CHAPTER XXVIII.

NORTHUMBERLAND AND DURHAM.

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INTRODUCTION.

THE counties of Northumberland and Durham are almost entirely occupied by rocks accumulated during Upper Palæozoic times. These rocks form a generally continuous series from the Cheviot lavas of Lower Old Red Sandstone age to the Lower Triassic Sandstones bordering the River Tees. With the exception of the last-named strata, no sedimentary rocks of Mesozoic or Tertiary date occur in the district, while beds of pre-Devonian age are confined to two small inliers of Silurian slates in the north and west.

The scenery is charmingly varied, and many of its leading features reflect the changes in the underlying geological structure. The igneous rocks of the northern border give rise to the rounded contours of the Cheviot range, all heather clad to the summit. The massive grits of the Lower Carboniferous series form the moorland crags of Mid Northumberland, while the flowing lines of many a vale bear testimony to their mantle of glacial drift. The scenery of the Coal Measure districts is on the whole flat and tame, but the Magnesian Limestone cliffs with their broken headlands and sea-worn stacks, their breccia-gashes and fantastic concretionary forms, constitute one of the most interesting seaboards in the country; nor from the standpoint of the historian are the physical features of Northumberland devoid of interest. Few tracts of country exist where the geological structure has influenced so effectually the history of the races which inhabit them. The Cheviot range has from earliest times formed a natural racial barrier, the scene of former tribal conflicts and more recent cattle-lifting excursions. Nor, if rumour be correct, was the last official raid from the Scottish side uninfluenced by geological considerations, though the booty collected on this occasion appears not to have been cattle, but scorpions.

South of the Border near the valley of the Tyne runs a second geological rampart, formed by the outcrop of the Great Whin Sill, and it is along the crest of this natural escarpment that the famous wall of Hadrian runs for many miles.

STRUCTURE.

From the granite fells of Cheviot and Hedgehope, which form the loftiest summits in the two counties, the beds slope gently to the east and south, so that the general strike of the rocks sweeps broadly parallel to the contour of the Cheviot mass ; thus in the northern portion of Northumberland the beds dip generally towards the sea, while as we approach the neighbourhood of Corbridge in the Tyne valley the dip of the beds becomes gradually more southerly.

This seeming regularity in the general structure is, however, frequently interrupted by foldings and dislocations, so that, locally the beds are much disturbed and in places repeated. The vast sheet of dolerite alluded to above as the Great Whin Sill, intruded partly along and partly across the bedding planes of the Lower Carboniferous rocks, has further modified their outcrop in many places. In Durham the Carboniferous beds on the south and west have also a general southerly dip, while the Permian rocks on the east have a more regular slope towards the mouth of the Tees.

One of the chief tectonic features of Northumberland is the presence of an important disturbance which runs down the middle of the county, nearly southward, from the neighbourhood of Lowick to Rothbury, whence it bends south-westward passing to the south of Swindon and the north of Elsdon Common and away through Otterburn to Blackburn Common, where it becomes broken up into a complicated series of dislocations. Two very interesting facts are connected with this disturbance ; one is that it follows very closely, though at some distance from it, the contour of the old Cheviot volcanic area ; the other that being essentially a strike fault and having its downthrow on the west and north-west, it repeats the beds on its eastern and south-eastern side. In the northern portion of the county between Lowick and Chillingham it forms a faulted synclinal, bordered on its eastern side by a sharp anticlinal fold, the general effect being to repeat the "Tuedian" beds and the "Fell Sandstones," and even the "Carbonaceous" and lower members of the "Calcareous" divisions of the carboniferous beds near Lowick. This synclinal axis can be traced nearly as far south as Newtown Mill on the river Breamish, where it disappears beneath a thick covering of drift. It seems pretty certain, however, that the axis of this disturbance is shifted a mile or two to the east in the neighbourhood of Eglingham by a strong east and west fault which curves in a general westerly direction from Embleton Bay to Eglingham. The main dislocation, starting again at the Eglingham burn near Shipley Moor, bends away south-south-west to Rothbury, crossing the Aln near Bolton. From Rothbury it follows the south bank of the Coquet, crossing the Grasslees burn near Billsmoor Park and

the Elsdon burn near High Carrick. Here it is known as the great Swindon Fault, and has a downthrow according to the late Hugh Miller, junior, of 2,700 ft. to the north.*

Another fracture, possibly a continuation of this fault, starting from Dunshield, a mile farther south, runs westward, accompanied by several other parallel fractures. One of these, partly occupied by a whin dyke, passes westward into Cumberland. One or two other east and west faults to the south of the Cheviots, of considerable importance, may be mentioned. The most northerly of these runs along the southern margin of the Silurian inlier at the head of the Redewater. South of this a large fault, called by Hugh Miller the Dour-Hill-End Fault, runs from the Coquetdale to the Liddesdale Fells crossing the Rede at Cottonshopeburn Foot; it has a downthrow of about 1,000 ft. to the south with parallel shatters in Upper Redesdale. Similar shatters also occur to the north and south of the great Swindon fault. In the south of the county the "90-fathom Dyke," starting from the coast at Cullercoats, and running westwards, brings the Coal Measures up to the south against the lower Permian rocks. Farther to the west the well-known "Stublick Dyke" runs due west from Corbridge parallel to the Tyne valley into Cumberland, throwing the beds down to the north and bringing the Coal Measures against the base of the Millstone Grit. In addition to these main lines of dislocation we find numerous cross faults, especially in the district to the east of the Cheviot mass. These are of a general radial character with respect to the Cheviot granite, and the faults traversing the andesites, though not as a rule continuous with these, have a similar arrangement. If we consider these dislocations as a whole they form a most interesting series apparently due to important movements in post-Carboniferous, and possibly also in post-Permian times. They appear to have been produced by pressure from the south-east forcing the beds against the rigid mass of the Cheviot igneous rocks which would thus act as a "horst." In this way the great buckle, already described, running from Lowick into Cumberland, would be produced parallel to the buried margin of this "horst," but at some distance from its present outcrop; much as a *bergschrund* opening along an Alpine range develops below the upper limit of the *névé* which remains clinging to the buried mountain slope. By the breaking of this fold the concentric and radial fractures would also result. If the pressure came from the south-east its full force would be exerted at the south-east corner of the "horst," and it is here, in the Swindon portion of the main dislocation, that we find the greatest signs of movement. Thus Hugh Miller wrote of this fault: "The high dips . . . are the result of the violent down-thrust and compression. . . . There is a strip of ground lying

* *Mem. Geol. Survey*, "Expln. of Sheet 8 (108, S.E.)," p. 70.

directly in the path of this fault that exhibits a succession of unusually acute curves in the strata."* The same thing is visible to the north of Chillingham where the faulted synclinal, already mentioned, occurs, and we may furthermore look upon the Stublick Dyke, the 90-Fathom Dyke, and kindred fractures as results of the same movement. With regard to the period at which this movement took place it is difficult to be certain, and it is possible that all the fractures may not be contemporaneous; nevertheless, some important evidence with regard to planes of movement in the younger rocks in the south of the district has been recently published. In a paper by Prof. Lebour and Dr. J. A. Smythe a horizontal thrust is described in the Coal Measures of the Whitley Cliffs.† In this interesting communication it is shown that considerable movement has taken place along a plane of weakness due to the presence of an unconformity in the Coal Measure series, and that this thrust shows movement from the south or south-east. Still more recently Dr. Woolacott has investigated the well-known breccia beds in the Magnesian Limestone of the Durham coast,‡ and has shown that considerable horizontal thrusting must have taken place in a general north-west and south-east direction. It seems probable therefore that the movements which we are considering took place, partly at all events, in post-Permian times, and it would be highly interesting if it could be shown that this set of movements was also connected with those which occurred on a still larger scale along the west of the Pennine range against the similar though much larger "horst" due to the presence of the Lake District rocks. It must be remembered, however, that many faults traversing the Carboniferous series do not penetrate the Permian rocks, and that some dislocations which do traverse both formations have a much larger throw in the lower series, pointing to later movements along the same lines.

