abbotsham, and Alverdiscot. They are referred to by Polwhele,* Vancouver,† Lysons,‡ Sedgewick

* *History of Devonshire*, p. 55 (1797).

† *General view of the Agriculture of the County of Devon* (1808).

‡ *Magna Britannia*, Devon (1822), p. 26.

and Murchison in 1840, and De la Beche. Mr. T. M. Hall refers to these authorities in a paper* from which the following quotations are taken :—"'The widest culmiferous band is nearly 18 feet in width, but several smaller strings of the same material traverse the slates and shales" at Greenacliff, between Rocks Nose and Portledge Mouth.

"At Pitt quarry in the parish of Abbotsham a great variety of characteristic plants are found in the grits adjoining the Culm bands. At Bideford may be seen a few yards north of the...railway station the black shales forming the outcrop of the veins which until a very recent period were worked to a considerable extent. The ruins of an old engine house still remain, and a quarry behind it affords fine specimens of fossil plant remains. About a mile east of this spot the present works consisting of a shaft and level adit are still carried on, for the purpose of obtaining the softer varieties of Anthracite, which when ground to powder are sold as a pigment under the name of 'Bideford Black.'" De la Beche figures the† mode in which the Anthracite occurs in the shales in irregular lenticular bands.

The whitish sandstones of Hawkridge Wood near Umberleigh belong to the anthracitic horizons extending from Lakes Nose through Bideford eastward to Alverdiscot and Chittlehampton. The Tawstock Anthracite ‡ mentioned by Mr. T. M. Hall is not as far as I can see shown on De la Beche's maps, although he indicated an Anthracite band at South Aller, at about half a mile from the Devonian boundary, near South Molton, which is probably at about the same horizon. A quarry near South Aller shows grey grits in beds and irregular masses in dark shales, the whole greatly disturbed and probably faulted: the strike if unbroken would account for

* *Trans. Dev. Assoc.* for 1875.—Notes on the Anthracite, &c.

† *Report on Geol. of Corn., Devon, etc.*, p. 125.

‡ At Hiscott in the parish of Tawstock there are two veins 9 feet in thickness—*Geology and Mineralogy of N. Devon* by T. M Hall, F.G.S., Ilfracombe, 1877 (Pamphlet).

the Anthracite workings in the low ground on the immediate flank of the Upper Devonian near Mornacot, about four miles further to the east. Proceeding from Aller westward on the south of the Coddon Hill beds of Tawstock we find grey sandstones, sandy grits and greenish sandstones, and shales; further west by the Torridge we encounter in Tapeleigh park, south of Instow Station, massive grits and thick shales, and nearer to the Station hard greenish grey grits and shales. These beds seem to be in immediate vicinity of an inlier of the Basement beds, as by an old note I find that ferruginous stained black shales or slates contain traces of fossils resembling *Goniatites*. On crossing the Torridge at this place, grey grits occur apparently with conglomeratic seams (from an abbreviated note made in 1878), south of Appledore.

From the above notes we gather that from the coast for a distance of twenty-four miles along the strike inland, the Basement beds are directly overlaid by rocks which exhibit the characters of the Morchard group, and in many respects present very strong affinities to the Ugbrooke Park sandstones. Further, the contact between the Anthracitic group and the Devonian at Mornacot, proves a fault boundary for a few miles at least, or an unconformity.

In all this district, for twenty-four miles from the coast, the appearances of rocks of the Exeter type, although not infrequent, are such as to suggest either the local prevalence of splintery shales and thin grits in the Morchard type, and probably all above the anthracitic horizons, or transgressive overlap of the Morchard type across the beds of the Exeter type on to the Basement beds.

In the first of these explanations, the common characters of the groups would leave it an open question whether the main types were stratigraphically distinct, or whether the Exeter type gradually passed into the Morchard type westward, through slight changes in sources of derivation or conditions of deposition.

In the second explanation, the presence of rocks of the Exeter type in such places as Umberleigh, around Hawkridge Wood, near Saterleigh and George Nympton in the district of South Molton, and on the coast north of Lakes Nose would be accounted for by the exposure through denudation of contorted inliers of the beds of the Exeter type through the overlying Morchard series, and the absence of such exposures in the vicinity of the Basement beds would be due to the final overlap of the Morchard series.

In these hypothetical suggestions I attach no weight to the feeble signs of conglomerate in one spot on the coast, and in another, perhaps, on the south side of Appledore. Trivial as these signs may appear, taken in conjunction with the coarse grain of the rocks, they strengthen the correlation of the Ugbrooke Park, Conator, Rydonball, and Lifton, etc. sandstones, with the sandstones of Appledore, Tawstock, Umberleigh, and South Molton; but as to the main question as to whether the Exeter and Morchard types have a purely local or an absolute stratigraphical value they cannot be adduced as evidence.

In defining the limits and characteristics of the Morchard type it must be borne in mind that beds of a common character, such as hard even bedded lilac grits may possibly belong to the higher horizon, the Eggesford grits, but although such a reservation might by laborious investigation prove to be correct, I do not think it could materially affect the general conclusions put forward in this paper.

EGGESFORD GRITS.

The Upper Culm Measures differ from all the lower types in the prevalence of hard, more or less even bedded, rather fine grained grits, with dark shale partings in places, and intercalations of shale and slate. As a whole this group is characterized by its regular character as contrasted with the Morchard type, and by the prevalence of grits of a different

nature and more uniform thickness and jointing, as contrasted with the shales and grit beds of the Exeter type.

By these distinctions it is not meant that grits of a similar nature do not occur in the Morchard and Exeter types here and there, but that these types nowhere exhibit a development of grits similar to those of the Eggesford series. The junction of the Eggesford grits with the Morchard series is as I have already said rendered very indefinite through the repetition of the junction beds by plication; but eliminating this perplexing element there is every reason to conclude that no break of any kind occurs between them, but on the contrary the one series passes downward into the other by a transition almost imperceptible.

In my paper on Coal prospects south of the Mendips,* I spoke of the probability of the shallowing of the main synclinal structure of the Culm Measures eastward.

Evidence of this has been given in the foregoing pages in treating of the distribution of the Morchard type more particularly. Along the Exe Valley Railway, which traverses the Culm Measures across their strike, there is only one observation favouring the occurrence of the Eggesford grits, namely a partial exposure in a cutting for the most part walled up, of even grits with shale partings dipping northward at 65°. Whether this observation denotes the presence of a thin synclinal band of Upper Culm Measures or not, the fact that the main synclinal structure flattens out from west to east is in no way affected by it, as this is shown by the distribution of the mass of the Eggesford grits. The main mass of these grits probably attains its greatest continuous development on the coast between Hartland Point and Bude as its superficial breadth decreases from the Torridge valley eastward. These beds are developed at Monkleigh, Torrington, and Newton Petrock in an area about seven miles in breadth, in which, through the shallow nature of the synclinal and constant

* *Proc. Somerset Archæol. and Nat. Hist. Soc.* vol. xxxvi. p. 111.

repetition by innumerable small folds, exposures of rocks resembling those of the Morchard type and probably belonging to that group are here and there visible, as on the east of Torrington Common where an anticlinal affects sandy shales with plant traces, at Moors Hill, east of Marland, where micaceous beds are exposed, and in the neighbourhood of Beaford. In the Taw Valley the Eggesford grits are developed about High Bickington, extending eastward through Kings Nympton perhaps beyond Meshaw Moors, and about Eggesford, where they are well exposed in the railway cuttings, the rocks of the Morchard type appear to separate the High Bickington development from that about Eggesford, suggesting the intervention of an anticlinal near Burrington, perhaps prolonged westward across the Torridge Valley near Beaford. If this is the case the main synclinal would fork into two on the west of the Torridge, one connecting the Torrington and High Bickington developments, the other those of Newton Petrock and Eggesford. The Eggesford development may extend westward to Thelbridge, but in the area east of the Taw I could find no distinctive mass of grits like those of Eggesford, High Bickington, and Torrington; so that if the Eggesford grits are present they have lost their distinctive characters and cannot be separated, even theoretically, from the rocks of the Morchard type. This is what we should expect to find in the easterly troughing out of the main synclinals, namely a constant repetition of the junction beds of both types by contortion, which on the margins of the Torrington and Eggesford developments makes any definite line of boundary impossible. For example, in the district for some miles north of Monkleigh, it is difficult to say to which groups the section given at Ford, the rocks at Lancross, Littleham, and other places, really belong.

By the high road south of Lancross, thick and thin-bedded grey grits, with intercalations of dark shale of a splintery character, dip S at 65°, and seem to be abnormally undisturbed

for about 300 yards. A similar difficulty is encountered near Buckish Mill, on the coast; but as we proceed in the direction of Clovelly the distinctive nature of the Eggesford group is unmistakable; grey and lilac-grey thick-bedded even grits, with intercalations of dark grey shale here and there, the whole bent into a beautiful series of normal and inverted folds. The sketch (*fig.* 4), represents a natural arch or tunnel worn by the sea, in a stack of hard grey quartzveined grits dipping

Fig. 4.

Beach reef in Eggesford Grits, 70 chains from Clovelly Pier.

landward, at about 70 chains from Clovelly Pier. At about 18 chains from the Pier red quartzveined grit is exposed.

INLIERS AND EASTERLY PROLONGATIONS.

The inlying masses of Culm Measures in the New Red rocks between Collumpton and Broad Clist consist of shales and grits belonging either to the Morchard or Exeter type. The record of *Goniatites* at Pinhoe, in Mr. Vicary's collection coupled with the southerly appearance of the Culm limestone through plicated repetition at Westleigh, near Burlescombe, affords the possibility that representatives of the Basement beds might by careful search be brought to light in these inliers, and the presence of Devonian fossils in the gravelly New Red rocks, recorded by the late Rev. W. Downes, points in the same direction. Be this as it may, the distribution of the Culm Measures between Exeter and Burlescombe, *i.e.*, on passing beneath the New Red rocks, justifies the conclusion that the main synclinal structure of the Culm area is very unlikely to continue beneath the Upper Greensands of the Blackdown Hills, and that no calculations as to the introughing of productive Coal Measures can be entertained with any degree of probability within the borders of Devon.

In the Paper referred to* the Rev. W. Downes recorded the occurrence in the New Red gravels of Uploman, on the north side of the Tiverton Valley, of fragments containing *Strophalosia caperata*, Sow., *Spirifera disjuncta*, Sow., *Rhynchonella pleurodon*, Phil.; the section, over 30 feet in depth, consisted of rubbly angular and subangular grit gravel in a sandy matrix. He also described the cuttings in the Exe Valley Railway, then being constructed, and noticed the increase in size of the grit fragments northward toward the termination of the New Red at Bolham. In these gravels near Bolham he found fragments of rotten stone, which he referred in part to the porphyrites of Washfield, near Tiverton, in part to altered palœozoic grits; in the latter he obtained *Strophalosia caperata, Spirifera disjuncta, and Productus prolongus*, Sow. These fragments he referred to disturbances consequent on volcanic action at Washfield. "The subjacent rocks must have been bent and shifted by its deep-seated forces, which would have brought deep-seated rocks to the surface, at least in a fragmentary condition." In a postscript, he mentioned the discovery of *Rhynchonella pleurodon* "in the Trias at Silverton . . . upon the same line of igneous disturbance." Mr. Etheridge suggested a fold to account for a hidden source of supply for these Devonian stones, but this Mr. Downes dismissed as demanding too great a disturbance in view of the distance of the exposed Devonian outcrop to the north of the localities. I think, however, the suggestion of Mr. Etheridge is very probable as regards the Uploman and Bolham fragments, but the Culm inliers further south render such an explanation for the Silverton occurrence doubtful. I would point out the following considerations as worthy of notice in accounting for these Devonian fragments. As we have seen, the general synclinal structure of the Culm is very shallow and contracts eastward without deepening, a fact deducible from the southerly repetition of the Culm limestone at West-

* *Trans. Dev. Assoc.* for 1881, pp. 293–297.

leigh, the apparent northerly folding up of the *Goniatite* beds of the same series at Pinhoe, and the absence of representation of the Upper Culm Measures (Eggesford grits) in the districts bordering the New Red.

Furthermore, as has already frequently been mentioned, the occurrence of small folds throughout the area is incalculable, the tendency of these folds being to repeat horizons so constantly that dips prove nothing as to thickness, the real dip lines being obliterated by contortion, so that a large area of contorted beds might be formed of a small thickness of originally horizontal beds. It is, then, in such an area that the channels in which the New Red rocks were deposited would have been scooped out, and it is scarcely conceivable that the processes of denudation would not have laid bare the underlying Devonian rocks in or near the mouth of the Tiverton Valley and in the Crediton Valley. I cannot endorse the view of the porphyritic emissions explaining the occurrence of the Devonian fragments, as I failed to observe signs of volcanic *ejectamenta* in the gravels of the Tiverton New Red,* which appear to me to underlie the lava and ash of Washfield; but I do not deny that the volcanic episode may have been an interlude in the deposition of the gravels, and that Mr. Downes' reference of pumiceous fragments in them to the Washfield Volcanic rocks may be perfectly correct.

OUTLIERS.

Reference has already been made to the Culm Measure Outliers between Ipplepen and Newton Abbot, and at Goldstreet Farm on the Devonport and Tavistock Railway. These are all accounted for by faulted relations with the Devonian. De la Beche's mention† of the occurrence of dark

* I obtained Brachiopods in red grit surface fragments, probably relics of neighbouring New Red breccia, at West Bowleigh, near Stokeleigh Pomeroy, in 1876-7.

† Report p. 58.

flinty shales at Hurrygulter on the north, and Helstone on the south, of Camelford suggests the presence of outlying patches of cherty Coddon Hill beds on the margin of the Brown Willy Granite. At Denham's Bridge in the area east of Padstow he mentions* black carbonaceous slates which is somewhat suggestive of Culm Measures. In the late Dr. Harvey Holl's section, from Yealm Bridge southward through South Petherwin, a small patch of Culm Measures is shown at Pollinny, but that may be a tongue proceeding west from the Culm area on the north of Lezant. Another patch is shown at Higher Trelabe in the same section two-and-a-half miles further south. Again in his section, from Minwonnet through Pollaphant to the Brown Willy Granite, an outlier of Culm rocks is shown at about half a mile from the Granite boundary. This is apparently on strike with the Culm at Higher Trelabe and suggests a synclinal strip of considerable extent. There can be little doubt that detailed investigations in the Upper Devonian area between Launceston and Camelford would very materially modify the general appearance of De la Beche's maps.