LITERATURE.

The literature bearing on the Geology of the two counties is somewhat extensive. The papers of special interest will be alluded to under the detailed descriptions given below. Among the more general works to which the writer is specially indebted may be mentioned: The papers by the late George Tate of Alnwick published in the Transactions of the Berwickshire Naturalists' Field Club, Prof. Lebour's well-known "Handbook to the Geology of Northumberland and Durham," his excellent summary of the Geology of Durham in the Victoria County History, the numerous papers published in the Transac-

* *Op. cit.*, pp. 71 and 72.

† *Quart. Journ. Geol. Soc.*, vol. lxii (1906), p. 530.

‡ *Mem. Univ. of Durham Phil. Soc.*, No. 1 (1909).

tions of the North of England Institute of Mining and Mechanical Engineers by the same accomplished writer, and the detailed sheet memoirs of the Geological Survey by Messrs. Hugh Miller, junior, C. T. Clough, and W. Gunn. Detailed description of the geology of many of the Northumberland parishes by the writer will be found in the *History of Northumberland** (1893-1907, vols. i-viii). In the Cheviot area the admirable map and memoir by Mr. Clough, together with petrographical papers by Dr. Teall and Mr. Kynaston, will be found invaluable by anyone interested in the study of this fascinating district.

The two counties have been visited by the Members of the Association on two occasions; the first time in August, 1886,† and again in July and August, 1903.‡ During these two expeditions all the formations described in the following pages were traversed.

STRATIGRAPHY.

The following table gives a general classification of the formations which occur in the two counties :