FOSSILS.

Apart from the investigations of Dr. Woodward and the lists he gives, no new information, except in the extension of the fossil finds of Mr. Lee to many other localities, can be given. As I have shown, *Trilobites* have been found at Hestow Farm and near Whiteway Farm in the Waddon Barton districts, and *Goniatites spiralis* in many places in the same district, as also on the south of Launceston.

When however we come to the enlargement of the Fauna we find the fossils collected by the late Rev. W. Downes from the Basement Culm beds near Burlescombe uncertain as to determination, and most of those in Mr. Vicary's collection await determination, so I quote Dr. Woodward's lists. †

* *Ibid* p. 90.

† *Geological Magazine* for 1884, p. 534.

Culm Measure Plants determined by Mr. R. Kidston.

Asterocalamites scrobiculatus Schloth., sp. (*Bornia radiata.* Brong.)

Calamites Rœmeri, Gopp.

Sphenopteris n., sp.

Lepidodendron Rhodeanum (?)

Lepidophloios, sp. *Haloni i* (fruiting branch of *Lepidophloios.*)

Sigillaria (?)

Stigmaria ficoides, Brong.

Dadoxylon (Sternbergia) Sternb. in Mr. Vicary's collection.

"All these plants have (says Mr. Kidston) a calciferous sandstone facies and are equivalent to the Culm of Germany."

Fossils from Culm Basement beds, obtained by late Mr. J. E. Lee, Waddon Barton, revised and augmented by R. Etheridge, Junr., and Dr. H. Woodward.

Orthoceras striolatum, Sandb. (chiefly external casts).

Orthoceras sp. (there are probably more than two species of Orthoceras).

**Goniatites mixolobus*, Phil. (as figured by Roemer).

Goniatites sphœricus, Martin, sp. (as figured by Roemer).

Posidonomya Becheri, Bron.

Posidonomya corrugata, Eth. (? Young of *P. Becheri*).

Pecten, n. sp.? of Carboniferous facies different from Von Koenen's figures.

Pteronites, sp. (form related to *Pt. persulcatus*—M'Coy).

Pteronites, sp. (form related to *Pt. latus* M'Coy).

Avicula lepida, Goldf.

Chonetes rectispina, Von Koen.

Chonetes deflexa, Von Koen.

Spirifera Urei, Flem.

* Through the kindness of Dr. Woodward I was shown many of his specimens not yet examined, amongst which *Goniatites spiralis*, as figured by Phillips, is abundant.

Fenestella sp. (condition of *Hemitrypa hibernica* M'Coy).
Phillipsia Leei, H. Woodward.
Phillipsia minor, H. Woodward.
Phillipsia Cliffordi, H. Woodward.
Phillipsia articulosa, H. Woodward.
Primitia Barrandiana? Jones M.S.
Casts of small corals probably *Monticuliporidæ*.
Casts of small organisms (probably sponge spicules.)

Dr. Woodward adds, "I think it can no longer be denied that the Posidonomya and Goniatite shales of both North and South Devon are really (as suggested by Dr. A. Geikie and now shown from their fossil contents by Mr. John E. Lee) at the very base of the Carboniferous series and are equivalent to the Lower Carboniferous series of the Rhenish provinces and the Hartz."

"There is little doubt also that the plant remains which occur in the associated sandstones of the same regions are older than those of the Millstone grit series, and must be correlated with the Calciferous sandstone series."

VOLCANIC ROCKS.

De la Beche* in pointing out the contrast between the carbonaceous rocks of North and of South Devon, afforded by the "intermixture of schistose trappean ash among the beds," and of intrusive greenstones in the latter area, remarked, "Doubts may be entertained as to the date of the greenstone, but none can exist respecting the ash, which has evidently been contemporaneously deposited," &c. The chief areas of vulcanicity are shown on De la Beche's maps in the Tavistock and Launceston country, on the west of Dartmoor, and on the easternmost margin of Dartmoor, in the district between Dunsford, Chudleigh and Bovey Tracey. Both these groups appear to be as De la Beche considered,† contemporaneous in the Lower Culm Measures.

* Report, p. 119.
† *Ibid*, p. 141.

In the district between Dunsford and Chudleigh, De la Beche's* lines show the position of the district in which the greenstones occur, but can rarely be found to coincide with the actual boundaries of the rocks; instead of about 16 large patches of greenstone, there are more than 50, but many of them very small. The rocks are mostly Dolerites; the Botter rock mass of Hennock being the largest, and a band extending from near Doddiscombleigh in a south-westerly direction to Combe, south of Christow, the longest. This latter band being roughly parallel to a contemporaneous Ash, may be a Lava, and a similar probability attaches to several thin bands of Dolerite which run along the strikes (notably, to a band parallel to a Tuff band at Ridon Farm, S. of Trusham), but the majority are evidently intrusive. The Dolerites are well exposed near Crocomb Bridge, south of Trusham, by the Teign Valley railway, between Trusham and Ashton Stations, north of Ashton Station, and in quarries near Doddiscombleigh. Between Doddiscombleigh and Cato Hall, south of Trusham, Tuffs are interstratified with the Culm Measures. The most important band can be traced for a distance of two miles, with an average breadth of about 100 yards, from its apparent termination at about three quarters of a mile south of Christow Church, only broken by the Alluvium of the Teign, on the east side of which it is exposed in the railway cutting, running thence along the summit of the hill, at the foot of which Ashton is situated. The line of this Tuff band affords a most useful guide to structure; it is probably continuous, with some Tuff striking at right angles to its main trend towards Doddiscombleigh, and the same horizon may be represented at Shute, near Doddiscombleigh, where Tuff is exposed for a very short distance, apparently on an east and west strike.

At Ridon Farm, south of Trusham, the same band may be continued by Tuff striking north and south, in which case the

* *Vide Ibid*, p. 112.

horizon is shifted from its apparent termination south of Christow, on the west side of the River Teign, by fault to the east side of the river, or it is repeated by plication.

North of Trusham and east of Ridon Farm, a thin band of Tuff strikes south-east. A further continuation of the horizon is suggested by a broader band of Tuff, which can be traced in a north and south direction for nearly half a mile on the east of Crocomb Bridge, south of Trusham. No further instances of the occurrence of Tuffs on the east of Dartmoor have been observed, but from Crocomb Bridge to Bovey Tracey the general distribution of the Dolerite patches agrees more or less with the strike. Between Bovey Tracey and Lustleigh there are several patches of Dolerite. From Bovey Tracey southward, in the attentuating strip of Culm Measures on the borders of Dartmoor, a few small patches of Dolerite occur near Brimley, and one near Standcombe Farm, on the south-east of Ramshorn Down. The extreme distances at which Dolerites are found, from the Granite boundary, are at about two and a half miles, near Doddiscombleigh, and at Ruggardon, south-east of Trusham. The Culm rocks with which the contemporaneous Ash beds are associated evidently belong to the Basement beds from the proximity of traces of the calcareous (Culm limestone) horizon at Wooder, near Doddiscombleigh, Bileing, south of Christow, and Cato Hall, south of Trusham.

Following round the northern boundary of the Granite, De la Beche's maps show no greenstones for about 10 miles from Bridford, when a series of long patches, commencing near South Zeal, is shown rounding with the deflected strike, south of Okehampton, toward Lidford. These bands continue the strike of the Bridestow, &c., limestone patches round the Granite toward the limestones of Whiddon Down and Drewsteignton; hence we may assume a contemporaniety for them with the Basement Culm beds.

On the west of Dartmoor De la Beche's maps show very

large masses of Greenstone in the Culm area; detailed investigations would no doubt prove, as in the Chudleigh district, that the boundaries are generalized, and that the large masses betoken the sporadic occurrence of numerous patches of less extent. Owing to the occurrence of igneous rocks in the Devonian (Grauwacke of De la Beche), especially between Davidstow and Trecarrel Bridge, along the valley of the River Inny, De la Beche * found the development of Tuffs and Greenstones about Tavistock—an insuperable obstacle to the assignment of a definite boundary between the Culm and Devonian. Holl placed the boundary south of Lamerton, and this, I think, is correct, so that all the Ash beds about Tavistock would be included in the Culm. From the evidence afforded by the South Western Railway cuttings volcanic rocks would appear locally to form the actual base of the Culm. "Commencing† on the west with Willapark Point Cliff, near Boscastle, we find a thin bed of 'schistose trappean ash,' interstratified with the black slates and grits of the mass of the hill. Proceeding eastward it becomes difficult to assign the same rocks near Lesnewith more to one system than to the other, and there is the like difficulty with the trappean Ash extending thence along the boundary to Hallworthy." The bands of Tuff mentioned in this passage are not shown on De la Beche's map. ‡ "Greenstone occurs among the grits and shales at Minwonnet, near Trewin, at Trewithick, near Launceston, and in the town of Launceston itself; while schistose trappean Ash occurs at Tregadillack and on the top of the hill rising on the South of Launceston." De la Beche's section (*Fig.* 2, *Plate* 4) shows Porphyry (not indicated on his maps) in carbonaceous limestone and roofing slate in the valley between the Greenstones of Trewithick and Tregadillack.

"A well-marked band of volcanic trappean Ash," commen-

* Report, pp. 108, 109; also, pp. 140, 141.

† *Ibid*, p. 119.

‡ Sheet 30 of the Ordnance Geological Survey.

cing at Dunterton and broadening at Milton Abbot, extends irregularly eastward for about eight miles to the vicinity of Mary Tavy. Mr. Rutley* compared a section of vesicular schistose rock, full of small specks and granules of calcspar, in this band, near Curlhanger, with varieties of the Nassau Schalstein. He notes the exposure of over 20 feet of Ash in a quarry in it, near Kilworthy. A mass of Greenstone running in a nearly parallel direction on the north is shown to bend southward on the east side of Rams Down and to join it. Mr. Rutley† described the west end of this band and a patch of similar rock at Greston Bridge near it, as decomposed Greenstone (serpentinous rock), "resembling Basalt;" adding that the Greston Bridge patch consists "of two beds, parted by and resting upon black shales, approximating to Lydian stone. Near this Milton Abbot Tuff band, on the south another Tuff band is shown, commencing near Milton Abbot and said to continue to Sowtentown, a distance of seven miles from west to east. Mr. Rutley observed "rubbly decomposed Ash" opposite Lamerton Church, and scoriaceous fragments on the surface, near Shortaburn, in this band.‡ Between this band and Tavistock a broad mass of Ash is shown on the map; Mr. Rutley notes, "a good exposure of schistose Ash in the main road from Tavistock to Milton Abbot, which, at Longford Farm, shows interbedded vesicular bands, about three to four inches in thickness, lying in a somewhat horizontal position."§ De la Beche's map shows this band after great constriction of breadth expanding westward and joining the Lamerton band at Sowtentown. Mr. Rutley is disinclined to prolong it so far. The prolongation of the Lamerton band westward to Cock's Tor seems to be Gabbro, also running in the direction of, if not to contact with, the Ash

* Mem. Geol. Sur. on Brentor, &c., 1878, p. 24.

† *Ibid*, p. 17, map and pl. 6, fig. 4.

‡ *Ibid*, p. 23.

§ *Ibid*, p. 22.

mass on the north of Tavistock.* Mr. Rutley considered it probable that the three Ash bands of Milton Abbot, Lamerton, and that on the north side of Tavistock, "are but repetitions of the same beds."

On the east side of Tavistock there are two bands of Ash: near the westernmost I obtained a S.E. dip and Mr. Rutley† noticed a north westerly dip in the easternmost; so they are probably connected by a synclinal.

Near Stiles Wick on the west of Tavistock and near the south border of the Ash mass, a patch of greenstone is shown on the map, which if surface evidence can be relied on appeared to Mr. Rutley to be a decomposing Diorite. All the Ash bands mentioned above lie to the south of Brentor. "A very marked band of Ash in which there are cinders occurs on the east of Brentor from near North Brentor to South Brentor."‡ "A mixture of compact trappean rock principally greenstone with Ash occurs about a mile from Brentor at Wick on the north west, part of a band which becomes entirely Ash in the direction of Upperton. Greenstone is also found near Bowden more on the north of the Tor, which is associated with Ash in the continuation of the same band toward Barcomb." Mr. Rutley§ says, "The strips of Ash on the north and east of Brentor, although showing local variations, may also be regarded with a fair amount of probability, as being continuations of the beds on the south and west. Brentor itself differs considerably from these Ash beds which encircle it." De la Beche‖ discussed the phenomena presented by Brentor at length, describing it as an ancient volcano from which were emitted the greenstones as lavas, and the Ash bands north and north-west of Tavistock. Mr. Rutley confirmed De la Beche's view showing the volcanic character of

* *Ibid*, pp. 16, 17, and 28.
† *Ibid* p. 22.
‡ De la Beche's Report pp. 121, 122.
§ Brentor Memoir p. 17.
‖ Report pp. 120-122, and Researches in Theoretical Geology, 1834, p. 385.

the Brentor rocks, from observations in the field and microscopic examination, proving them to consist of Basalt, Pitchstone, Pumice, and volcanic breccias. In 1880 Mr. Rutley communicated an interesting paper "On the schistose volcanic rocks west of Dartmoor," to the Geological Society.* In this paper he not only vindicated De la Beche's view as to Brentor being an old volcanic crater, but further suggested the emission therefrom of the several tuff and sheared lava bands associated with the Palæozoic strata as far south as Saltash, explaining the appearance of the bands on different lines of latitude in accordance with the late Dr. Harvey Holl's view of correlating similar strata by great general systems of folds. The probability of this explanation gains force from its simplicity; but although we may readily admit the probability of the emission of lava streams and showers of ash at different times from the same pipe, as is so well illustrated by figures 7 and 8 in Mr. Rutley's paper; that very admission precludes the possibility of ascertaining the relative age of the Palæozoic strata by volcanic interstratifications, as very considerable periods of quiescence may have intervened between the eruptions, so that volcanic rocks of Devonian age, and of Lower Carboniferous age may have come from the same sources. The occurrence of the lavas and ashes around Brentor, in an area where the Basement beds of the Culm Measures are over and over again repeated by plication, and Upper Devonian rocks are exposed near Lidford and Mary-Tavy, not only justifies our connecting the volcanic episode with the deposition of the earliest Culm sediments, but also points to the probability of a considerable repetition of the igneous rocks by plication. This repetition in the environs of Brentor seem to be effected by more or less gentle undulations, affording a very marked contrast to the constant small sharp plications of the Culm Measures in the areas north of Dartmoor and Brown Willy.

* *Quar. Journ. Geol. Soc.* for May, 1880, pp. 285-295.

Mr. Rutley says,* "On referring to the Geological Survey Map it will be seen that at two localities, Brazen Tor and Waspworthy, there are small patches mapped in as greenstones which are in actual contact with the Granite. These are Hornblende Rock (Amphibolite), and the line of demarcation between it and the Granite is a very sharp one" at Brazentor. "A little further to the south-west two large intrusive masses of somewhat similar character constitute the features known as Smear Ridge and White Tor. These, together with the Brazen Tor and Waspworthy patches, are probably connected at some little depth beneath the present surface. Cock's Tor situated a little further to the south is composed of a rock very similar in appearance to those just mentioned, but under the microscope it is seen to contain little or no free silica, and to be composed of diallage, plagioclase, titanic iron, and apparently a little apatite. It must therefore be regarded as a Gabbro." †"These may even be of later date than the Granite of Dartmoor, and so far as evidence goes there is nothing to show that they are in any way connected with the volcanic series of Brent Tor and its surrounding Ash beds."

The preservation of Brentor is discussed at length by Mr. Rutley, and indeed when this exceptional evidence of a crater vent is viewed in connection with the absence of any recognizable source for the Ash beds of the area on the east of Dartmoor, it seems almost certain that the intrusive Dolerites are in some cases intersected pipes from which the upper parts and crater orifices have been removed by denudation.

Although signs of volcanic activity are conspicuous by their absence in the Culm Measures of North Devon, Igneous rocks are most exceptionally present. On the north of Fremington bosses of hard apparently intrusive rock are visible by the Creek on the south of the Railway, whilst at about twelve chains north of the Railway a band of hard grey rock with a

* Brentor Memoir p. 15.

† *Ibid* p. 46.

vesicularly weathered surface occurs in the Basement beds of the Culm on the west shore of the promontory. At the village of Rose Ash in the South Molton district, and three miles south of the faulted boundary with the Devonian, the late Rev. W. Downes recorded* the discovery of a dyke of Minette (mica trap) in the Culm Measures. The rock was not seen by him in section, the excavation having been filled in. Judging from the description given it seems to me to belong to the series associated with the New Red, of which, besides the Washfield rocks, there is an example associated with a New Red outlier at Coleford Lodge near Stoodley Beacon, two miles to the north of the Washfield rocks, and seven miles from Rose Ash; also at the termination of the Tiverton New Red at Holmead where a small patch almost surrounded by Culm Measures occurs at eight miles from Rose Ash.

GERMAN CULM TYPES.

WESTPHALIA.

Herr Dr. Kayser† gives the downward succession in Westphalia as follows:—

Flötzleerer Sandstone.

Culm.—Alum shales, Posidonomya shales, Kieselschiefer and limestone.

Carboniferous Limestone { Upper dolomite zone (Ratingen) Pale coloured, thick bedded semi-crystalline limestone.

Upper Devonian.—Bluish grey to greenish shale and sandstone with feeble limestone intercalations at the base: blackish sandy shale equivalent to the Flinz.

"The composition of the Culm is," he says, "the most fluctuating in this succession, a band of Alum shale indeed forms its uppermost boundary. So far I could everywhere convince myself: on the other hand the beds underlying these exhibit

* *Trans. Dev. Assoc.*. for 1884, p. 498

† *Jahrb. d. Kgl. Preuss. Geol. Landesanst*, for 1881, p. 57.

small differences, in nearly every section, which are specially influenced by the very different thickness and purity of the Kieselschiefer and limestone." The Carboniferous limestone commences at the base of the Culm in a bed a foot thick at Neviges, thickening westward to 100 feet on N. of Velbert, and to over 100 feet at Ratingen near Dusseldorf. But, in the same proportion that the Carboniferous limestone gradually increases in thickness, the Culm diminishes, till finally at Aachen (Aix la Chapelle), and in Belgium it has altogether disappeared. Besides this reciprocity in thickness—more or less thick intercalations of Kieselschiefer or black alum-like shales sometimes crop up in the midst of the pure Carboniferous limestone, and sometimes at the junction of both types a decided alternation of light colored limestone beds of carboniferous limestone aspect and beds of Kieselschiefer takes place. The boundary between Culm or Carboniferous limestone and Upper Devonian (Kramenzel) is easy of detection. Kayser compares the Upper Devonian Fauna of Velbert and Belgium to that of the Pilton and Marwood (Baggy) beds of N. Devon. The Fauna of the Lower Culm and Carboniferous limestone bears out the idea of the deposition of the former in shallow, the latter in deeper and more open seas. Whilst the Carboniferous limestone possesses a rich very varied Fauna, composed of Cephalopods, Gasteropods, Bivalves, Corals, etc., the Culm Fauna has a very monotonous and homogeneous composition of some few Cephalopods (*Goniatites* and *Orthoceras*) and Pelecypods, whilst Brachiopods are scarce, and Gasteropods and Corals wanting.

As instances of the Culm Fauna exceptionally presenting a varied composition similar to that of the Carboniferous limestone, Kayser cites the Culm limestones of Iberg near Grund in the Upper Hartz which contain a series of Cephalopods, Brachiopods and Gasteropods unusual for the Culm (*Nautilus*, *Bactrites*, *Productus*, *Spirifer*). The Culm fauna of Herborn,

worked out by Von Könen,* amongst which is one *Gyroceras*, two species of *Nautilus*, many Brachiopods, two of which *Terebratula hastata* and *Productus humerosus* (=*sublævis*) are leading Carboniferous limestone forms, also a Cyathophyllum. Kayser gives a list of 29 species from the Culm of Aprath in Westphalia, many of the forms such as *Cladochonus Michelini*, *Chonetes Buchiana*, *Chonetes polita*, etc. being known Carboniferous limestone species.

Herborn is four miles from Giessen and five from Marburg; Von Könen's list of 44 species, and Kayser's list from Aprath are cited by Dr. H. Woodward, in comparison with the Waddon Barton Culm fossils. The Culm of Herborn is in a trough in the Devonian, and geographically connected with the Westphalian region on the north.

UPPER HARTZ.

The Culm Measures of the Upper Hartz are separated from those of Westphalia by more than 60 miles of Triassic rocks. Herr Groddeck† divides the Upper Hartz Culm into the following horizons in descending sequence :—

Grunder Grauwacke. Shales, with intercalated conglomerates, containing badly-preserved plant traces, chiefly *Calamites*.

Clausthal Grauwacke. Shales, with alternations of Grauwacke, only generally separable from the overlying series. In these beds beautiful plant remains are to be found.

Posidonomya Becheri and *Goniatites crenistria* occur in shales, with intercalated thin beds of Grauwacke; these may indicate a passage into the Posidonomya Schiefer, or belong to that horizon folded up.

Posidonomya Schiefer. Shales or clay slates, containing *Posidonomya Becheri* and *Goniatites crenistria* in places, and locally rich in plant remains.

* *Neu-Jahrb. f. Mineralogie, etc.* for 1879, p. 309, etc.
† *Jahrb. d. Geol. Landesanst. u. Berg. Akad.* 1882.

Kieselschiefer (chert beds). These beds seldom contain *Posidonomya*, and no plant remains occur in them.

Silicified Culm limestones, containing *Goniatites crenistria* and *Inoceramus carbonarius*, Röm (=*Posidonomya vetusta*, Sow.), occur on the margin of the Upper Devonian limestones of Iberg and Winterberg, near Grund.

The Culm rocks of the Upper Hartz are thrown into a series of N.E. and S.W. folds.

The composition of the grauwacke and conglomerate beds of the Culm indicates derivation from an area of Primitive Clay slates, with thick beds of splintery quartz, probably traversed by great quartz veins, and broken by many dykes or protuberances of Granite and felsitic porphyry. The succession from Lower Devonian to Grunder grauwacke indicates a gradual upheaval of the sea bed.

EAST THURINGIA.

The Culm area of East Thuringia is about 135 miles distant from that of the Upper Hartz, in a south-easterly direction. Herr Liebe* describes the Culm rocks as consisting mainly of a succession of shales and grauwacke and grauwacke sandstones, susceptible of a general separation into a Lower division, consisting chiefly of shales, with grauwacke sandstones, and only a few beds of coarse grauwacke; and an Upper, composed principally of grauwacke, of medium and coarse grain, with intercalations of shale, and only a few grauwacke sandstone beds.

The Lower Culm furnishes roofing slates; the grauwacke sandstones in it are very thin-bedded—one to two inches; and it also contains flat lenticles of very hard dark sandstone, which are distinctive of the lower beds. Conglomerates occur here and there in the Lower Culm; they consist of well-

* 1884, *Abhandlungen zur Geologischen Special Karte von Preussen u. Thuringischen Staaten, Band V.; Heft.* 4.

worn fragments, chiefly of quartzite, quartz and slate, besides chert, adinole, orthoclase, plagioclase, carbonaceous alum shale, bound in very fine sandy paste.

The base of the Lower Culm is sometimes formed of granite conglomerate, sometimes of blackish limestone not exceeding seven feet in thickness. The relations of the granite conglomerate and limestone are reciprocal. The granite conglomerate is chiefly composed of well rolled fragments of granite and granitoid rocks, and a very little fine grauwacke material. The limestone is oolitic and contains Foraminifera. In the extreme south-east of the district it is accompanied by one or two beds of dark grey limestone with many Brachiopods including *Productus mesolobus*. These limestones represent the Carboniferous limestones. There are also in the Lower Culm above the base, beds of calcareous grauwacke with many traces of fossils, chiefly crinoid joints. Near Elsterberg the Kieselschiefer or chert beds are absent from the Lower Culm, but at some feet above the basement limestones globular geodes and flat lenticular cakes of cherty material occur. These geodes contain Goniatites, especially *Goniatites crenistria* and *Goniatites mixolobus*. Compare with this the Goniatite nodules near Instow, in Exeter, from Cocktree Moor and near Baldoak Farm.

The Upper Culm of E. Thuringia contains a preponderance of conglomerates, similar to those of the Lower Culm but with very ferruginous calc-carbonate cementing matter. The shales are of a paler colour and coarser texture than in the Lower division, and contain no roofing slate. The thickness of the Culm rocks, owing to the absence of sharp divisional lines and constant foldings and disturbances, cannot be estimated with certainty. *Posidonomya Becheri* has not been found in the E. Thuringian Culm. The plants, though certain species are often more plentiful in certain parts of the series, are too widely distributed to have zonal values. *Calamites transitionis*, Göpp, is more plentiful in the Upper Culm, *Sagenaria remota*, Göpp (*Dicty-*

odora Liebeana of Geinitz and Weiss) is most plentiful on the boundary between Upper and Lower Culm. *Palæochorda spiralis*, Geinitz, is more abundant in the Lower Culm. *Phyllodocites thuringiacus*, Gein, and *Ph. Jacksoni (?)* Emmons, occur throughout.

Herr Weiss† speaks of the junction of the Culm and Upper Devonian as quite conformable. He gives the following list of plants :—

Archæocalamites radiatus, Brongn.
Archæocalamites tenuissimus, Göpp.
Artisia, sp.
Archæopteris Dawsoni, Stur.
**Bythotrephis (Chondrites) Göpperti*, Gein.
Chondrites succulens, Hall.
Chondrites flexuosus, Emmons.
Chondrites vermiformis, Ludwig.
Calamites transitionis, Göpp.
Cardiopteris Hochstetteri, Stur.
Cycadopteris antiqua, Stur.
Cyclopteris dissecta, Göpp.
Crossopodia Henrici, Gein.
**Dictyodora (Dictyophytum) Liebeana*, Gein.
Fucoides bipinnatus, Richter.
Knorria longifolia, Göpp.
Lepidodendron (Sagenaria) remota, Göpp.
Lepidodendron cyclostigma, Göpp.
Lepidodendron Jaschei, Röm.
Lepidodendron minutissimum, Göpp.
Lepidodendron transversum, Göpp.
Lepidodendron veltheimianum, *Presl.*
**Lepidophloios angulatus*, n. sp.
Lophoctenium comosum, Richter.
**Lophoctenium Hartungi*, Gein.
**Lophoctenium rhabdiforme*, n. sp.
Megaphytum Hollebeni, Cotta.
Megaphytum, simplex, Göpp.
Naites priscus, Gein.
Nereites Loomisi, Emmons.

Those marked * are figured by *Weiss.*

† *Jahrb. d. Königl. Preuss. Geolog. Landesanstalt.* for 1883, p. 81, &c.

Nöggerathia Rückeriana, Göpp.
Odontopteris.
Palæochorda spiralis, Gein.
Palæochorda marina, Emmons.
Palæophycus Hartungi, Gein.
Palæophycus falcatus, Ludwig.
Palæophycus macrocystoides, Gein.
Phyllodocites Jacksoni, Emmons.
Phyllodocites thuringiacus, Gein.
Pinites Catharinæ, Richter.
**Sphenopteris, Gulielmi imperatoris*, n. sp.

In East Thuringia, Herr Liebe† shows that the Culm and Upper Devonian overlap the Middle Devonian, the former resting directly on the Cambrian, between Greiz and Pausa, near Lobenstein, and with the intervention of breccia, constituting the Uppermost Devonian, between Greiz and Reichenbach. He therefore infers an elevation in the Middle Devonian period, and a sinking at the beginning of the Upper Devonian continued during the deposition of the older beds of the Culm.

There are some Diabase patches in the Lower Culm, near Saalfield and near Elbersdorf; but volcanic breccia ceased in the uppermost part of the Upper Devonian. With this compare the junction of the Culm and Upper Devonian, obscured by volcanic beds in the Tavistock and Brentor district.

Herr Dr Richter‡ describes the Thuringian Culm as occupying two basins, separated by about 11 miles of older rocks of the Frankenwald.

The Eastern basin has been referred to above : the Southern lies S.S.W. of it. In a section across a part of the Southern basin, Culm rocks are shown resting directly on Middle Devonian, which, in the vicinity, supports an outlier of Upper Devonian. The Culm conglomerates of the Southern basin contain many chert (Kieselschiefer) fragments derived from the Lower Silurian.

Those marked * are figured by *Weiss.*

† 1884. Op. cit.

‡ *Zeitschr. d. D. Geol. Ges. XXI., pp.* 408, 411, *Taf. VI. Prof.* 3, 1867.

SAXON CULM MEASURES.