PERIOD.	FORMATION.	Maximum thickness in ft.
RECENT.	{ Peat, Alluvium, River Gravels, Raised Beaches.	
GLACIAL.	{ Boulder Clay, Gravels, Moraines, and Kames.	
TRIAS (KEUPER) PASSING DOWN INTO UPPER PERMIAN.	{ Red Sandstones and Marls, with Salt, Gypsum, Anhydrite	1,200 (?)
PERMIAN	{ Magnesian Limestone	800
	{ Marl Slate	15
	{ Yellow Sands	100
~~~~~	Unconformity.	
UPPER CARBONIFEROUS.	{ Upper Coal Measures	900
	{ Middle Coal Measures	2,000
	{ Lower Coal Measures	150
	{ Millstone Grit	400
LOWER CARBONIFEROUS (including Yoredale Beds of Durham and Bernician & Tuedian Beds of Northumberland).	{ Calcareous Division	3,200
	{ Carbonaceous Division	
	{ Fell Sandstone Group	
	{ Cement Stone and Lower Freestone Group	
	{ Basement Conglomerate	
UPPER OLD RED SANDSTONE (?)	{ Windy Gyle Conglomerate.	
~~~~~	Unconformity.	
LOWER OLD RED SANDSTONE.	{ Andesitic Lavas and Ashes.	
	{ Ashy Sandstones and Mudstones.	
~~~~~	Unconformity.	
SILURIAN.	{ Wenlock Shales and Greywackes of the Border.	
	{ Tarannon Shales ? (Teesdale).	

* Issued under the Direction of the Northumberland County History Committee.

† *Proc. Geol. Assoc.*, vol. ix, pp. 555 and 582.

‡ *Proc. Geol. Assoc.*, vol. xviii, p. 307.

INTRUSIVE ROCKS.

POST-CARBONIFEROUS.	{	Basaltic and Andesitic Dykes.	
		Dolerite Sheets	{ Great Whin Sill. Little Whin Sill.
LOWER OLD RED SANDSTONE.	{	Mica Porphyrite Dykes.	
		Quartz Felsite Dykes.	
		Cheviot Granite.	
UPPER SILURIAN OR LOWER OLD RED SANDSTONE.	{	Mica-trap Dykes.	

SILURIAN.

The only exposures of Lower Palæozoic rocks in the two counties occur, as might be expected, on their western borders. The oldest representative would appear to be a small patch of greenish slate which crops out at the old Pencil Mill a little above the High Force in Upper Teesdale, where it is traversed by a much decomposed minette dyke. These beds have been assigned by some writers to the age of the Skiddaw slates, and by others to that of the Tarannon Shales; but, as they are entirely unfossiliferous, their exact age still remains a matter for speculation.

In Northumberland, Silurian rocks occupy a small area near the Scottish border, forming apparently a continuous strip some $6\frac{1}{4}$ miles long and $\frac{3}{4}$ -mile wide, which runs in a north-easterly direction from the Redewater, near Lumsden, to Makendon, on the upper Coquet, and thence northward to Deel's Hill, in which direction the width of outcrop of the slates increases considerably. At the western end two branches are given off partly encircling Lumsden Law.

The south-eastern border of these Silurian beds is determined by a long boundary fault which runs the whole length of their outcrop from the Redewater, near Lumsden, to the north side of Outer Golden Pot, and throws them against the Fell Sandstone division of the Carboniferous beds, the maximum throw in Eaker Rigg being estimated by Hugh Miller at 1,000 ft. The northern boundary of the Silurian near Ramshope, and again near Brownham, appears also to be a faulted one. In the neighbourhood of the Redewater the Silurian beds are unconformably overlain by lower Carboniferous beds, while their relation to the Old Red Sandstone ash is seen in two gullies on the west side of Thirl Moor.

The rocks are best exposed near Makendon and Ingram and in the upper reaches of the Redewater, near Whitelee, where they consist of greenish-grey pencil slates and greywackes. Occasional bands of conglomerate occur, the pebbles being formed of pieces of contemporaneous shale. The finer shales are cleaved and highly contorted, and usually dip at high

angles; wherever they are overlain by the basement Carboniferous series the rocks are liable to be stained red.

As a rule these beds are quite unfossiliferous, but badly preserved specimens of *Monograptus flemingii*, Salt, and *Orthoceras (Creseis) primævum*, Forbes, have been obtained from the finer striped slates in Lumsden, Spithope, and Coomsden Burns. These beds have been traced south-west into Kirkcudbright, where they are much more fossiliferous, and it is chiefly from the latter district that the evidence for the Wenlock age of the Northumberland beds is derived.

Intrusive rocks of pre-Devonian age are rare in Northumberland. Two mica trap dykes, however, are exposed cutting the Silurian shales. One of these crosses the Border about one-third of a mile south-west of Brownham Law, and the other occurs about a mile west-south-west of Thirl Moor, and two-thirds of a mile north-west of Outer Golden Pot. This latter dyke appears as a brownish weathered rock, studded with silvery flakes of mica. It is 1 to 3 ft. wide, and forks into two branches. These two dykes, with the minette dyke previously mentioned as occurring in Upper Teesdale, are the only intrusive rocks of pre-Devonian age so far recorded as occurring in the two counties.

ROCKS OF LOWER OLD RED SANDSTONE AGE.

The group which succeeds the Silurian in the north-west of Northumberland is a most interesting one, and forms the well-known Cheviot Hills. The rocks forming this igneous complex comprise a series of lavas, ashes, and fine sedimentary mudstones, or ashy sandstones, together with granites and dykes representing the late phases of igneous activity. The whole of these rocks were erupted during the Devonian period, and represent a volcanic centre which has undergone extensive denudation.

The lavas consist essentially of andesites, more or less altered, which range from the typical porphyrites of older writers to vitreous hypersthene-augite-andesites or pitchstone-porphyrtes. Their microscopic structures were first fully described by Dr. J. J. H. Teall in 1883,* who concludes that all the rocks belong to one of the three groups, mica, augite and hypersthene-andesite, and that, allowing for modifications in their structure produced by subsequent changes, they do not differ essentially from andesites of recent date. The typical colour of the rocks is purple, but shades of red are not uncommon, and some of the vitreous varieties are black. Many of the flows are extremely amygdaloidal, the vesicles being drawn out in the direction of flow; frequently they are much compressed vertically, so much so that a fissile character is often imparted to the rock. The

* *Geol. Mag.*, dec 2, vol. x (1883), pp. 100, 145, 252, 344.

cavities are filled with varieties of silica, calcite, and green earth, the siliceous amygdules giving rise to the well-known agates and jaspers of the Coquet, the Redewater, and Ramshope Burn.*

The lowest flow near Philip differs from the normal type by containing an abundance of mica, and by the presence of large twinned feldspars. The typical andesites usually contain secondary products due to decomposition, the feldspars being kaolinised and the ferruginous minerals altered to chlorite and viridite. Ferrite and epidote also occur, while the glassy base is frequently devitrified.

The black, resinous-looking flows (pitchstone-porphyrries of the earlier writers) are much less altered, and contain porphyritic crystals of labradorite, hypersthene, and augite. Analysis by Dr. Petersen† show that the glassy base is richer in silica and alkalis and poorer in lime, iron, and magnesia than the bulk of the rock, potash being in excess of soda, and that it has the composition of a trachyte or liparite. The rock is frequently traversed by bright red veins, which are very characteristic, and appear to have been formed shortly after consolidation.

Fragmental volcanic rocks are comparatively rare; several bands have, however, been traced by Mr. Clough, and described by him in the Geological Survey Memoir on the Cheviot Hills. The most notable sections occur at the foot of the Henhole and opposite Blindburn; also in the basement bed near Philip, and in the Wholehope and Yoke Burns. Still thicker ashes are found near the head of Davidson's Burn and near Makendon, and in places a series of five or six beds of ash may be traced, separated by fine-grained felstone-like flows. In addition to ashes, fine sedimentary mudstones, or ashy sandstones, occur locally, and Mr. Clough records the occurrence of a conglomerate 20 ft. thick in the Coquet about a quarter of a mile above Windyhaugh.

The *Cheviot Granite*, as first pointed out by Dr. Teall,‡ though sometimes resembling a normal grey granite, and at other times a syenite, especially towards the margin of the mass, is essentially an augite granite, the principal constituents being a soda-orthoclase, oligoclase, black mica, a colourless augite, quartz, and a little magnetite. The rock is of especial interest since it is the only known occurrence of an augite granite in Britain, and it may be compared with the augite granites of Laveline and Oberbrück in the Vosges. The rock is usually fine-grained, and is seldom porphyritic, though it is coarse in the northern parts of its outcrop, and again in

* J. Thomson, *Proc. Berwick Nat. Club*, vol. ix (1881), p. 537.

† Teall, "Petrographical Notes," etc., *Proc. Geol. Assoc.*, vol. ix (1886), p. 583.

‡ *Geol. Mag.*, dec. 3, vol. ii (1885), p. 106.

Linhope Burn, about 150 yards above its junction with Staindrop Burn. Chemical analysis shows great uniformity in composition throughout the mass, the silica percentage varying between 66 and 67.12. In microscopic sections, the augite appears colourless, and contains inclusions of magnetite; it is sometimes abundant, especially in the syenitic varieties, as at Linhope Spout; it seldom occurs in definite crystals, and it is a non-aluminous iron-bearing species of the diopside type. Both orthoclase and plagioclase are usually present, sometimes one and sometimes the other predominating, the former being frequently red, while the latter is white or grey, as is well seen on Staindrop. The ground mass is frequently a micro-pegmatite, especially near the margin, a fact which emphasises the resemblance of this rock to the hornblende granites of Charnwood and the gabbro of Carrock Fell. It is true that no original hornblende has been recorded from any of the exposures of the Cheviot granite, but it is possible that the hornblende of the Leicestershire and Cumberland rocks may, in part, be secondary after augite.* Mr. Kynaston† records the presence of a pale enstatite in the granite of Staindrop Rig, Linhope, and Dinmoor Hill, similar to that which characterises the andesites; he also records the presence of tourmaline, especially near the margins of the mass and in the neighbourhood of faulted areas, as, for example, near the head waters of Lambden and Hawsen Burns, where it occasionally takes the form characteristic of luxullianite, and would appear here, as elsewhere, to owe its origin to pneumatolitic action.