Over 20 miles east of the East Thuringian Culm area, near Wildenfels, south-east of Zwickau, according to Herr Dalmer,* all the members of the Silurian and Devonian of the Thuringian Fichtelgebirge, besides Lower Carboniferous and an Archœan inlier, are brought together in the small space of about six square miles. Between Zwickau and Dresden, Culm rocks are again represented near Chemnitz, Frankenberg and Hainischen. The Lower Carboniferous rocks of Wildenfels consist of shales, grauwacke, conglomerates and limestones, agreeing petrographically with the Thuringian Culm rocks.

The shales are dark grey and earthy, and contain numerous pale sandy beds. The grauwacke and conglomerate are characterized by abundance of chert (Kieselschiefer) fragments and also contain quartz and felspar grains as well as pieces of clay slate, quartzite, and diabase, but Archœan detritus which enters largely into the composition of the Chemnitz Hainischen Culm is absent.

The limestones are partly intercalated in the grauwacke shales and conglomerates, partly form the base of the whole system; at Schonau conglomerates occur below them. The limestones are moderately thick bedded, rich in crinoid joints weathering out in relief, among which *Melocrinus lævis*, Goldf., is often recognizable. Hand specimens are identical with specimens from the Fichtelgebirge. Ten beds of limestone are known, some being from 3 feet 3 inches to 6 feet 6 inches, others over 65 feet thick. The limestones contain Foraminifera, possibly in part *Endothyra*, corals of Carboniferous limestone species. *Aulophyllum fungites*, Milne, Edw., *Diphyphyllum concinnum*, and a form allied to *Lithostrotion proliferum*. There is no proof that the Wildenfels Culm rests on older beds than the Clymenia limestones of the Upper

* Ueber das Vorkommen von Kulm u. Kohlenkalk, etc.—*Zeitschr. d. D. Geol. Gesell*—p. 379, 1884.

Devonian, whilst the Chemnitz Hainischen Culm rests nearly horizontally on highly inclined Silurian strata; coupling this with the relative distribution of Archœan detritus, Herr Dalmer considers the Wildenfels Culm newer than the Chemnitz Hainischen, and that the chief effects of the movements that produced the Erzegebirge system of folds were attained in the interim.

According to Rothpletz, beside plants typical of Lower Culm, there are others belonging to Sturr's upper division in the Hainischen Culm.

SILESIAN AND MORAVIAN CULM.

The Culm rocks again appear near Waldenberg at 130 miles east of the Chemnitz Hainischen Culm, and between Waldenberg and Glatz, at and near Hausdorf and Falkenberg, and in greater development, occupying considerable areas, near Jägerndorf, Troppau, Olmutz and Brünn, more than 215 miles from the Chemnitz Hainischen Culm, south-east of Glatz.

In* Silesia the Culm beds begin with coarse conglomerates, which again make their appearance in the higher horizons of the productive Coal Measures, and are less developed in Upper than in Lower Silesia. The Culm of Upper Silesia and Moravia, as typically developed† in the districts of Troppau, Jägerndorf, and Leobschütz, consists of an alternation of *Posidonomya Becheri* bearing shales (not calcareous), grauwacke sandstones and grauwacke conglomerates containing the distinctive land plants of the Culm. The only occurrence of *P. Becheri* in Lower Silesia was discovered by Herr Dames at Bögendorf.

The Culm in the vicinity of Hausdorf and Frankenberg in the Glatz district, as described by Herr Dathe,‡ constitutes a small area bounded by Gneiss on one side, and largely

* Groddeck, *Jahrb. d. Geol. Landes Anst. u. Berg. Akad.*, 1882, p. 64.

† F. Römer—*Geol. of Upper Silesia*, 1870, pp. 56 and 57.

‡ Dathe. Jahrb. d. Geol. Landes Anst. u. Berg Akad, 1882, pp. 228-260.

concealed by diluvium. The Culm rocks consist of sandy shales, finely fissile in the lower part, in thicker laminæ higher up, with numerous beds of sandstone, often containing felspar grains and forming arkoses. At their junction with the Gneiss the Culm rocks are so largely derived from it as to form in places gneiss conglomerate. Fossiliferous limestones* occur only in thin beds, or lenticles alternating with the shales and sandstones. Numerous beds of Gabbro Conglomerate, formed of Gabbro, Serpentine, etc., occur at various horizons, some being on the boundary between the Culm and Upper Carboniferous, at which horizon dolomitic limestones are locally found, as at Reichels Koppe above the Gabbro Conglomerates. There are also three beds of Variolite bearing Conglomerate, composed of well rolled fragments of quartz, hornstone, schist, granite mostly pegmatitic, adinole and eruptive rocks but without gabbro fragments. The lowest bed is about 3 feet thick; the highest is about 32 feet, and separated from the Upper Carboniferous by a band of shale and Gabbro Conglomerates. Olivine Gabbro, apparently contemporaneous, occurs in two places in the Culm, viz.: at Hausdorf and at Colony Weitengrund. Schütze advocated an unconformity between the Culm and Upper Carboniferous, an appearance which Herr Dathe accounts for by faults. Dathe gives the following junction section by the road to Wenzeslaus mine, in descending order:—

White quartz Conglomerate—Upper Carboniferous.
Gabbro Conglomerate.
Fine shaly micaceous sandstone.
Gabbro Conglomerate.
Shales and Grauwacke.

At Freiberg,† in Lower Silesia, as at Iberg, in the Upper Hartz, inlying Upper Devonian limestone crops up in the

* For fossils see—Smenow—Fauna of Silesian Carboniferous Limestone, *Zeit. d. D. Geol. Gesell.* VI. pp. 317-414.

† Dames, *Zeitchr. d. D Geol. Gesell.* vol. 20, p. 469, 1868.

Culm grauwacke and shales. At Iberg the bordering Culm limestones have been completely silicified.

In each of the above-mentioned areas there is some point, or points, in common with the British Culm Measures. The Culm beds of the Westphalian area, in fossils and lithological character, correspond more or less closely to the Basement Culm of Devon, where typically developed. The Flötzleerer may be roughly classed with the Millstone grit, with the Yoredales in part, or with the mass of the grits and shales of the Culm.

In the Hartz the Grunder grauwacke would be homotaxeous with the Eggesford grits; the Clausthal grauwacke with the Morchard and Exeter types; and the Posidonomya Schiefer and Kieselschiefer with the Basement beds.

In Thuringia the shales and grauwacke sandstones compare with the main mass of the Devon Culm; whilst the cherty geodes, with *Goniatites*, suggest such occurrences as the *Goniatite* nodules at and near Exeter and at Instow, perhaps constituting a subtype of the Chert and limestone beds.

The Saxon area only offers a general comparison through the basement limestone and overlying grauwacke shales and conglomerates.

The Silesian and Moravian area, except in the occurrence of shales and grauwacke and of *Posidonomya Becheri* shales, does not betray a very strong analogy to the Devon types.

Taking into account the variable nature and situation of the sources of supply and different conditions of sedimentation, occasioned by local movements in the several areas, it is easy to account for the prevalence of Culm conglomerates in Silesia, Saxony and the Hartz; and their comparative absence in Westphalia and in Devon and Cornwall.

The general modification exhibited by the Carboniferous rocks of Britain and the Franco-Belgian and German areas below productive Coal Measures, seems to consist in a more or less reciprocal development of a medial series of arenaceous rocks, and a lower series containing calcareous rocks.

The Millstone grit, and the Carboniferous limestone may be regarded as the pure types : these by admixture of muddy sediments becoming debased, through local sources of supply and varying geographical conditions have their analogues in the Yoredales, Culm shales sandstones and Conglomerates, Lower Carboniferous Shales, Posidonomya Becheri Shales and limestones and so forth. The variations of the arenaceous division and its reciprocal relation to the underlying series, coupled with the local interblending of arenaceous, argillaceous. and calcareous materials, renders any absolute chronological correlation of the various types, as can be seen from the Culm areas, very doubtful. But as a whole and in homotaxeous subdivisions, the Carboniferous is distinct from the underlying Devonian, and bears, in spite of the inconstancy of its types, strong internal evidence of its individuality.

*PART II.**

MECHANICAL EFFECTS

PRODUCED BY THE PRESENCE OF THE DARTMOOR GRANITE

UPON THE SURROUNDING STRATA.

THE effects produced by the Granite mass of Dartmoor upon the structure and distribution of the Culm Measures are enormous. This is shown by irregularity of distribution, deflection of strike and constriction of outcrop. Viewed in connection with these effects the alteration of the Culm Measures for a mile or two outward from the Granite boundary becomes comparatively insignificant.

EFFECTS ON THE DISTRIBUTION OF THE CULM MEASURES.

De la Beche remarked, "From the vicinity of Tavistock to that of Holne Chase near Ashburton the southern boundary of the Carbonaceous system runs along the edge of the Granite of Dartmoor for a distance of about 46 miles. Throughout this distance the protrusion of the Granite has thrown up the edges of the beds, rendering them in a few places nearly vertical, as can be seen on the high road from Okehampton to Exeter at Ramsleigh near South Zeal."† The extension of Culm rocks (probably in plicated association with the Uppermost Devonian beds) southward to Walkhampton, and from Dean Church near Ashburton round the southernmost projection of the Granite at Ivybridge toward Cornwood adds a further distance of 14 miles to De la Beche's

* *The official permission does not apply to Part II., which embodies the Author's views apart from his connection with the Geological Survey.*

† *Report on the Geol. of Corn. Devon, &c.*, p. 109.

46, and only leaves 10 or 11 miles of the Granite in contact with the Devonian area between Walkhampton and Cornwood; but even in this small distance the alteration of the beds in the vicinity of the Granite renders it impossible to assert that Culm Measures may not be brought in here and there by plication or fault. At Shaugh Bridge Tunnel the appearance of certain buff beds suggests altered shales of the Culm Basement beds of the Brimley type.

The general strike of the Culm Measures is East and West, or rather E. 10° to 15° S., and W. 10° to 15° N., consequently assuming the North and South Movements, which produced this strike, to have operated on Culm and Devonian rocks alone, without the interference of the Granites of Dartmoor and the Brown Willy mass, the southern boundary of the Culm Measures would run from Boscastle, on the north of Launceston and Lifton, on the south of Lydford, through Ilsington, across the Bovey Valley to the English Channel, at about a mile north of Teignmouth. The effect of Dartmoor on the distribution of the Culm rocks is, however, the production of a southerly deflection, reaching its maxima on either margin of the Granite, carrying the Culm 15 miles further south on its eastern border, and about eight miles further south on its western margin. So that there is about 100 square miles of Culm Measures on the west of Dartmoor, to the south of the presumable site of their boundary, supposing Dartmoor to be non-existent; and on the east of Dartmoor about 30 square miles. It is a curious fact, that as far as one can judge the Culm and Devonian junctions are at Boscastle and on the North of Teignmouth, thereby justifying my assumpton that the line joining these places, removed from the effects produced by the Granites, would represent the strike boundary had no Granite existed to interfere with it. It seems somewhat anomalous that whilst the southerly extension of the Culm on the east of Dartmoor is so much greater, its area is so much less than that on the west side. In this consideration there are

three factors which ought to be taken into account—1st. The Brown Willy Granite "shoves the calcareo-trappean and fossiliferous country of South Petherwin and Padstow to the northward at Tintagel,"* "where the beds of the grauwacke are merely forced seaward in a great curve by the protrusion of the neighbouring Granite."† The effect of the Brown Willy Granite on the Culm is to deflect its boundary 10° to 15° further S. of E.; but in the area between Tavistock and the Brown Willy Granite, the east and west line of the Granite patches of Kit Hill and Hingston Down suggests a subterranean easterly continuation of the Brown Willy mass toward Dartmoor, and to the north of these Granite patches the normal strike appears to be resumed for some miles, so that there is reason to conclude that a subterranean ridge connecting these patches with the Brown Willy mass has checked the deflecting tendency produced by the latter from extending as far southward as it would otherwise have done.

Secondly. On the east of Dartmoor there is no evidence of the subterranean extension of the Granite eastward to check the southerly deflection of the Culm Measures, or to increase their expansion by protecting them.

Thirdly. The eastern border of Dartmoor is very irregular; whilst its western boundary is much more even in trend, the indentations at Meavy being on a smaller scale than those at Bovey and Ashburton. These irregularities in the Granite seem to have protected the contact rocks. It is an open question whether the contact rocks in the Cornwood and Meavy indentations may or may not be altered Culm Measures, of the Basement beds.

EFFECTS ON STRIKE.

The general effects of the Dartmoor Granite on the Strike of the Culm Measures are as I have already pointed out well

* De la Beche's Report, p. 165.

† *Ibid*, p. 56.

shown by the chain of limestone patches which occur at intervals from Drewsteignton to Launceston. The true position of the Drewsteignton band would be seven miles to the south, if there had been no Granite obstruction.

Taking the limestone bands and lenticles of Doddiscombleigh, Bileing near Ashton, and Cato Hall north of Chudleigh into account, the effect of the Dartmoor Granite on this calcareous horizon has been to deflect its strike into a curve 30 miles in length extending round the northern border of the Granite, which may be described as an arc subtending an angle of about 120° As long as the Granite boundary exhibits a rough parallelism to the general strike as its northern margin does, the calcareous horizon as shown at South Tawton and Drewsteignton is nowhere more than a mile from the Granite, but south of Okehampton the strike runs parallel with the south westerly trend of the Granite margin to Bridestow, and continues in the same direction from Bridestow toward Lifton although the Granite boundary deflects southward. In discussing the distribution of the Culm it has been shown that its main boundary with the Devonian both on the east and south of Dartmoor instead of being forced northward, as might have appeared natural from the deflection of the strike we have been considering, is deflected southward.

De la Beche in the passages cited draws attention to the uptilting of the Culm Measures on the Granite margin. The same phenomenon is shown in the Granite junctions with the Devonian rocks of Cornwall in all his sections and in the instances mentioned in the text where the junctions are not brought about by fault. I have never seen anything to warrant a contrary opinion, nevertheless it is necessary to ascertain how far this uptilting extends. In a series of folded strata this is rendered apparent by the outward peristence of strike parallel to the Granite boundary upon which the contact rocks are tilted up. Where as in the case of the northern boundary the uptilt is along or nearly along the

general strike such effects could not be traced, but where as in the case of the eastern and western granite boundaries, the uptilting has the effect of turning the strike sharply round, we are at once in a position to gauge its outward extension. In the eastern district, making use of the information already detailed as to the distribution of contemporaneous volcanic rock and calcareous matter between Dunsford and Chudleigh, we find that whilst the general east and west strike is maintained to the north of Doddiscombleigh to the south of that village there is evidence of a struggle between the general east and west strike and an obstruction tending to produce a subordinate north and south strike: as a consequence the strike constantly varies, having a tendency to run in an irregularly zig-zag fashion, and only to exhibit the direct uptilt at and very near the Granite boundary. The Devonian valley of Chudleigh is thrust up between faults which exhibit a rough parallelism to the Granite boundary on the west and to the limits of the Doleritic rocks intervening. From Trusham the tendency of the strike is to round with the Granite. At Bovey Tracey and Ashburton the uptilted beds being through the sinuosities of the Granite boundary constantly altered in strike, and from Bickington to Ashburton the Culm being a comparatively narrow band and faulted against the Devonian there is no need for further reference to the east side of Dartmoor.

On the west side of Dartmoor the uptilting of the beds seems to be confined to the Granite margin, but the true bedding is in many cases doubtful. The effects on the strike are somewhat similar to those manifested on the south of Doddiscombleigh in the Chudleigh area, the beds being repeated in a triangular area, apex at Launceston, base on Dartmoor between Bridestow and Walkhampton: to use an homely simile like a concertina pressed together at one end whilst it is opened out at the other. The beds affected usually belong to the Basement Culm Measures with volcanic rocks,

and Upper Devonian at Lidford, Mary Tavy and probably also at Tavistock station S.W.R.

The uptilting of the contact rocks both on the east and west of Dartmoor seems to be rather a flattening out of the strata against the Granite, than actual uptilting, as from Horrabridge southward to Cann Quarry south of Bickley the Devonian seems to belong to the Uppermost beds (Cypridinen Schiefer) such as are exposed in places under the Culm and volcanic rocks from Lidford to Tavistock. In contact with the Dolerite masses the beds are often altered and exhibit a finely spotted character both in the Tavistock and Chudleigh areas. The Culm Measures, where intersected on their strike by the S.W.R. from Okehampton to Tavistock, often exhibit an appearance of dovetailing in the bedding, as if produced by the intersection of zig-zag plications. In the Devonian at Tavistock station, S.W.R., and by the G.W.R. at Yelverton, Horrabridge, near Shaugh Bridge Tunnel, etc. the planes of schistosity seem to be frequently almost horizontal. Although it is probable that these planes represent the direction of the actual bedding in many cases, it seems I think almost certain that they are joint or cleavage planes, as the welded laminæ of the slates in the Tavistock S.W.R. station cutting exhibit in places a distinctly gnarled structure, quite independent of the horizontal planes and cut across by them thus (*fig. 5*): A similar interplanal movement is very well shown in pale greenish slates in the G.W.R. cutting at Shaugh Wood (*fig. 6*). The similarity in colour and interplanal structure to gnarled chloritic rocks between Salcombe Estuary and the Prawle is very striking, yet in this case the gnarled rocks are unaltered, and nearly two miles distant from the Granite boundary. The same greenish Upper Devonian slates as shown in the S.W.R. cuttings south of Tavistock, at about five miles from the Granite, have only one set of planes of schistosity which is

(*Fig. 5.*)

(*Fig. 6.*)

apparently in most cases the true lamination, or coincident with it. Mr. Rutley* in commenting on the schistose character of the volcanic ash beds of Tavistock and round Brent Tor observed that so far as dips can be noted the rocks have undergone but little pressure laterally. The abnormal extension of the Upper Devonian between the Dartmoor and Brown Willy Granites would show that the beds have been kept at the surface, whilst at the same time exposed to a considerable strain, effecting contortions on so small a scale or under such conditions as to produce the effect of a general almost horizontal bedding.

CONSTRICTION OF OUTCROP.

In estimating the effects of the Granite of Dartmoor on the constrictions of outcrop, I purpose completing the evidence by also taking into consideration the effects on the Devonian rocks in this respect.

I have already shown that the main synclinal structure of the Culm Measures is complicated by undulations which seem to cause the Upper beds to fork from the Torridge valley westward into two synclinals, so that in measuring the breadth of outcrop of the Culm rocks, it will be necessary to treat the synclinal as a simple one, and to take the position of the axis along the general strike from Welcombe on the west coast through East Putford, Beaford, Chumleigh and Cruwys Morchard to the New Red boundary on the south of Tiverton. This line I believe has about an equal distribution of the Upper Culm Measures or Eggesford grits on the north and south side of it. From this central line the constriction of the Culm Measures is shown by perpendiculars drawn southward to the northern boundary of the Granite, and to the Devonian junction on either side of it. The relative breadths of outcrops are as follows:—From Chumleigh to the north border of the Granite, near South Tawton, 13½ miles. From a point

* Brent Tor Memoir, p. 22.

between East Putford and Beaford due south of Torrington to the Devonian boundary near Tavistock 27 miles; a line drawn parallel $4\frac{1}{2}$ miles further west gives a distance of 25 miles. This distance would be increased if the line were taken closer to the Granite, through the southerly deflection of the Culm rocks, to about 29 miles, and would be diminished to $21\frac{1}{2}$ miles if the line were drawn near the west coast due south from Welcombe. On the east side of Dartmoor it is necessary to ignore the Culm rocks skirting the Granite between the Bovey valley and Ivybridge, and to take the line from Cruwys Morchard southward to Teigngrace in the Bovey valley, which is the best mean distance obtainable, and amounts to 23 miles. The latitude of Ivybridge is 11 miles further to the south. The distance from the Triassic boundary near Tiverton where the central line enters it to the coast at about a mile north of Teignmouth is 23 miles.

Twenty-three miles may be taken as the normal mean breadth of the Culm Measures where apparently uninfluenced by Granite on either side of Dartmoor.

The maximum deflections southward along the Granites make the extension of the Culm Measures, measured from the same line, 29 miles on the west and 35 miles on the east of Dartmoor. The normal outcrop breadth of 23 miles is therefore constricted by the Granite to $13\frac{1}{2}$ miles, a difference of $9\frac{1}{2}$ miles.

The southerly projection of Dartmoor has quite as important an effect in constricting the Devonian, as its northern extension has upon the Culm Measures.

Notwithstanding numerous disturbances and local changes of strike, the general strike of the Devonian rocks of the Chudleigh and Kingsteignton districts and of the area bordering the Culm Measures from the Bovey Valley, as far south as Dean Church and Totnes, exhibits a trend roughly conformable to the direction of the Granite boundary, the prevalent dip, folds being inverted, is south-easterly. This rule is not

applicable to the Devonian area between Totnes and Torquay, where the prevalent strike as shown by the distribution of the subdivisions is more or less in an east and west direction. Hence it follows that as the strata next the attenuating band of Culm Measures seem to continue on a south-westerly strike toward the southern border of Dartmoor; the westerly strikes of the Totnes area prolonged converge in the same direction, so that bands a considerable distance apart further north are by the constriction of the southern projection of Dartmoor, brought very much closer together toward Kingsbridge Road and Ivybridge. It is necessary to measure the extent of this constriction by a marked strike line or lines uninfluenced by the presence of the Granite. If a line be drawn on a map from the southern boundary of the Granite, near Ivybridge, to Berry Head, almost due east of it it will be found on minute investigation that the Devonian rocks on the south of it maintain a general east and west strike. This is shown by the continuous extension of the Lower Devonian grits (Staddon and Lincombe and Warberry beds) from the vicinity of Sharkham Point, near Brixham, to the vicinity of Modbury, whence they trend in a south-westerly direction to Holbeton, being prolonged thence westward to Staddon Heights, on Plymouth Sound.

In the district south of this line, from Ivybridge to Berry Head, notwithstanding numerous plications and faults, there is an extraordinary persistence of lithological types along their strikes, from the Lower Devonian grit boundary to the south coast. In the districts north of this line, on the contrary, as we advance further from the Granite we find around Newton Abbot, Paignton and Torquay, an entire absence of continuity in strike through numerous dislocations, shifting all the Devonian divisions of those areas and bringing into juxtaposition horizons considerably removed in time. In these areas the Lower Devonian grits are confined to the Paignton district and to the Torquay Promontory. The Paignton Lower De-

vonian is evidently the western end of an anticlinal, of which the Torquay Lower Devonian is a faulted off-shoot. The broken synclinal which separates the Lower Devonian grits of Paignton and Cockington from those of Modbury and Staddon, probably troughs out the Upper and Middle Devonian in the English Channel to the east of Berry Head. The Lower Devonian Grit boundary, as being a definite line to measure from, will be taken in estimating the breadths of outcrop of the Middle and Upper Devonian rocks, intervening between it and the Granite, the distances being measured in this case across the strike, as far as possible, to the Culm Measure boundary, on either side of Dartmoor and to the Granite at Kingsbridge Road, Ivybridge, and Bickley.

The outcrop of the Upper and Middle Devonian from the Lower Devonian boundary in the Paignton area, to the Culm boundary between the Bovey Valley and Ashburton varies between 7 and $8\frac{1}{2}$ miles. From the Paignton Lower Devonian boundary to the nearest part of the Granite boundary near Dean Church deducting a mile for intervening Culm Measures the distance is $7\frac{1}{2}$ miles. From the Lower Devonian boundary on Black Down, east of Modbury to the nearest part of the Granite boundary near Kingsbridge Road Station is $4\frac{1}{2}$ miles, ignoring intervening Culm Measures. From the Lower Devonian boundary near Modbury northward to the most southerly projection of the Granite at Mooredge near Ivybridge is not quite $2\frac{1}{2}$ miles, ignoring intervening Culm Measures. From the Lower Devonian boundary at Holbeton northward to the Granite is $4\frac{1}{2}$ miles, the increased distance being due to change in strike from the vicinity of Modbury. From the Lower Devonian boundary at Staddiscombe east of Staddon to the south-western edge of the Granite near Bickley is 7 miles.

From the Lower Devonian boundary of Staddon to the Culm boundary near Tavistock is 13 miles. From the Lower Devonian boundary on the west side of Plymouth Sound,

Mount Edgecombe Park and Maker, across Hingston Down Granite mass to the Culm boundary is 15 miles.

From these figures it is apparent that the constriction of outcrop is greatest due south of the most southerly projection of the Granite and lessens on either side of this point from $2\frac{1}{2}$ to $4\frac{1}{2}$ miles, a difference of 2 miles. On the east of Dartmoor where the Granite boundary is sinuous the breadths of outcrop are comparatively regular, varying between 7 and $8\frac{1}{2}$ miles, comparable with the 7 miles from Staddon to Bickley where the Granite boundary has a similar irregularity.

On the west of Dartmoor, where there is evidence of the subterranean extension of the Dartmoor and Brown Willy masses, we find the greatest breadth of outcrop 13 to 15 miles. That is to say the release of constriction has produced an expansion of the strata almost twice as great on the west side of the Granite as compared with that on the east : and the difference between the expansion on the west and the maximum constriction on the south of Dartmoor is no less than 13 miles. Put briefly in tabular form, the breadths of outcrop of the Culm Measures, measured south from their central line, and of the Upper and Middle Devonian, from the Lower Devonian boundaries north or north-west, is as follows :—

West of Dartmoor.	To Dartmoor.	East of Dartmoor.
Culm, $21\frac{1}{2}$ to 27. Where deflected by granite 29.	$13\frac{1}{2}$ to $15\frac{1}{2}$	23 : by deflection along granite to Ivybridge 35.
Middle & Upper Devonian, 13 to 15.	$2\frac{1}{2}$, $4\frac{1}{2}$, 7.	7 to $8\frac{1}{2}$.

The average outcrop of the Culm on either side of Dartmoor is about 23 miles : the Granite on the north has reduced it therefore by $7\frac{1}{2}$ to $9\frac{1}{2}$ miles.

The average breadth of the Upper and Middle Devonian differs greatly, being 14 miles on the West, to $7\frac{3}{4}$ on the East, whilst the constriction on the South of Dartmoor varies with the southerly advance of the Granite boundary, $2\frac{1}{2}$ being the minimum breadth or maximum constriction, $4\frac{1}{2}$ the average, and 7 the least amount of constriction.

I account for the greater breadth of outcrop on the West of Dartmoor, thus: the eastern boundary of the Granite is so irregular that its effect on the Devonian through its easterly projection to Hennock constricts the outcrop just as the southern boundary at Bickley constricts the strata due south of it. On the other hand the western boundary of the Granite runs in a general north and south direction, and therefore can have no effect in constricting an east and west strike. Further, the intervention of the Hingston Down and Kit Hill Granites renders it extremely probable that a subterrannean connection of the Dartmoor and Brown Willy Granites exists at depths sufficient to protect the overlying Devonian from yielding to the compression to which a greater thickness of soft strata would be subjected by the North and South movements.

From these three lines of enquiry, viz.: distribution of Carboniferous and Devonian rocks, deflections of strike, and constrictions of outcrop, we learn that the presence of Dartmoor has had an enormous effect upon the surrounding strata. We learn that that effect has in no way been produced by the action of the Granite as a motive force; that so far from these facts affording one shred or tittle of evidence for the upheaval of the Granite into or through the strata by which it is surrounded, they seem to contradict such a theory completely.

Thus, if the Granite had been upheaved in Culm and Devonian strata, after or during the North and South movements, the deflection of the limestone patches from Bridestow to Launceston would have had the same effect on the main Culm and Devonian boundary and have carried the Devonian northward along the Granite to a point east of Bridestow. On the east side of the Granite the Devonian would have been the contact rock and not Culm Measures to the South of the Bovey Valley. The uptilting of the beds would have been an extensive and not a very trifling affair on the east and west borders

of the Granite. The Lower Devonian Anticline instead of terminating in the Paignton district would have become more pronounced toward the Granite. Finally we should expect the older rocks such as Lower Devonian, and not the Lower Culm and Upper Devonian, to have been shoved up on the borders of the Granite.

RELATIONS OF THE GRANITE MASSES OF DEVON AND CORNWALL.

In the foregoing notes allusion has been made to the probable subterranean connection of Dartmoor and Brown Willy. De la Beche not only conceived this to be the case but advocated the connection of all the Granite masses of Cornwall with Dartmoor,* in the following remarkable passage.† "There will be little difficulty in perceiving that there is evidence of an elevatory force or forces, and that among the effects resulting from it or them, has been the protrusion of Granite, which, judging from the bosses now exposed to view, would give an axis of elevation extending from about E.N.E. to W.S.W.; an accumulation of more modern rocks concealing the eastern continuation of it beyond Dartmoor, while the Atlantic covers its western portion beyond the Scilly Islands. There will be little difficulty in considering that the superficially isolated patches of Granite in Devon and Cornwall are connected beneath the intervening slates, and that the latter have been borne up upon the back of the concealed and connecting Granite masses in such a way that their constituent beds are seen to be more clearly turned out of their previous positions at the points where the Granite, being impelled upwards with greater force or meeting with less resistance, broke through them." The tracing out of De la Beche's minor sub-divisions in Cornwall, and the relations of the stratified rocks in Devon, clearly show that the sub-

* Report pp. 157, 187, 188.