The granite frequently weathers out into characteristic tors, as in Staindrop Rig and Coldlaw Cairn.

The boundary of the granite area is difficult to define, as it is for the greater part covered by superficial peat deposits. Broadly, it occupies a circular area of $2\frac{1}{2}$ to 3 miles in diameter, having Hedgehope as a centre. The western boundary appears to be about one mile west of the summit of Cheviot, its southern boundary running roughly parallel to the Breamish from Aulsey, south-east of Lint Sands, to Linhope. Two irregular extensions occur to the north and west; the former stretches across Broadstruther Burn to Common Burn, the latter to Tod Hill and the west side of Hare Law.

Dykes and Sills are numerous, intersecting the granite and penetrating the surrounding lavas in a general radial manner. These are of both intermediate and acid types, and have been described by Messrs. Clough, Teall, Watts, and Kynaston. The intermediate dykes are normal pyroxene porphyrites; orthoclase, when present, being subordinate to plagioclase, whilst both augite and enstatite occur. These rocks are of a dark

* Teall, *Proc. Geol. Assoc.*, vol. ix, p. 581.

† *Trans. Edin. Geol. Soc.*, vol. vii, (1899), p. 390.

grey colour when fresh, but are usually purple, or even red when decomposed. The rocks forming the acid type of dyke belong to two classes: the quartz-felsites or granophyres with micro-pegmatite ground mass, and the felsophyres—without micro-pegmatite. Dr. Teall and Mr. Kynaston have both described dykes of this latter class, while Prof. Watts has also described orthophyres belonging to this group. Biotite is sometimes plentiful, and the rock may then be compared with the mica-bearing quartz-porphyrries described by Messrs. Marr and Harker from the Shap district.

A very interesting feature recorded by Mr. Kynaston* found both in the intermediate and acid dykes, is the occurrence of granophyric groups of quartz and orthoclase forming phenocrysts in addition to the fine micropegmatite representing the final phase of the consolidation. Good examples of intermediate dykes, showing this phenomenon, are found in the Breamish, just below Linhope House, and in a dyke on the south side of Dunmoor Hill. This latter dyke also contains prisms of violet-coloured apatite, recalling a similar occurrence in the andesite from the Ochils, described by Dr. Flett. Examples of the double series of micropegmatite growths occur also commonly in the acid dykes, as, for instance, half a mile below Bleakhope. These structures may be compared with the granophyre groups described by Iddings from the rhyolitic rocks of Obsidian Cliff and Eureka, Nevada, and, perhaps, also with the veins traversing the gabbro in Skye, described by Sir A. Geikie, and figured by Professor Judd.† Some of the dykes also contain tourmaline. This mineral is, however, practically limited to those veins which occur in the neighbourhood of the margin, as, for instance, in those above Langleyford and in the Henhole.

The inter-relation of the granite, the dykes, and the lavas is an interesting problem; the lavas were evidently first poured out and the granite subsequently intruded into them, while the fact that the dykes cut both the lavas and the granite shows that they represent the latest eruptive phase. There appears to be undoubted evidence that the granite was intruded into the andesites at some period subsequent to the extrusion of the lavas, and after a sufficient lapse of time to allow of the partial alteration of the lavas and the infilling of the vesicles with quartz and of the cracks with calcite. As Mr. Kynaston has shown,‡ extensive contact alteration is clearly visible in the andesite within a zone half a mile in breadth surrounding the granite; this is proved by the development of secondary flakes of biotite, granules of pyroxene and magnetite, the clouding of the fel-

* *Trans. Edin. Geol. Soc.*, vol. vii (1890), p. 300.

† *Quart. Journ. Geol. Soc.*, vol. xlix (1893), p. 189; and vol. l (1894), p. 212.

‡ *Trans. Edin. Geol. Soc.*, vol. viii (1905), p. 18.

spars, and the conversion of the agate of the vesicles into clear quartz and the calcite veins into granular pyroxene. At the same time, there can be no doubt that in the Cheviot area we are dealing with a compact petrographical province where the source of supply for the lavas, the granite, the dykes, and the sills was the same. A certain amount of differentiation apparently took place before the extrusion of the lavas, the residual magma represented by the granite being distinctly more acid, while the subsequent intrusion of the two classes of dykes may be satisfactorily accounted for by assuming this early differentiation.

LOWER CARBONIFEROUS.

The first detailed scheme of classification for the Carboniferous rocks of Northumberland was proposed by the late George Tate, of Alnwick, in 1856, and more fully described in 1859. Previous to this, the lower beds had been regarded by many writers as of New Red Sandstone age, and are so coloured in Greenough's geological map published in 1820. In 1831 R. D. Thomson correlated the Carham Limestone with the Magnesian Limestone of Durham, while William Smith included the lower beds in the Old Red Sandstone in his geological map published in 1828; Sedgwick, however, in his address to the Geological Society in 1831,* compared them with "the red beds of Mountain Limestone and sandstone, which, both in Cumberland and Lancashire, sometimes form the base of the whole Carboniferous series," and, according to De La Beche,† he considered them to be of the age of the Great Scar Limestone of Yorkshire and Cross Fell.

Tate pointed out that the lower beds formed a distinct division below the Productal and Encrinal limestones on both sides of the border, and in 1856 he proposed the name *Tuedian* for the beds seen between Carham and Norham, lying below the Mountain Limestone, and forming "a marked transitional series intercalated between the Mountain Limestone and the Old Red Sandstone" distinguished by the peculiarity of the shales, by the thin beds of Magnesian limestone, by the absence of brachiopods, and by the presence of *Modiola*, entomostraca, and fish remains.‡

In 1866 he divided the beds above the Tuedian and below the Millstone Grit into two divisions; the upper group he called *Calcareous*, on account of the number and thickness of the limestones found in this division, and he included in it all the beds from the base of the Millstone Grit to the base of the Dun Limestone. For the lower group he proposed the name *Car-*

* *Proc. Geol. Soc.*, vol. i, p. 287.

† *Geol. Manual*, 3rd Ed., 1833, p. 391.

‡ *Proc. Berwick Nat. Club*, vol. iv (1889), p. 151.

bonaceous, since this division contained the majority of the workable coal seams in the north of the county.* In 1863 Messrs. Howse and Kirkby divided the lower Carboniferous beds in Northumberland and Durham into Yoredale, Scar Limestone, and Tuedian, while in 1875 Professor Lebour pointed out that the terms *Calcareous* and *Carbonaceous* were misleading in the south of Northumberland, since the best coals were there found associated with the Great and Little Limestones in the upper part of Tate's "Calcareous" division, and he proposed the term *Bernician*† to describe the mixed type of deposits represented in the Border Counties. Hugh Miller, however, as a result of detailed mapping in the south of the county, maintained that Tate's classification was equally applicable to that region.‡ More recently the officers of the Geological Survey have adopted the following classification in the Northumberland Memoirs :

LIMESTONE GROUP OR CALCAREOUS DIVISION (from the base of the Millstone Grit to the base of the Dun Limestone).
 SCREMERTON COAL GROUP or Carbonaceous Division.
 FELL SANDSTONE GROUP or Upper Tuedian.
 CEMENT STONE GROUP or Lower Tuedian.
 BASEMENT CONGLOMERATE.

In Durham, the lower Carboniferous rocks are thinner than in Northumberland, averaging some 1,200 ft., as against a maximum of 8,000 ft., or more, in the centre of Northumberland. They consist of limestones, sandstones, and shales, but coal seams are quite subordinate.

As long ago as 1821 these beds were sub-divided by Westgarth Foster, the limestones were arranged in tabular form, and a definite name was allotted to each. These names have been adopted on the Geological Survey maps.

The following table represents the more constant members of the series beginning at the top :

15. Fell Top Limestone.	8. Cockle Shell Limestone.
14. The Little Limestone.	7. Single Post Limestone.
13. The Great or Main Limestone.	6. Tyne Bottom Limestone.
12. Four Fathom Limestone.	5. Jew Limestone.
11. Three Yard Limestone.	4. Tenth or Little Limestone.
10. Five Yard Limestone.	3. Smiddy Limestone.
9. Scar Limestone.	2. Robinson's Lime.
	1. Melmerby Scar Limestone.

The lowest of these beds, however, the Melmerby Scar Limestone, although seen resting on the Silurian rocks in Teesdale,

* Tate, *Proc. Berwick Nat. Club*, vol. v, p. 283; *Nat. Hist. Trans. North. and Durham*, vol. ii (1868), p. 1.

† Lebour, *Trans. N. Engl. Inst. Min. and Mech. Eng.*, vol. xxv (1876), p. 225; *Geol. Mag.*, dec. 2, vol. ii (1875), p. 539; and "Handbook of the Geology of Northumberland and Durham" (1886), p. 58.