† *Ibid* p. 360.

terranean connection of the Granites would produce an enormous mass at least 100 miles in length, and from 10 to 30 miles in breadth crossing the general strikes and exercising no elevatory influence. The question naturally suggests itself, upon what did the Culm and Devonian rocks borne up upon the back of this mass rest before it was thrust up? This question seems to me unanswerable.

The subterranean connection of the Granite masses is a question of such great importance that I propose to examine the evidence bearing upon it, namely the distribution of the Granites and the distribution of the Elvans.

The distribution of the Granites and Elvans naturally necessitates a reference to Cornwall, but as the subject has here only a direct bearing upon the relations of the Carboniferous rocks to the Granites, I have no intention of treating it exhaustively.

DISTRIBUTION AND RELATIONS OF THE GRANITE MASSES.

Dartmoor is the largest Granite mass, occupying an area of about 225 square miles. Its effects on the stratified rocks have been discussed. The peculiar shape of the mass, exhibiting no relation to the prevalent east and west strike, has aided materially in producing these effects. Its greatest length from north to south in the line of Belstone near Okehampton is nearly 22 miles, whilst its greatest breadth from east to west on the latitude of Lidford is 18 miles, decreasing to 15 miles on the latitude of Withycombe on the Moor, to 7 miles between Meavy and Buckfastleigh, and increasing to 10 miles on the latitude of Dean Church.

The subterranean connection of Dartmoor with the Brown Willy Granite would I think account for the anomalies in structure and extension exhibited by the Devonian rocks if we suppose that they rest upon a solid basis of Granite at no great depth from the surface, forming a ridge the highest peaks of which are represented by the Granite patches of Hingston

Down and Kit Hill. Hingston Down is 7 miles from Dartmoor and less than 2 miles from Kit Hill, which is 6 miles from the Brown Willy Granite. The shapes of these little Granite masses are irregular.

The Brown Willy Granite mass has an area of about 65 square miles. Its longest axis is 12 miles, from Camelford, in a south-easterly direction, and its greatest breadth, from Alternon south-west, is 9 miles. Its contour is not nearly so irregular as Dartmoor, sinuosities of boundary being apparently confined to the vicinity of Warleggon on the south and Camelford on the north. De la Beche's map shows a small patch of Killas near the easternmost termination of the Granite in the vicinity of the Cheesewring. This is the only appearance of an outlier of the stratified rocks on Granite in De la Beche's maps. A great deflection of strike has been produced in the Upper Devonian strata by the Brown Willy Granite,* the axis of disturbance from Camelford to Tintagel being in line with the longer axis of the Granite mass. In this connection the occurrence of Ottrelite at Tintagel is noteworthy.

The Brown Willy Granite near Cardinham is from 5 to 6 miles distant from the northernmost termination of the St. Austell Granite, the western end of the former being almost due north of the eastern end of the latter. The St. Austell Granite is about 40 square miles in extent; its shape is irregular, the breadth from north to south, near its eastern termination, being $5\frac{1}{2}$ miles, decreasing in its western part to 2 miles; the longer axis from east to west is about $10\frac{1}{2}$ miles. A small contiguous Granite patch occurs on the south side of Tregoss Moors, and the small Granite patches of Castle an Dinas and Belovely Beacon, further north, are from 2 to 3 miles from the main boundary.

All the Granites we have hitherto mentioned occur in the area of the dominant east and west strikes, which terminate to the south of Grampound and Perran Bay; the Granites of

* De la Beche's Report, p. 165.

Western Cornwall occur in an area where the prevalent strikes are south-west or south-south-west. The St. Austell Granite is 15 miles from the Penryn Granite mass, the nearest Granite being the small patch at Cligga Head, 11 miles west of it. The Cligga Head Granite is 2 to 3 miles from the small patch at St. Agnes Beacon, which is from 4 to 5 miles north of the St. Day Granite.

The Penryn Granite mass, about 40 square miles in area, is so close to the St. Day and Camborne masses on its northern border, that their subterranean connection can hardly be denied. Between the Penryn Granite and the Land's End mass, from 8 to 12 miles west of it, lies the Germoe Granite, at about 3 miles from the Penryn mass, and the little patch on St. Michael's Mount, 3 miles from the Land's End Granite.

The shapes of the West Cornwall Granites are very varied and without any regard to the strikes of the surrounding rocks. A remarkable deflection of strike occurs between Truro and Falmouth. On the borders of the Land's End mass, near Penzance, the deflection of the hard Greenstone bands; the fractured condition of the St. Michael's Mount Granite at its junction with the Killas, pointed out by De la Beche; all these are readily explicable on the admission that these Granite masses occupied their present positions prior to the operation of the movements which produced the east and west strike, and that the deflections from that strike were mainly produced by the obstruction of these hard masses rising amongst, and perhaps supporting, softer materials.

From the foregoing it will be seen that an irregular chain of Granite patches, in which 11 miles is the longest interval, extends from Dartmoor to the Land's End : that as far as one can judge from De la Beche's Report supplemented by his maps, the effects of the larger masses on the surrounding strata are exactly similar to those I have detailed in the case of Dartmoor, *i.e.*, the greatest mechanical effects are produced at those points where the set of the Granite boundaries or the

distribution of the Granite masses would occasion the greatest interference with, or obstruction to, the movements which produced the dominant strikes and where the converse is the case, these effects are inappreciable, or as in the case of the supposed shallow subterranean connection between Dartmoor and Brown Willy seem to have a protective tendency.

DISTRIBUTION OF THE ELVANS.

In order to ascertain the distribution of the Elvans west of Dartmoor we must refer to De la Beche's Geological Survey Maps,* these may I think be thoroughly relied upon as regards general distribution, but we are not at liberty to infer that individual Elvans shown proceeding from the Granite boundaries as on the south and west of Brown Willy do not also intersect parts of the Granite. As a matter of fact the difficulty in tracing Elvans in Granite is admitted by De la Beche as the reason why so few are shown on his maps within the Granite boundaries.

The normal direction of the Elvan dykes is more or less coincident with the general strike in the districts in which they occur—thus, from Grampound and Perran Bay, northward and eastward, the Elvans, with few exceptions, maintain nearly east and west directions ; whilst in Western Cornwall their prevalent trend is from E.N.E. or N.E. to W.S.W. or S.W., and the exceptions to this rule occur either as the consequence of strain or in accommodation to a changed strike.

A glance at the little map will show that the distribution of the Elvans between the Granite masses accords with the supposed subterranean connection of the Granites.† Thus the Morwell Down Elvans between Dartmoor and Hingston Down are supplemented by a series of east and west Elvans between Kit Hill and the Brown Willy mass. The Elvans on, and proceeding from, the south side of the Brown Willy mass, westward, are not far apart from the system of Elvans on the

* *See* also Report, p. 174—185.

† Report, p. 184.

north of the St. Austell Granite, which extend westward on either side of the small Granite patches of Belovely Beacon and Castle an Dinas. These last seem to be shifted southward by a remarkable N. and S. Elvan, proceeding from Watergate Bay, and to continue to the Cligga Head Granite ; from thence the connection with the West Cornwall Elvan systems is shown by Elvans at St. Agnes Head and on Penhallow Downs which are not far from, and run in the same direction as, the Elvans of the Camborne system, which extend to the Land's End Granite.

Besides these there are other Elvans which point outward from Granite masses, either to Granite at a distance as is the case with the Elvans on the S.W. side of Dartmoor, and on the east side of the Penryn mass or proceed in the direction of no superficial exposure of Granite, as in the case of the Camelford and Blisland Elvans on the West of the Brown Willy mass. The Camelford Elvan although not shewn in superficial continuity is no doubt continuous with the Elvan in line with it running toward Padstow. Elvans of these classes suggest the outward extension of the subterranean prolongation of the Granites from their margins at no great depth in the first case, and in the second may indicate a connection with subterranean Granite ridges or bosses. Isolated Elvans having no visible connection with Granites occur in the following places :—near Modbury, De la Beche's map shows an Elvan starting at about five miles south of the Dartmoor Granite, running in a south-westerly direction to the coast. This Elvan runs in line with the Eddystone Rock. Further south, Quartz Porphyry is shewn under Mica Andesite, and apparently passing into it, in a quarry at the eastern end of the New Red outlier of Thurlstone.

With these two exceptions no Elvans have been noticed south of Dartmoor. On the north of Dartmoor several Elvans occur in line with the New Red of the Crediton valley. They are much decomposed, and from 7 to 8 miles distant from the

nearest part of the Dartmoor Granite boundary. To this system evidently belongs an east and west Elvan, occurring on Itton Moor, near North Tawton, about a mile south of the New Red bouudary, and 4½ miles north of the Granite. Very great interest attaches to these Elvans owing to the granitoid fragments in the New Red of the Crediton valley, and to the frequent signs of contemporaneous vulcanicity afforded by patches of Melaphyre or Porphyrite. Coupling both these facts in connection with the ocurrence near Thurlstone, it seems probable that Granite may occur at no great depth beneath the Crediton valley, and that there may be some connection between the latest intrusive Elvans, and the New Red volcanic eruptions.

In a quarry near Furzeham Cleave in the Hatherleigh district, two Elvan bosses coming up along the bedding planes of the Culm Measures terminate abruptly at some feet from the surface. Such a sight impresses one strongly with the notion that there are not only many such Elvans in the Elvan districts, but that the absence of Elvans in certain districts in South Devon and Cornwall is no *à priori* reason for inferring that they may not be present beneath. In other words, if we admit that the Elvans were ejected through fissures in Granite, and that the Granite masses, if not all subterraneously connected at least individually, slope downwards from some distance from their margin beneath the environing rocks, according to the gentle or rapid declivity of the slopes, molten dykes proceeding upwards through and from the Granites, would terminate nearer to or further from the surface.

Near Rivaton Farm, about 15 miles north by west from Dartmoor, felsitic blocks occur on the surface. They were said to resemble a rock near Gwennap in Cornwall, and claimed by the British Association Boulder Committee as a proof of ice transport. In 1879* I showed that the distribution of these blocks in a N. and S. line on the summit land was much more ration-

* *Trans. Dev. Assoc.* for 1879.

ally explained, as the harder portions of a dyke left outstanding by the surface wasting of the surrounding softer Culm Measures.

In the Devonian area of North Devon in the line of the Lundy Island Granite, and the Syenite of Hestercombe on the Quantocks, we have several exposures of felsitic rock, the intrusive character of which was pointed out from an exposure at Bittadon, by Professor Bonney.* Mr. Townsend Hall described a Granite vein, 9 inches thick, in the Triassic outlier of Portlemouth.† With the exception of an indication of Quartz Porphyry near Christow, I know of no Elvans on the east of Dartmoor; judging from the maps the district east of the St. Austell Granite is devoid of Elvans; also, the district east of Truro.

Where the presence of the Granites has greatly obstructed the movements causing the dominant strike, and in consequence extensive strike deflections have been produced, the Elvans are also deflected, as at Camelford and Penryn; but in passing from Granites to slates, as is so well shewn in the Penryn Granite, they ignore the immediate deflection cutting across Greenstone, north of Penryn, and rounding northward with the general deflection of the strike toward Truro till they coalesce with the system following a more normal strike.

The radiant Elvans on the west of the Germoe Granite, and the furcating Elvan in the Penryn Granite, occur at the points where the obstruction of the Granites to the N. and S. movements would be greatest, and where radiating strains would occur. This also tallies exactly with the fractured condition of the St. Michael's Mount Granite.‡

De la Beche describes the Elvans as varying in thickness "from a few to 300 or 400 feet."§ He gives a sketch of an

* *Geol. Mag.* for May, 1878, p. 207.

† *Trans. Devon Assoc.* for 1879.

‡ Figured De la Beche's Report, p. 169.

§ *Ibid* p. 174.

Elvan in Wheal Alfred abandoned mine, near Gwinear,* "about 300 feet thick," dipping N.W., at an angle of 45° in slates. The Elvan is traversed by a tin and copper lode.

LODES AND FISSURES.

I do not propose to treat the mineral veins and lines of fracture further than to notice their general bearings on the question of the distribution of the Granites and Elvans.

De la Beche notes† that "Granite or its modification Elvan, occurs near, or at, all the localities where tin and copper ores so abound as to be worked," "while the granite influence was not essential to the accumulation of the ores of lead, antimony, manganese, zinc, or iron" in workable quantity. Profitable lead lodes are said to be "generally removed from the Granites." He points out a remarkable coincidence in the direction of the tin and copper lodes with the Elvans (which they frequently cross) in the St. Agnes, Gwennap, Redruth, and Camborne districts, also at St. Austell, excepting Polgooth Mine, and near Tavistock. That these observations were considered to bear upon the subterranean connection of Granite masses is evident from the following paragraph.‡ "Now if granitic matter extends as we have supposed beneath a considerable part of the metalliferous districts of Devon and Cornwall, we have the lines of Elvans and principal tin and copper lodes upon a great back of pre-existing Granite, at first taking a western course from Dartmoor to the Brown Willy and Hensborough (*i.e.* St. Austell) bosses, then striking down W.S.W. to the Land's End and Scilly Island Granites."

In dealing with the faults, mineral veins, and cross courses, De la Beche gives a small diagram map§—which is worthy of study in connection with what has been said respecting

* *Ibid* p. 330.
† *Ibid* p. 286.
‡ *Ibid* p. 310.
§ *Ibid* p. 309.

strikes and Elvans. It shows nearly E. and W. lines traversed by nearly N. and S. lines to the east of St. Austell, and in Western Cornwall changes in direction of both systems, the former running from W.N.W. to E.N.E. or from E.S.E. to W.N.W., whilst the traversing lines have a frequent N.N.W. and S.S.E. tendency.

The succession of the various phenomena is given in the following order — consolidation of Granite, Elvan fissures, most of the tin and copper lodes generally in coincident directions with lines of pre-existent fissures. "The north and south lines . . . . . are clearly seen in Cornwall to have been the last set of fissures with the exception of E. and W. slides."

The north and south Elvan of Watergate Bay seems as I have said to shift the east and west Elvans to Newlyn on the south whence their course assumes a W.S.W. direction. This remarkable Elvan is in line with the disturbances produced by the Granite obstruction in the Penryn and Truro districts.

To sum up the results of the above observations:

Firstly.—The distribution of the stratified rocks in relation to the Granite masses; the deflections of strike in the vicinity of Granites viewed in connection with the distribution of strata and the constrictions and expansions of outcrop, on the one hand, and with the distribution of the Granite masses, their variations in contour and peculiarities in shape, on the other; negative the idea that these phenomena, are in any way due to, or connected with, the upheaval of the Granites, whilst directly pointing to the production of these anomalies by the action of the same set of earth movements upon stratified rocks surrounding masses, of sufficient consistency to have obstructed the contractile forces, and to have preserved their original outlines, thereby exercising great mechanical effects upon the surrounding strata.

Secondly.—The distribution of the Granites in an irregular chain of masses and small patches nowhere more than 11 miles apart; the distribution of the Elvans as connecting links between the Granites; the distribution of Tin and Copper lodes in relation to Granites and Elvans; render it highly probable that many, if not all, of the Granite masses are subterraneously connected at no great depth. This idea seems to explain the extension and structure of the higher Devonian strata between the Dartmoor and Brown Willy Granites.

Thirdly.—The distribution of the Elvans shows the behaviour of erupted Granites during the north and south movements, viz.: the accommodation of these intrusive sheets to the general strike lines produced by the movements, or to other lines produced by great strain or obstruction to the ordinary effect of these movements. Whilst the distribution and shape of the Granite masses and patches is quite out of accord with the general strikes and appears to have been the obstructive agency causing their deflection.

Fourthly.— From their behaviour in areas respectively exhibiting normal and deflected strikes, it appears clear that the emission of the Elvans commenced after the N. and S. movements had been long enough in operation to permit of the full effects of the obstructing mass or masses on the more yielding Palæozoic strata.

Fifthly.—From the relations of fracture lines there is reason to think that the emission of the Elvans extended over a long period, the north and south Elvans being the most recent. If we may take the Thurlstone occurrence, and the connection of Elvan dykes in the vicinity of the New Red rocks of the Crediton valley (which contain many granitoid fragments, and some lava sheets) in evidence, the emission of Elvans may even have continued at intervals down to the earlier stages of the deposition of

the New Red in Devon (probably of the age of the Lower Rothliegende).

ERUPTIVE THEORIES, &c.

In all the lines of evidence pointing to the above conclusions I have merely endeavoured to show that the Granites (or masses capable of producing them by re-crystallization *in sitû*) existed in a solid condition in their present sites amongst the Palæozoic strata previous to the operation of the N. and S. movements which produced the contortion of the latter along a general east and west strike interfered with by these rigid masses. It is now necessary briefly to consider the age of the Granites relative to the surrounding strata : this has almost invariably been regarded as synchronous with the metamorphism produced in the strata bordering the Granites, and in the case of Dartmoor as therefore post-Carboniferous.

If then the Devon and Cornwall Granites were erupted at the close of the Carboniferous epoch before the east and west movements came into play, it seems to me that all the evidence in favour of subterranean granitic extension must be ignored, as such an extension involves the, to me, unanswerable query, upon what did the Palæozoic strata rest before their Granite basis came into existence.

I have frankly admitted in my earlier attempts to explain the relations of Dartmoor Granite to its surroundings by suggesting a laccolite, that the admission of the subterranean connection "seems to contradict" that hypothesis.* A wider consideration of the subject has led me to think the subterranean partial, or complete, connection of the Granite masses as more than probable, and for several other reasons to regard the laccolite hypothesis as quite untenable.

It seems to me that the admission of a subterranean connection of the Granite masses is equally against the theory of the eruption of the Granite in the overlying rocks, and I

* Trans. Devon Assoc. for 1888 p. 157.

think the mass of evidence brought forward in the above pages is against it.

Further, it is difficult if not impossible to imagine a shallow water formation like the mass of the Culm very far removed from some derivative source and extending over so large an area unbroken by the presence of unconformably inlying masses of older rocks ; there being no evidence of a marked change in conditions in the transition from Upper Devonian to Basement Culm rocks, and no proof of unconformability.

Major-Gen. Mahon contributed a very interesting paper on the Bude Culm Measures,* from which I quote the following:—

"The Culm series as seen at Bude appears to have been deposited in tranquil water, undisturbed by strong currents."

"As regards their origin, microscopic evidence favours the view that the materials of which the Bude rocks are composed were derived from the waste of a crystalline area, for they are made up of fragments of quartz, felspar and mica, with some schorl and zircon crystals—all characteristic of granitoid rocks, together with some crystalline fragments of a more schistose character. It is also material to note that they do not contain a single grain of such rocks as slate or limestone."

"The silt deposited by the Bude waters was made up of granitic materials supplemented on the spot by the products of organic life, carbon and iron."

He gives an analysis of the Bude shale and compares it with two analyses of British Granites, by the late J. A. Phillips, as follows :—

	Bude Shale.	*British Granites.*	
Silica	73·20	— 73·70 —	74·54
Alumina	11·20	— 14·44 —	14.86
Oxide of Iron ...	8·40	— 1·92 —	2·76
Lime	—	— 1·08 —	0·29
Magnesia	1·44	— Trace —	Trace
Potash	Trace	— 4·43 —	3·73
Soda with traces of Potash, Sulphates & Carbon	5·26	Soda 4·21 — — Trace —	3·49 ——
Phosphoric Acid ...	Trace	— 0·61 —	0·87
Water	0·50		

* Geol. Mag. for 1890, pp. 112, 113, 114.

The correspondence of these analyses is remarkable ; but when we compare the ten analyses of specimens of Cornish Killas, given by the late J. A. Phillips,* with the Granites above cited the resemblance is not nearly so striking. Mr. Phillips remarked—"It has been shown by Daubreé and others that felspathic rocks, subjected to prolonged trituration in presence of pure water, undergo a decomposition by which alkaline silicates are obtained in solution, while the rock is reduced to the state of mud or sand. Decompositions of this nature must have been effected on an extensive scale during the transformation of such rocks into clay slates ; and the composition of the resulting sedimentary beds may therefore be expected to differ considerably from that of the rocks from which they were originally derived." From the table of analyses alluded to, he said, "it becomes evident that neither Granites nor Elvans could result from the rearrangement, by heat or otherwise, of the constituents either of one or of any number of such slates. In the first place a great deficiency of silica will be observed ; and secondly, slates contain, almost without exception, a larger amount of soda than of potash, while the Granites and Elvans are potassic rocks.

Whatever may be the derivation of the Palæozoic rocks of Devon and Cornwall, their extent and development points to the removal and redistribution of very great masses of pre-existing rocks, and as no rocks other than the Granites seem to exhibit an unconformably inlying position amongst them, from Bristol to the Land's End—it is difficult to resist the suggestion that Granites, or rocks, capable of conversion to Granite by *in sitû* metamorphism, were actually levied under contribution to supply part at least of their materials. In 1888 I dismissed this idea,† which had occurred to me years before, owing to the absence of signs of marginal accumulation.

* Q.J.G.S. for August, 1875.—"The Rocks of the Mining Districts of Cornwall, &c.

† Trans. Dev. Assoc. for 1888. p. 147.

The great prevalence of argillaceous sediments in the pre-carboniferous rocks of South Devon and Cornwall, where, notwithstanding shoaling, conditions must have gradually introduced the accumulation of the Culm Measures, as opposed to the arenaceous characters displayed at intervals throughout the North Devon series, does not seem to be altogether explainable by the suggestion that the arenaceous types indicate proximity to the old shore line, and the argillaceous sediments distance from it, and tranquil deposition in deeper waters.

The subject of the derivation of the Culm and Killas is too hypothetical however to be even admitted as suggestive evidence in the Granite question at present.

The assumption that the age of the Granite is one with that of the contact metamorphism, or indeed any assumption as to the age of the Granite, has to be considered with the restrictions imposed by the mechanical aspect of the subject, viz.: 1st—that both the Granite and surrounding rocks seem to have occupied their present relative positions prior to the N. and S. movements, and were mutually affected by them. 2nd—that the evidence as to subterranean connection of Granites at no very great depth, whether partial or complete, is too probable to be ignored.

The first restriction permits of the upheaval or eruption of Granites during or just after the latest stages of carboniferous deposition, such eruptions being unaccompanied by any appreciable mechanical effects.

The second restriction for reasons before stated renders the post-carboniferous upheaval or eruption almost unthinkable, and would almost necessitate the genesis of Granite (in its present form) *in sitû* by the re-melting of a pre-existent rock. In that case the age of the Granite would not imply date of upheaval, but the post-carboniferous solidification of the rock in its present aspect, out of pre-existing materials *in sitû*. This view would allow of the fusion of such materials during the N. and S. movements, after the mechanical effects pro-

duced by their obstruction when in a rigid state had attained their maxima.

De la Beche's views on the intrusive character of the Granites are expressed in very many passages scattered through the chapters of his Report which, though often recapitulatory, are as a rule distinguished by the consideration of the subject in different aspects. He suggested* the protrusion of the Granites in connection with the main forces of contraction to which the contortion of the Palœozic rocks of S. Wales and S.W. England is due, such contraction affording a weakened crust through which any subjacent fluid rock might be forced up "through ground more especially weakened, perhaps as ancient volcanic vents."

The last suggestion was advanced on the ground of the proximity of evidences of volcanic action to the Granites, their absence in North Devon, and the apparent truncation of Greenstones by Granite of which test instances are selected from the vicinity of Christow and Bridford on the east of Dartmoor. The Botter rock Hennock, the case alluded to, is a large apparently intrusive mass of Dolerite, very hornblendic, which is in contact with the Granite, its eastern termination indenting or pushing back the Granite boundary for 200 or 300 yards.

Two small patches of Greenstone are shown in contact with Granite at and near Waspworthy (N.E. of Tavistock) on De la Beche's Map *(The Geol. Sur. Map)* very large masses occurring in the vicinity. Of these Mr. Rutley† says, "The masses of Gabbro extending between Crayston and White Tor, Wheal Friendship and Smear Ridge are no doubt connected with one another at some depth beneath the surface, and it is probable that the small patches (Amphibolite), occurring in contact with the Granite at Waspworthy and Brazen Tor and the strip extending from Cock's Tor to Indescombe, are

* Report pp. 187, 188 and 167.

† Brent Tor Memoir p. 46.

offshoots from the same deep seated mass. These may even be of later date than the Granite of Dartmoor."

CONTACT METAMORPHISM.

The effects of contact metamorphism on the rocks bordering the Dartmoor Granite* are most apparent within half-a-mile of the Granite boundary. In those districts where Greenstone masses abound both on the east and west side of the Granite it is often difficult to distinguish the limits of the contact metamorphism produced by the former. The most common form of alteration in Devonian and Culm shales, is the development of a spotted character, Mr. Rutley noted this near the eastern end of the Hingston Down Granite, at Morwell rocks, comparing the rock to finely speckled *fruchtschiefer*. This spotty development occurs in the Culm shales on the east of Dartmoor, near Ivybridge, Cornwood, Shaugh Bridge, Yelverton and Horrabridge on the south and west, and in many other places.

As Horrabridge is 2 miles from the Granite boundary and the alteration of the Upper Devonian there is the same as at Yelverton a mile from the Granite, and further south at half-a-mile from the Granite; whilst at Bickley at a mile from the Granite the alteration is not apparent to the eye, it would appear as if the Granite surface sloped more gently outward under the Devonian in the direction of Yelverton and Meavy.

Whilst the Granite boundary is on the whole fairly accurate on the maps, the apophyse-like projections at Walkhampton and Meavy are exceedingly doubtful. Mr. Teall in a paper on "Metamorphism in the Hartz and West of England,"† says, "the breadth of the contact zone, other things being equal, is dependent on the slope of the upper surface of the Granite beneath the actual surface, it is an indication of the direction in which the Granite extends and possibly of that from which it came."

* *Vide* Worth Trans. Dev. Assoc. for 1887. De la Beech Report pp. 267, 268.
† Trans. Roy. Geol. Soc., Corn., Nov. 1st, 1889, p. 13.

In the dark Culm shales Chiastolite crystals are developed here and there where suitable rocks occur within a half mile of the Granite, but there are places, near Bovey Tracey and Lustleigh, where the actual contact alteration with the exception of more or less induration may be regarded as *nil.* The Culm grits are, near contact, often converted into quartzite, the arenaceous mudstones into mica schist, the chert beds into porcellanized banded flinty rock.

Mr. Worth notes talcose alteration in clay slates near Meavy, sericitic at Shaugh, Andalusite near Cornwood, Mica Schist "with foliations of mica,* felspar, and quartz fairly marked" at Meavy and Ivybridge. "Felstone with microporphyritic quartz and a considerable development of tourmaline" was noticed by him near Shaugh, Tavy Cleave and Okehampton.

The Culm limestones† in Meldon quarry near Okehampton can scarcely be said to be altered at all, although within a mile of the Granite boundary and in the vicinity of Greenstones and hard flinty Culm Measures. I am indebted to Mr. Teall for the following petrological notes on specimens I collected during leave of absence last December.

1.—South of Shaugh Tunnel. "A dark bluish compact rock. Under the microscope with a low power clear spaces occupied by aggregates of quartz are seen to lie in a brownish matrix. Here and there may also be seen aggregates of blue tourmaline. With a high power the brownish matrix may be resolved into an aggregate of extremely minute prisms of a pale colourless tourmaline. Similar prisms occur as inclusions in the quartz. The rock is therefore essentially composed of tourmaline and quartz, and may be described as

* See also De la Beche, p. 267.

† Mr. Teall, Op. cit. referring to the borders of the Hartz Granite (Rammberg) says. "The different kinds of rock show differences as regards facility of alteration. Calcareous rocks are most easily effected; next in order come the clay slates; next to these the greywackes; and last of all the quartzites and other siliceous rocks."

a tourmaline hornfels. The relations of the clear spaces of quartz to the rest of the rock are rather suggestive of a fragmental origin. The re-crystallization has been too complete to afford any clue to the original character of the rock from the hand specimen."

2.—Same locality. "One part of this specimen resembles the last; the other part is a coarser grained aggregate of quartz and an altered pinkish felspar. The microscope section was taken from the compact portion which is similar to the last but with more quartz and less tourmaline, and may be described as a tourmaline hornfels."