‡ *Mem. Geol. Surv.*, Explanation of Sheet 8 (108 S.E.), p. 5.

is considerably higher in the Carboniferous series than the beds forming the base of these deposits in Northumberland. Though not represented at the surface in Durham, it has been proved in several mine-shafts, and Prof. Lebour assigns to it an average thickness of 132 ft. On the Eden side of the Pennine escarpment it is, however, well exposed.

On the whole it may be stated that in passing from Yorkshire to Scotland the limestone beds thin out, and the sandstones and shales increase in thickness as we approach the old northern shore-line. This statement applies especially to the Melmerby Scar Limestone and the beds underlying it in the Shap and Kendal districts to the west. Thus in Northumberland we have no massive limestones representing the thick Lower Scar Limestone of Yorkshire, these beds being represented by the massive sandstones, shales, and coals of the Fell Sandstone and Scremerston Coal divisions, together with the few thin limestones and intercalated beds forming the base of Tate's "Calcareous" series.

The detailed correlation of the Northumberland beds with the Mountain Limestone and Yoredale rocks farther south on stratigraphical evidence has always been found a very difficult task. Prof. Lebour, after tracing the six highest limestones of the Yoredale Series of Durham into Northumberland, remarks: "But if the upper members of the Bernician Series can thus be correlated from south to north with safety, this is no longer so as we descend lower down in the series," and he frankly abandons the attempt.* The most important contribution to this subject of recent years is the paper by the late W. Gunn on the correlation of the lower Carboniferous rocks of England and Scotland.†

In this paper the limestones are correlated together as follows, the first name in each case being that by which the bed is known in North Northumberland, and the last that by which it is known in Wensleydale.

4. The *Dryburn* Limestone of North Northumberland, the *Ten-yard* Limestone, the *Great* Limestone of South Northumberland, Teesdale, and Weardale, and the *Main* Limestone of Wensleydale.
3. The *Low Dean*, *Eight-yard*, the *Four Fathom* and the *Underset* Limestones.
2. The *Acre*, the *Six-yard*, the *Three-yard*, and the *Little* Limestones.
1. The *Eelwell* or *Main* Limestone, the *Nine-yard*, the *Five-yard*, and the *Fossil* Limestones.

The beds below these in North Northumberland, between the *Eelwell* and the *Oxford*, he considers may represent the

* "Handbook of Geology of Northumberland and Durham," p. 65.

† *Geol. Mag.*, dec. 4, vol. v (1898), p. 342, and *Trans. Edin. Geol. Soc.*, vol. vii, p. 361.

Scar, Cockleshell, Single-post, and Tyne-bottom Limestones of Weardale and Teesdale, and he places the *Oxford* on the horizon of the "Hardraw Scar," or lowest limestone of Phillips's Yoredale Series.

The above correlation is founded on stratigraphical evidence only, and it will be interesting now to turn to the fossil evidence and see what light recent zonal work in the lower Carboniferous rocks farther south can throw on this problem, especially with regard to the lower limit, which should be assigned to the Yoredale Series in Northumberland and the correlation of the remaining portion of the Bernician and the Tuedian rocks with the Melmerby Scar Limestone and underlying beds of Westmorland and Cumberland. For this purpose it will be necessary first to describe the Northumberland beds in some detail.

The Tuedian Group.—The lowest beds of the Carboniferous series would naturally be expected to occur on the flanks of the Cheviot area resting upon the Cheviot andesites, and such is to some extent the case. The boundary, however, between these two formations is by no means a clear one, and, as so frequently happens along the junctions of rocks of different character, the Carboniferous rocks are found to be faulted against the andesites throughout the greater portion of their contact. One of these faults appears to run along the northern boundary of the Cheviot mass, from the Scottish Border south of Presson-hill, eastwards to Crookham. A second fault, starting from Kirknewton, curves eastward through Akeld to Wooler. The southern boundary of the lavas is also for the most part a faulted one, but the junction is greatly obscured by drift. Near Milfield, however, the Basement bed of the Carboniferous contains angular fragments of andesite, and is seen to rest unconformably upon the lavas. As pointed out by W. Gunn, this is probably the section recorded by Sedgwick. It is possible, however, that the lowest strata are absent here owing to the overlap of the Carboniferous beds on to the island of Cheviot rocks which doubtless stood out above the waters of the early Carboniferous sea.

The oldest beds of Carboniferous age in the north of the county are the so-called Kelso Traps, which are taken by Gunn as the dividing line between the Carboniferous and the Old Red Sandstone. The rocks are olivine-diabases, containing 47.53% SiO_2 , and having a sp. gr. of 2.95. They are often amygdaloidal and much decomposed, the general colour being grey, dotted over with rusty flecks, due, according to Prof. Watts, to pseudomorphs of iddingsite after olivine. The rocks are only seen in contact with the lower Tuedian beds near Carham, where the shales and cement stones include a thick bed of dolomite, containing 44% of carbonate of magnesia.*

* Analysed by R. D. Thomson, *Mag. Nat. Hist.*, vol. v (1832), p. 637.

On the east side of the Cheviots at Ilderton and Roddam Dene conglomerates, containing pebbles of Cheviot andesite, occur, and similar beds are found on the Scottish Border at Windy Gyle, at the head of Howhope. By the English surveyors these beds are taken as basement Carboniferous, while the officers of the Scottish Geological Survey include similar beds among the Upper Old Red Sandstone deposits.

In Tate's type district along the banks of the Tweed, the lower Tuedian beds, according to Gunn, reach a thickness of nearly 3,000 ft. They consist of reddish and white sandstones, green and dark-coloured shales and thin magnesian limestones or cement stones, but no true coal seams occur.

The fossils are mainly land and shallow-water forms, plants, lamellibranchs, gasteropods, and fish remains; a species of orthoceras, however, occurs. Some very interesting examples of early arachnida, crustacea, and arthropoda have been discovered by the collectors of the English and Scottish Surveys, and the latter have been recently described by Mr. Peach.* On the whole, the most characteristic fossil in the series north of the Cheviots is, perhaps, the annelid *Spirorbis helicteres*, which occurs in great abundance. The beds are but poorly represented on the eastern flank of the Cheviots; the upper portion of the series is, however, exposed in the crest of the denuded anticlinal fold, already mentioned, which runs from Holburn to Chillingham. In Redesdale, the Tuedian beds are only exposed in the upper portion of the valley, where they are about 600 ft. thick; they are not seen south of the important fault which runs from Linshields to the Scottish Border at Bell's Linn, which brings in beds about 1,000 ft. higher in the series on its south side.

In Coquetdale and upper Alndale they occupy a large area between Rothbury and the Cheviot andesites. In this latter district several additional magnesian limestones make their appearance, and the group must have thickened out to the west of Rothbury to at least 1,000 ft. Farther west, in the neighbourhood of the Border, at the head of the north Tyne and the Kielder, the lower beds become more markedly arenaceous, and in this district and in upper Redesdale Messrs. Hugh Miller and Clough have sub-divided the Tuedian into a lower or Freestone and an upper or Cement Stone Group.

In the valleys drained by the Kielder and the head waters of the north Tyne the Tuedian beds give rise to extensive landslips. Farther south they occur along the Cumberland border and reappear from under the Fell Sandstone in the Bewcastle district and along the Scottish Border in the Kershope Burn.

The fauna south of the Cheviot range shows the incoming

* *Mem. Geol. Survey*, "Crustacea of the Carboniferous Rocks of Scotland," 1908.

of estuarine conditions, entomostraca being especially abundant. Near the Scottish Border, in Coomsdon Burn and Chattlehope Burn, schizopods and scorpions have been found together with plants and fishes of lower Carboniferous age. The fauna still consists largely of shallow-water lamellibranchs and gasteropods, together with *Spirorbis helicteres*; but the most significant fossil found in these beds is the interesting form *Mitcheldeania gregaria*, Nich. ; this genus appears to be closely allied to *Solenopora*, and is no doubt also a calcareous alga.* In west Northumberland it appears to be especially characteristic of the highest calcareous beds of the cement stones which lie immediately below the base of the Fell Sandstone. It occurs in a limestone at this horizon one mile north of Lorbottle, and again about a mile south of Bickerton, where the beds are repeated on the east of the great fault; also near Holystone and south of Hilchester in the Coquet valley, and again in the same limestone in Whitfield Burn, on the south side of the great Swindon fault. Farther west it occurs abundantly in the highest cement stone band in Coomsdon Burn, and also in the White Kielder not far below its source. Still farther south and west the same fossil occurs abundantly near the head of Lewis Burn, and just over the Cumberland border at the head of the White Line and its tributaries, the Bull Cleugh and Ashy Cleugh, where it forms extensive beds of limestone. Between here and the Scottish Border it occurs frequently, and was originally described by the late Prof. Nicholson from a limestone at the base of the Fell Sandstone on the Scottish side of the Border, near Kershope Foot.

Associated with it on the Cumberland border is another important fossil, *Athyris glabristria*, Phill. (*roysii* of Authors), which occurs abundantly in the Shap Dolomites of Westmorland. Two other fossils may be mentioned here, as they are of great importance in any question of correlation of these beds with the rocks to the south, namely, *Syringothyris cuspidata* and *Orthotetes crenistria*. They occur together in Catcleugh Burn, a short distance from the Scottish Border south of Bell's Linn, and again at the head of Lewis Burn. The exact horizon of the beds in which they occur is not clear, as the ground is much obscured by drift and intersected by faults, but they lie probably at the top of the Cement Stone Group or the base of the Fell Sandstone. That this is their true position is borne out by their association with *Mitcheldeania* in the Lewis Burn, and in numerous exposures over the Cumberland border to the south-west, and also by the fact that beds crowded with *Syringothyris* occur below the Fell Sandstone near the head of Larriston Burn, a mile or two to the west.

Contemporaneous basalt flows occur sparingly in this series, and are almost limited to upper Redesdale. There appear to

* It was originally included by Prof. Nicholson among the Hydroid Zoophytes.

be two beds—the lower about 50 ft., the upper about 16 ft. thick. They were ascertained by Hugh Miller to occur at, or just above, the junction-line between the Lower Freestones and the overlying Cement Stone beds.

The Fell Sandstone division contains the beds between the upper limit of the Cement Stone Group and the lowest coal seam of the overlying Scremerston Series which, in North Northumberland, is usually the *Wester* coal, and is represented in the south of the county by the Lewisburn Series. These sandstones are massive and false-bedded, but vary considerably in texture; the prevailing tint is light red, but white and brown layers also occur, shales and coal being altogether subordinate. In the centre of the county some of the individual beds of sandstone must reach 150 ft. in thickness, the formation totalling some 600-800 ft. They usually form conspicuous features, especially in the Chillingham and Rothbury districts. The marked irregularity in their planes of deposition, which have been compared by Prof. Lebour to a kind of cyclopean false-bedding, prevents the accurate mapping of individual beds for any distance. With the exception of plant remains, only one fossil is recorded from this division in Northumberland, namely, the interesting fresh-water mollusc, *Archanodon jukesi*, discovered some years ago in beds of this age on the south side of Newtown Moor.* As previously mentioned, these rocks form conspicuous hill ranges in the north and centre of the county. Starting from the northern border, the beds run from Tweedmouth Station and along the south side of the road to Grindon Common, thence nearly due south, keeping east of the river Till to Ford, and thence south-east to Doddington and Weetwood Hall. Here the outcrop crosses the Till and continues by Newtown Moor, on the west of the river Breamish, to the neighbourhood of New Bewick, where the beds disappear under the drift (see map, Plate XXII). East of this line of outcrop, as far as the general course of the Hetton Burn and the Till, the ground is occupied by rocks belonging to the overlying Carbonaceous and Calcareous groups. Farther east, however, owing to the great faulted synclinal, already described, which runs from near Lowick to Lilburn, the Fell Sandstones are again exposed. They occupy both flanks of the denuded anticlinal ridge, which, it will be remembered, runs from Shepherd's Kirk to Old Bewick, east of the broken synclinal fold. Along the western side of this anticlinal they form a narrow strip of ground running due south from Shepherd's Kirk to Chillingham Castle, with a high dip to the west, while on the east side they dip gently to the north-east, and form the ridge of high ground near Holburn Grange, in which St. Cuthbert's Cave (locally known as Cuddies Cove) is excavated. (Plate XIX.) Farther south they crop out

* R. Howse, *Nat. Hist. Trans. North, and Durham*, vol. vii, p. 173.

in a series of fault blocks, forming Lyham Moor, Chatton Park Hill, Amersidelaw Moor, Sandyford Moor, and Hepburn Moor, the beds being shifted alternately to the east and to the west by the numerous dislocations which cross the ridge in this portion of the district.

In the neighbourhood of Eglington this double outcrop of the Fell Sandstones is shifted several miles to the east by the Embleton—Bewick fault, the eastern strip running by Hulne Park and Alnwick Moor to Longframlington Common, and the western strip passing through Glanton and Lorbottle to Rothbury Common.

To the south of Rothbury these beds bend round to the west on either side of the great Swindon fault; here the beds are coarse grained, and reach a thickness of 1,700 to 2,000 ft. From here the northern outcrop ranges north, and then west along the west side of Coquet Dale, in which district the beds were originally known as the Harbottle Grits. Skirting the southern flank of the Cheviots by Riddlees Cairn they form the massive fells of Dour Hill and Ellis Crag, and cap all the fells on both sides of Redesdale between the Silurian boundary and the large fault which runs from Coquet Dale through Cottonhope Burn Foot. To the west of Redesdale, the beds become thinner and finer grained, while on the Border at Peel Fell, in the upper Tyne valley, the formation is reduced to some 500 to 600 ft. in thickness. Throughout the district described there are no fossils recorded from these beds other than plants and the fresh-water mollusc already mentioned.

On Carter Fell a massive bed of basalt occurs in this series, which may be a contemporaneous flow, but there is no satisfactory evidence to say whether it is so or not. It is possible that it represents the volcanic group which occurs at the top of the Fell Sandstone series on Larriston Fells, where it underlies the Lewisburn coals, and which reappears near Kershope Foot. It may also possibly be contemporaneous with the well-known volcanic group of Arthur's Seat, near Edinburgh.

The Carbonaceous Division is especially well developed to the north-east, and to the south-west of the Cheviots. In the north of Northumberland it attains a maximum thickness of 900 ft., diminishing to 550 ft. as it is traced to the district south of Lowick. It consists essentially of sandstones, shales, and coals, with numerous thin, impure limestones. Its lower limit is taken by Tate and the officers of the Geological Survey* at the base of the *Wester* coal, the lowest workable seam, and its upper limit at the base of the Dun Limestone. There are six principal seams, including the *Scramerston* main coal, which is over 4 ft. in thickness, and several other subordinate seams, there being sixteen altogether over one foot in thickness; and it is note-

* W. Gunn, *Mem. Geol. Survey*, "Explanations of quarter sheets 110, N.E., N.W., S.E., S.W."

Photo by E. J. Garwood.

ST. CUTHBERT'S CAVE, NORTHUMBERLAND, WEATHERED OUT OF THE FELL
SANDSTONE.

To face page 678.

worthy that the roofs of the coal seams are, in the majority of cases, formed by limestone, while the two lowest seams of the series, the *Cooper Eye* and the *Wester* coal, have limestone bands in the middle of the seams.

The main outcrop in the north of the county runs from Berwick, through Ford and East Horton, to Chillingham Barns, the beds having a general easterly dip. They occupy a strip of country on the east of the Fell Sandstone outcrop, from one mile to one mile and a half in width. The group is again exposed farther east on either side of the north and south anticlinal axis previously described. On the west side of this the beds dip steeply with the Fell Sandstone towards the west, while on the east side they partake of the prevalent easterly dip towards the sea.

Between Eglington and North Charlton they occupy a much wider extent of country, the principal coals worked being known as the *Top* and *Bottom* seams; these are frequently repeated by a series of small east and west faults. South of the large cross fault running from Embleton to Eglington, the series is shifted with the Fell Sandstone several miles to the east, and the outcrop again narrows passing to the west of Alnwick, where two coal seams are again exposed.

In the Swindon district, north of the Swindon fault, the beds thicken to 1,000 ft., while farther west, in the Tarsset—Blackburn district, and in the basin of the North Tyne, to the west of Bellingham, Hugh Miller estimated the total thickness of this division at about 2,600 ft.

Still farther west, in the upper valley of the North Tyne, the beds include two groups of workable coals, the *Plashetts* coals near the top and the *Lewisburn* coals near the base of the series. The *Plashetts* coals are overlain by the Piper Cross limestone, which would seem to represent the base of the overlying Calcareous series in this district.

The fauna of the Carbonaceous division changes considerably as the beds are traced from north-east to south-west. In the north the beds are of shallow-water character; only some dozen species of fossils are recorded. These include a spirorbis, entomostraca, lamellibranchs, a bellerophon and fish remains. As we pass to the south of the Cheviots the limestone bands increase in number and thickness, and the fauna becomes correspondingly more marine. The shales are specially rich in plants, ostracods, bryozoa, lamellibranchs, and gasteropods; but in the Rede valley corals are absent, and brachiopods, with the exception of *Spirifer trigonalis* and a rhynchonellid, are represented by inarticulate species. In the upper Tyne district, the Piper Cross limestone and associated beds contain specimens of *Lithostroton junceum* and *L. m'coyanum* and large *Producti*, and these beds, considered palæontologically, undoubtedly form the true base of the Calcareous series in this district.