3.—Shaugh Tunnel. "Angular and more or less rounded fragments sometimes composed of one, sometimes of several individuals of quartz. Matrix as before largely composed of extremely minute tourmalines. The evidence of fragmental origin is strong."

4.—Same locality. "A pale grey mica schist. The rock is essentially composed of two micas and quartz. Blue and brown tourmaline and probably also andalusite occur as accessories. There are also numerous small brownish, nearly opaque grains. The constituents of the rock have developed *in sitû*. In structure and composition it is a true schist."

5.—Shaugh Tunnel, south side. "A pale coloured medium grained schist. Similar to the above but with chlorite largely replacing brown mica."

6.—Between Yelverton and Bickley Stations. "A schistose spotted rock intermediate between a phyllite and a mica schist. The specimen shows distinct traces of strain-slip-cleavage (Sorby's joint cleavage). The essential constituents are two micas and quartz. The spots are irregular in form and cannot be identified as belonging to any definite mineral species. They appear under the microscope merely as somewhat browner portions of the mass. The cleavage planes are defined by lines of opaque grains in transverse sections, and as these planes weather brown, the grains are probably iron ore."

7.—One mile south of Yelverton Station. "A fine grained mica schist. The strain-slip-cleavage which is obscurely seen in the hand specimen stands out conspicuously under the microscope when the thin section is examined. The essential constituents are the same as before—two micas and quartz. These micas have not been distorted by the movements which produced the strain-slip-cleavage; but the structure of the rock has determined their orientation. Some of the flakes are arranged parallel with the original lamination or foliation and some parallel with the transverse cleavage. The individuals are not bent as they would have been if the strain-slip-cleavage had been produced during or after the crystallization. The rocks of the district were obviously cleaved before they were metamorphosed."

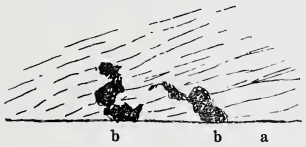
8.—North of Bickley Station. "A lead coloured spotted phyllite with strongly marked cleavage. The main mass of the rock is of so fine a grain that the determination of the constituents is attended with great difficulty. Quartz and mica are certainly present. There are also many minute opaque or dark brown grains: these may be ilmenite. A few minute prisms of tourmaline may also be recognized. Embedded in the above as in a matrix are pseudo-porphyritic plates of a brown mica. These have been developed by the contact action. They are just recognizable as black specks on the cleavage surfaces by the aid of a good lens. The brown spots which are conspicuous to the unaided eye occasionally give hexagonal cross sections. They are crowded with the material of which the rock is mainly composed and do not give sufficiently definite characters for identification. They represent the attempt of some mineral, possibly cordierite—to form, and must like the brown mica be referred to contact action."

Mr. Teall also described a specimen for me, from the Elvan shown in Cann quarry south of Bickley on De la Beche's map. Except for a few inches at contact the Devonian slates or shales in this quarry are unaltered.

Cann Quarry. "A white fine grained massive rock composed of a micro-crystalline aggregate of quartz and felspar (unstriated) with scales of white mica—Aplite."*

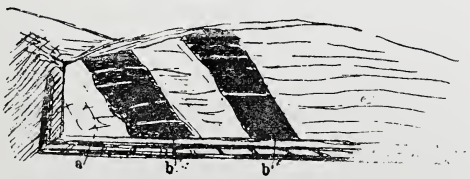
The first five specimens described in the above (Nos. 1 to 5 inclusive) were obtained from the railway cuttings immediately south and north of Shaugh Tunnel which touches the Granite, so that they may be regarded as contact rocks. The behaviour of the dark rocks as may be seen from the accompanying sections, *b.b.*, *b.b.*, simulates that of dykes of igneous rock, but the appearance of cutting across the bedding of the slates, *a.a.*, is apparently due to the dominant planes

Fig. 7.
SOUTH OF SHAUGH TUNNEL.



of schistosity being lateral cleavage planes, which as I have before remarked give to the Devonian slates of Horrabridge and Yelverton an appearance of nearly horizontal bedding.

Fig. 8.
NORTH OF SHAUGH TUNNEL.



No. 7 is about half-a-mile from the Granite, and No. 6 was obtained between a quarter and a half-a-mile from the Granite. Both these specimens are important as proving the production of cleavage before metamorphism. Strain-slip-cleavage, or "Ausweichungs-clivage" Dr. Hatch remarks "may be re-

* *Vide* Rutley. Brent Tor Memoir, p. 43. Marginal Granite near contact with Amphibolite patch Granulite or Aplite.

garded as an advanced stage of minute puckering, some or all the surfaces of contrary flexure having become shear planes." Taken in connection with the puckering in unaltered slates south of Bickley and at Tavistock S.W.R. Station the petrological evidence bears out the view that the greatest mechanical strain as evidenced by gnarling or puckering and transverse cleavage-planes is to be explained by the crushing of softer against and upon harder material by the operation of the N. and S. movement, and not by upheaval, for the upheaval or intrusion of Granite in a molton state would have produced the metamorphism before the cleavage, as the mechanical effects on the strata round the Granites are certainly not such as could have been produced by a fluid mass, which would not be rigid, and therefore incapable of greater relative resistance.

Of the 10 samples of Cornish Killas analysed by the late Mr. J. A. Phillips only one from De la Bole is any distance from the Granite, those from Botallack, Camborne and Dolcoath being practically contact rocks.

The Dolcoath rock has an imperfect cleavage.

Botallack, from surface near lode, cleavage to a great extent obliterated; from one hundred-and-thirty fathom level, "has lost all traces of cleavage and breaks with the polished surfaces so generally observed in serpentinous rocks. Under the microscope, this rock is seen to consist of a transparent base, permeated by minute crystals, apparently of hornblende, whose larger axes cross each other in all directions. In addition to these disseminated hornblendic crystals, there are patches made up of bundles of similar crystals, of which the longer axes are arranged in the same direction. Magnetite is disseminated in granular patches throughout the rock. Sections of several of the neighbouring rocks shew that hornblende is sometimes more or less replaced by chlorite, and that the amount of disseminated magnetite is very variable.

Killas from Huel Seton, Camborne, one-hundred-and-sixty

fathom level. This is a very hard grey clay slate of which the cleavage has in the majority of cases been to some extent obliterated by metamorphism."

I quote the above passages as tending to shew that the Cornish rocks had been cleaved before being metamorphosed. [For alteration in Greenstones, see the writings of De la Beche,* J. A. Phillips,† F. Rutley.‡]

Mr. Worth remarks§ respecting the metamorphism on the borders of Dartmoor "there has been reciprocal action affecting the Granite also. Generally speaking there has been a disintegrating influence on the contact felspars with an exceptional development of Tourmaline." "The borders of the moorland differ very materially from the central region." "Schorlaceous rock is found all along the edge of the Moor, and the evidence seems conclusive that it has been produced by an alteration of the original Granite."

Mr Rutley,‖ referring to the contact of Granite and Amphibolite at Brazen Tor, about 6 miles N.E. of Tavistock, says, "The Granite close to contact is very fine-grained and felstone like, loose blocks showing black nests and segregations of schorl. The nearest approach to contact shows a rapid change from Gabbro into schorl-spotted elvanitic, rock or fine-grained Granite, and then passes on into porphyritic Granite" ("within 100 yards of the junction of the Granite with the Amphibolite.") The rock from the top of Brazen Tor "is a coarsely crystalline Granite, the chief components being orthoclase plagioclase, biotite and quartz, with segregations of schorl," weathering in relief. "The section examined shows some interesting fluid cavities, some of which, in addition to bubbles, contain minute cubes of rock salt," as shown in *Fig.* 5, *Plate* ix.

* Report.

† Q.J.G.S. for Aug. 1875, vol. 31 ; vol. 32, pp. 155, 178 ; vol. 34, p. 471, etc.

‡ Brent Tor Memoir, p. 38.

§ Trans. Dev. Assoc. for 1887. See also De la Beche's Report, p. 191.

‖ Brent Tor Memoir, p. 26 and p. 42.

[On the origin of saline inclusions in Granite, see papers by Mr. A. R. Hunt.*]

In Cornwall, the late Mr. J. A. Phillips observed†—"The cleavage-planes of the slates almost invariably dip from the intruding masses of Granite, but usually at a less angle than the line of contact of the two rocks. Near the point of junction the Granite often becomes fine-grained, and not unfrequently sends off veins into the adjoining slates. Masses of Granite are also sometimes found imbedded in slate; and fragments of slate enclosed in Granite are occasionally met with." He speaks of "the clay slate resting upon the flanks of the several Granite masses of Cornwall and partially filling up the hollows between them." "The Granite of Cornwall is usually coarse-grained, but varies considerably in this respect in different localities. In addition to quartz, felspar and mica, it almost invariably contains schorl, with sometimes as accessories, chlorite, apatite, fluorspar, beryl, cassiterite, garnet, and pinite. In some districts mica is replaced by a talc-like mineral, and the rock thus apparently passes into protogine. Coarse-grained Granites are occasionally traversed by granitic veins of a finer texture."

De la Beche referred to Granite veins in Granite,‡ "as distinguished from the granitic dykes termed Elvans, these veins are tortuous in their courses." "There are few of the larger masses in which these veins are not observable." "The Granite veins on the east of Trewavas Head are remarkable for the small angle they make with the horizon and for the included fragments of slate which they contain in one or two places. "Many of the schorlaceous veins in Granite may probably be classed under the same head with these veins."

§ "The variable character of common Granite near the joints

* Brit. Assoc. Trans. Devon Assoc. for 1890. p. 238.

† Q.J.G.S. for Aug., 1875.

‡ Report, pp. 171, 172. *See* also Ormerod; Rep. Brit. Ass. for 1869—Sketch of the Granite of the northerly, etc.

§ Report, pp. 190, 191.

may be observed in many localities, and is very conspicuous in that of St. Michael's Mount, which is generally far more quartzose toward the joints than in the intermediate spaces," showing apparently a chemical change in the rock, "subsequently to the production of the joints, or perpendicular or highly inclined divisional planes, and therefore an arrangement produced subsequently to the consolidation of the rock, if the joints have been produced since such consolidation." He adds that as the joints, commonly-cut Granites and slates alike, at their junction, the same date must be assigned to both. The late Mr. Ormerod* has described the north and south and east and west joints in the Dartmoor Tors and the pseudo stratification of the Granite.† The late Mr. J. A. Phillips‡ observed, "The Granite constituting the larger areas is usually divided into floors resembling beds, which form sheets in the central portions of the several masses, while the edges bend beneath the surrounding sedimentary rocks and approximate in conformation to the surface of junction between the two."

From the consideration of contact Metaphorphism and the changes in and structure of Granite masses we gather that the appearances of Metamorphism in the Granites and their environments are reciprocal. That the Metamorphism was produced after and perhaps as a new phase in the great dynamic movements to which the contortion and cleavage of the Palæozoic rocks are due.

That, as has been shown in the foregoing notes, the Granites or *in sitû*, rigid representatives having played an important obstructive part during the great dynamic movements, they could not have been then in a plastic state, and could not afterward have been upheaved, so that their fusion and subsequent consolidation would appear to have been effected *in sitû*.

* Quart. Journ. Geol. Soc. for Aug., 1869, p. 273.

† De la Beche's Report, pp. 163, 164; p. 271 and p. 346. Ussher, Trans. Dev. Assoc. for 1888, p. 141, etc.

‡ Q. J. G. S. for Aug., 1875.

The consolidation of Granite in its present aspect may therefore be regarded as post Carboniferous, or possibly coeval, with the later stages of Carboniferous deposition; but the age of the rock in which this metamorphosis took place may date to a remote antiquity, and to a genesis under conditions of formation antecedent to the Palæozoic rocks.

De la Beche and J. A. Phillips are in unison in expressing an opinion that the Elvans were formed during or after the consolidation of the exterior portions of the Granite. The latter says, "The Elvans of Cornwall are rocks occurring in veins or dykes, which have almost identically the same ultimate chemical and mineralogical composition as the Granites of the district; the aggregation of their constituents however is often very different."

From the consideration of the Elvans in a previous section I observed that their emission commenced after the N. and S. movements had been long enough in operation to permit of the full effects of the obstructing mass or masses on the more yielding Palœozoic strata, and that their emission extended over a long period. The fusion of these obstructing masses, as we have seen, commenced at, roughly speaking, the same period; and I think it may be admitted that the fusion and subsequent consolidation extended over a long period, so that at no one time was any of the masses in a general state of fluidity, for had this been the case, as we have no reason to infer that the N. and S. movements had ceased to act the plastic masses would not have consolidated in the moulds of their original rigid outlines. The pseudo stratification planes might be explained as the consequences of lateral pressure on the masses during the N. and S. movements.

The Granite veins with slate inclusions in the instances referred to by De la Beche, occur where the obstruction of the masses in their previous rigid condition would, as in the case of St. Michael's Mount, have been most pronounced. The relations of the hard Greenstones to the Granite as at Hennock

are explainable on the relative fusibility* of both rocks, the former remaining rigid whilst the latter was plastic.

My friend Mr. A. R. Hunt commenting on the origin of saline inclusions in the Dartmoor Granite and quartz, etc., veins in the surrounding rocks, observes, "From some cause or other the Granite of Dartmoor has been cracked throughout, as evidenced by many of the porphyritic felspars. A rise of the isogeotherms or plutonic action of which latter there is abundant evidence in the Elvans and Granitic veins are possible sources of the acquired heat."†

CONCLUSION AND SUMMARY.

From the relations of the stratified rocks to the Granites of Devon and Cornwall there is no obtainable evidence as to the upheaval of the latter.

From evidences of great mechanical disturbance and of metamorphism in areas bordering the Granites, and from the shapes, relative positions, internal structure of the Granite masses, from the distribution of the Elvans, mineral veins and joints, it appears, that the genesis of the Devon and Cornish Granites seems to have resulted from the metamorphism *in situ* of pre-existing rocks of Pre-Devonian age, which had in a rigid state, exercised an obstructive influence on the N. and S. movements and had thereby produced great mechanical effects on the surrounding strata prior to the alteration of the latter.

The contact alteration of the stratified rocks is coeval with the metamorphism of these ancient masses and the consequent genesis of the Granites, during the later stages, or at the close, of the Carboniferous epoch. The intrusion of granitoid rocks perhaps accompanied, certainly succeeded the solidification of the Granites and continued at intervals down to the Permian Quartz Porphyries.

* J. A. Phillips, Q.J.G.S., Aug., 1875.

† Rep. Brit. Ass. *See* also Trans. Devon Ass., 1890, pp. 238, 260.