The Calcareous Division.—The beds forming this division, as already explained, are characterised by the number and thickness of their marine limestones, alternating with shales, sandstones, and a few coals. They are exposed in the east and south of Northumberland, and are the only portion of the lower Carboniferous which extends into Durham. These beds form the coast line from Scremerston to Alnmouth, a little north of which the highest limestone, the Fell Top, comes in and forms a nearly continuous outcrop passing to the west of Felton and Milford to Harlow Hill. It then curves round to the west, and, crossing the Tyne valley near Broomhaugh, passes to the south of Corbridge, so that in the neighbourhood of Haltwhistle the beds of this series strike nearly due west into Cumberland. The base of the division is marked by the outcrop of the Dun and Redesdale Limestones, which follow the general outcrop of the Carbonaceous beds already described. The higher beds are again exposed in the valleys of the Allen, the Devil's Water, and the South Tyne. Good, workable coal seams occur at several horizons. Near the base lies the *Woodend* coal of the northern district, corresponding to the *Gunnerton*, *High Green*, or *Four Laws* seams of the centre and west of the county. Other important seams are the *Grenses* coal, below the Oxford Limestone, and the *Shilbottle* coal, below the Six-yard or Acre Limestone. In the upper part of the series, coals occur below the Great Limestone and the Little Limestone. The latter is the most persistent coal seam of this division in the county, and is found whenever the beds are exposed between Scremerston and Alstone. It is occasionally split up into several seams, and is known by different names, such as *Acomb*, *Clarewood*, etc.

The chief feature of the Calcareous division is the way in which the series spreads out and thickens in South and West Northumberland. This is in part due to the introduction of additional beds of limestone, no fewer than 20 beds being mapped by the Survey in the extreme south-west of Northumberland. Three new limestones are intercalated between the Fell Top and the Little Limestone, as shown by Prof. Lebour,* and others also make their appearance lower in the series. The former seem to persist into Durham, as proved by a recent boring in the Derwent valley.† The beds show more marked marine conditions than those below, and the limestones abound in the corals and brachiopods characteristic of the Yoredale beds and the Melmerby Scar Limestone of the Crossfell area. An interesting fossil very characteristic of several of these limestones in Northumberland is the large foraminifer, *Saccammina carteri*, Brady. The beds forming the Calcareous Group may be divided into two sub-groups; an upper group comprising the beds

* Lebour, *Trans. N. Engl. Inst. Min. and Mech. Eng.*, vol. xxiv, p. 73.

† J. B. Simpson, *Trans. Inst. Min. Eng.* (1902), vol. xxiv, p. 549.

from the base of the Millstone Grit to the top of the Oxford Limestone, and a lower group containing the remaining beds from the top of the Oxford Limestone to the base of the Dun, or Redesdale Limestone. It is difficult to determine exactly the equivalent of the Oxford Limestone in South-West Northumberland, but it probably corresponds to one or two of the limestones next below the Tyne-bottom Limestone of the Simondburn district.

We may now consider the question of the equivalence of the different divisions of the Lower Carboniferous rocks of Northumberland, as described above, with the zonal divisions suggested by Dr. Vaughan for the Bristol district.

The general correlation of the sub-divisions of the Westmorland and Yorkshire beds with those of the Bristol area has now been completed, and we may therefore compare the Northumberland beds directly with the succession as established for their nearer representatives in Westmorland.*

For this purpose it will be best to begin with the upper beds and work downwards. The highest division of the *Dibunophyllum* zone, or D₃, is almost certainly present in Northumberland, being represented by the Felltop Limestone and its associated beds. A puzzling feature, however, is the occurrence of *Posidonomya becheri*, so characteristic of Dr. Wheelton Hind's Pendleside Group elsewhere.† It occurs in North-East Northumberland, round the south side of Budle Bay, at several points between Easington Mill and Heatherhouse, close to the outcrop of the Whin Sill, and also near Glororum, farther south, in black and red baked shales, which appear to be about the horizon of the beds just above the Oxford Limestone. The exact position of these beds is, however, difficult to determine, but since *Posidonomya* is here associated with such forms as *Alveolites septosus*, *Orthotetes crenistria*, *Bellerophon decussatus*, and other forms which occur abundantly in the lower Yoredale beds, and since the typical cephalopods associated with it in the Pendleside beds are absent, it would seem as if it appeared here, near the base of the Yoredale Series, at a considerably lower horizon than elsewhere. We may conclude then that the Upper Calcareous division represents the middle and upper *Dibunophyllum*-zones of the south, or the Yoredale beds of Yorkshire. It is characterised by the corals *Lonsdalia floriformis*, and forms allied to *Cyclophyllum* (*Aulophyllum*) *pachyendothecum*, Thomson, together with *Dibunophyllids* of the upper group of Dr. Vaughan; examples of the typical forms of *Productus giganteus* and *Productus latissimus* also frequently occur. *Lonsdalia floriformis*, which characterises the base of D₂ in Westmorland and Yorkshire, occurs abundantly in the Dryburn Limestone of Beadnell and

* For summary of results, see E. J. Garwood, *Geol. Mag.*, dec. 5, vol. iv (1907), p. 70.

† *Quart. Journ. Geol. Soc.*, vol. lviii (1902), p. 347.

Lowick, and in the Acre Limestone near Scremerston, but species of *Lonsdalia* are found as low as the limestone next above the Oxford Limestone, and we may therefore adopt this horizon as the base of the Yoredale series in North Northumberland. An interesting fact is the occurrence in the Oxford Limestone of small dark concretions, due to the growth of the calcareous alga *Girvanella*. Exactly similar forms occur at the base of D2 in Westmorland, Lancashire, and West Yorkshire. Farther south, *Lonsdalia* occurs in the Eight-yard or Low Dean limestone to the south of Rothbury, and again in the Great, or Dryburn, limestone to the south of Chollerton, while the lowest position, known to the writer, in which it has been found in the North Tyne valley is in a bed not far below the Tyne-bottom Limestone, which must be somewhere very close above the horizon of the Oxford Limestone of the north, so that we may take the base of the Yoredales in the south as occurring at about the second limestone below the Tyne-bottom Limestone, which corresponds very closely with its position immediately above the Melmerby Scar Limestone in the Northern Pennines.

The lower portion of the Calcareous series, from the Oxford Limestone to the base of the Dun, or Redesdale, Limestone Group, appears to represent the lower *Dibunophyllum*-zone of the south, being characterised by the presence of *Lithostrotion junceum*, *Lithostrotion portlocki*, and *Alveolites septosus*, associated with *Cyathophyllum purchisoni* and species of *Dibunophyllum*. The lower limit of this zone in the western portion of Northumberland is difficult to decide, but it is certainly below the Redesdale Limestone. We may therefore provisionally take the base of the Dun, or Redesdale, Limestone as forming the base of D1 of the Bristol area.

The Carbonaceous series below the Piper Cross Limestone is, as a rule, characterised by the complete absence of corals, pointing to deposition in shallow water. In the extreme west of the county, however, in the river Irthing, dendroid *Lithostrotions* occur in the beds underlying the Plashetts coals, together with *Spiriferina lammosa*, etc. This series should therefore represent S2, or the lower Melmerby Scar Limestone of the Shap and Cross Fell districts. The Fell Sandstones below give no definite evidence of their age in Northumberland, but as the base of the Melmerby Scar Limestone of S2 age is underlain in the Shap area by the Bampton Sandstone where it is last seen to the south of the Trias, it is pretty certain that the sandstone which emerges from under the Trias to the north is of the same relative age. This view is confirmed by the evidence afforded by the Tuedian beds in the west of Northumberland and in the neighbouring portion of Cumberland. These beds are characterised by numerous lamellibranchs and gasteropods, among which *Modiola macadami* may be specially mentioned; but in

addition, as already stated, near the top of the series, in many places, occur *Syringothyris cuspidata*, *Athyris glabristria*, and *Mitcheldeania gregaria*. Now in the Shap district the first-mentioned of these has never been found above the top of C₂ and the base of S₁, and the same is the case in the Cross Fell escarpment. It seems practically certain, therefore, that the Tuedian or Cement Stone beds up to the zone of *Mitcheldeania gregaria* are the equivalents of the Michelinia and underlying *Thysanophyllum* beds of the Arnside and Kendal district, and are also contemporaneous with the Shap Dolomites, all of which have been shown to represent stage C of the Bristol area in the South.* It follows, therefore, that the Fell Sandstones must represent, in a general way, the overlying Bampton and Orton Sandstones which form the northern continuation of the Ashfell Sandstone, and have been shown to be the equivalent of the S₁ stage of the Bristol area.† That this correlation is correct is proved by an interesting piece of evidence recently obtained by the writer from the beds of the same age in North-East Cumberland, just beyond the Northumberland border. Here the base of the Fell Sandstone contains a calcareous band crowded with the remains of *Camerophoria isorhyncha* and *Spiriferina laminosa*, together with the earliest examples of species of *Lithostrotion*. This association of forms is confined in Westmorland to the beds lying at the base of S₁, while *Camerophoria isorhyncha* is characteristic of this horizon. Immediately below the *Isorhyncha* beds in the same district occur beds containing *Michelinia megastoma* and many species characteristic of the upper portion of the C stage at Arnside and elsewhere, so that there can now be no possible doubt as to the general age of the Tuedian and Fell Sandstone groups of Northumberland. Thus we may correlate the Lower Carboniferous beds of Northumberland with those of Westmorland and with those of Bristol as follows:

	NORTHUMBERLAND.	SHAP AND MELMERBY.	BRISTOL.
CALCAREOUS DIVISION.	Dryburn or Great Limestone.	Yoredale Beds.	D ₃
	Lowdean or Four Fathom Limestone.		D ₂
	Acre or Six-yard Limestone.		
	Eelwell Limestone.	Upper Melmerby Scar Limestone.	D ₁
	Oxford Limestone.		
CARBONACEOUS DIVISION.	Woodend or Four Laws Limestone.	Lower Melmerby Scar Limestone.	S ₂
	Dun or Redesdale Limestone.		
	Scremerston or Plashetts and Lewisburn Coals.	Orton and Ashfell Sandstone.	S ₁
TUEDIAN.	Fell Sandstone.	Shap Dolomite.	C Z ₂ (?)
	Cement Stones and Lower Freestones.		

* See E. J. Garwood, *Geol. Mag.*, dec. 5, vol. iv (1907), p. 71.

† E. J. Garwood, *op. cit.*, p. 72.

UPPER CARBONIFEROUS.

The *Millstone Grit* consists of alternations of grits and shales having a maximum thickness towards the south of 500 feet. It forms a narrow strip of country running from the coast at Alnmouth to the Tyne valley near Bywell. South of this it spreads westwards as it comes under the influence of the general westerly trend of the rocks in the south of Northumberland, and is farther extended in that direction by the downthrow on the south side of the Stublick Dyke. In Durham it forms much of the high ground bordering Weardale and Teesdale to the west of Witton Wear and Pierce Bridge. In all this district, especially towards Alnmouth, it is by far the least important division of the Carboniferous rocks; as Prof. Lebour has often pointed out, the grits are scarcely in any way different from many of those which occur in the beds above and below, while the shales which intervene between the grits are absolutely identical with those of the overlying and underlying divisions, though whether fossils specially characteristic of this period will ultimately be found remains to be determined.

The *Coal Measures*, though interesting in themselves, cannot be fully described here, as most of our information has been derived from evidence obtained from colliery workings. Their western outcrop follows the edge of the strip of Millstone Grit described above, and runs from Warkworth to Ovingham on the Tyne, and thence in a general south-south-east direction to Witton Wear. South of this they extend westwards towards Eggleston to within about four miles of Middleton in Teesdale. Their eastern limit is formed by the sea-coast between Warkworth and South Shields. It then forms a zig-zag outcrop running nearly due south to Ferry Hill, whence it bends west and south to East Thickleigh. Outliers occur between Staindrop and Barnard Castle, and others to the south of the Tyne valley between Hexham and Haltwhistle, preserved on the downthrow side of the Stublick Dyke, as already mentioned. The total thickness of the beds is some 2,000 feet. The lower Coal Measures contain only two workable seams; the remaining seams over two and a half feet in thickness are some seventeen in number, and belong to the middle and upper Coal Measures. The more important seams are the *Brockwell*, at the base; the *Busty*, *Harvey*, *Hutton*, *Lew Main*, and the *High Main* near the top of the series, from which the famous Wallsend coal was formerly obtained in the south of Northumberland. The top of the Coal Measures is nowhere seen, as it was extensively denuded before the deposition of the overlying Permian rocks. The coal seams are usually underlain by fireclay and frequently divided, when traced from one portion of the coalfield to another, by "partings" of shales, rendering the correlation of the seams in the different colliery workings a matter

of some uncertainty. The coals are chiefly bituminous, though Cannel coal occurs locally in the upper part of some seams, but true anthracite is not found.* The invertebrate fauna of the Coal Measures is comparatively uninteresting, consisting chiefly of fresh or brackish-water lamellibranchs; these sometimes form mussel bands, often nearly entirely composed of *Carbonicola aquilina*, which are valuable for purposes of correlation. At least seven such bands occur at different horizons, those above the High Main and the Low Main being the most persistent.

Marine fossils, such as *Lingula*, are practically confined to the lower or Gannister series.

Through the exertions of the late Mr. Attney a very interesting series of fish and amphibian remains have been obtained, chiefly from the shale above the Low Main Seam, and these are now displayed in the Hancock Museum in Newcastle. The fish include teeth and spines of sharks of the genera *Diplodus*, *Pleurocanthus*, *Cladodus*, *Gyracanthus*, etc., while the Rays are represented by *Janassa* and the Dipnoi by *Ctenodus*. The tailed batrachians include the genera *Anthracosaurus*, *Pteroplax*, *Loxomma*, and *Urocordylas*. Although these divisions appear to have been accumulated during a period of quiet deposition, signs of contemporaneous erosion are not altogether wanting. In addition to the well-known "wash-outs" indicative of river erosion, traces of denudation on a larger scale sometimes occur. A very interesting case of this kind has recently been described by Professor Lebour and Dr. Smythe from the Northumberland coast near Whitley. Here a striking unconformity occurs, marked by rolled and weathered pebbles derived from the mussel band lying above the Low Main Seam. Analysis shows that these pebbles are poorer in phosphate and carbon dioxide and richer in ferric iron than the underlying mussel band from which they are assumed to be derived. The section is complicated by the effects of the powerful thrust already alluded to, which has developed along the plane of weakness produced by the unconformity (see page 664).

PERMIAN.

The *Permian* system occupies a large area in the east of Durham, where it is developed to its fullest extent in Britain. It forms the rocky and picturesque coast line from South Shields nearly to the mouth of the Tees, and is also present as a small but well-exposed outlier at Tynemouth, Cullercoats and Whitley in the south-east of Northumberland.†

The system is divided into three main divisions. At the base

* M. Walton Brown, "The Correlation of the Coal Seams of the Carboniferous Formation of the North of England," *Trans. N. Engl. Inst. Min. and Mech. Eng.*, vol. xxxvii, p. 3.

† E. J. Garwood in "A History of Northumberland," vol. viii, pp. 2-16, Plates I and II and Appendix 1.

are the yellow sands, an irregular false-bedded deposit of rounded sand grains, which is often absent and never more than 100 feet thick; it appears to be, in part, at all events, an æolian formation, and may represent old sand dune deposits fringing the subsiding margin of the old Permian Gulf. These beds have recently been fully described in an interesting paper by Prof. Lebour.* The sands are the chief water-bearing deposit in East Durham, and have given great trouble to colliery engineers in the construction of shafts to the underlying Coal Measures. They rest unconformably upon the denuded Coal Measures, and have yielded no organic remains, so that their Permian age is not absolutely proved. The thickness of Upper Coal Measure beds removed before their deposition is also unknown, though the knowledge recently acquired regarding the development of the successive floral zones in Upper Carboniferous times may some day throw light on this problem.

The succeeding beds of Marl Slate representing the Kupferschiefer of Germany are well seen at Cullercoats in Northumberland, and at Claxheugh, Midridge, and Ferry Hill in Durham. It nowhere exceeds 15 feet in thickness, but it is famous on account of its interesting flora and its fish fauna, which includes, besides the well-known species of *Palæoniscus* and *Platysomus*, examples of the forms *Dorypterus*, *Acentropus*, *Pygopterus*, *Acrolepis*, and *Crelacanthus*; amphibians of the genera *Lepidotosaurus*, and the first true reptiles found in Britain, represented by *Proterosaurus*, also occur. Among the plants, *Caulopteris* (*Ullmania*) *selaginoides* and species of *Neuropteris* are found.

The Magnesian Limestone which overlies the Marl Slate is 800 feet thick, and consists of three divisions, a lower compact limestone and basal conglomerate, a middle "shell" and "cellular" limestone, and an upper "botryoidal" limestone.† Though never a true dolomite so far as the bulk of the rock is concerned, it frequently contains a high percentage of magnesium carbonate. This mixture of the lime and magnesium carbonates has given rise to a unique series of concretionary structures, the lime in many of the beds having segregated out of the mixture of the two carbonates during the consolidation of the deposits to form a diversity of concretionary forms. These were first described by Sedgwick,‡ but we are still ignorant of the laws which govern the production of the varied and interesting forms which are so characteristic of the upper beds between Marsden and Sunderland. As Prof. Lebour remarks: "It is a theory accounting for the multifarious character of the concretions and the 'honeycombed,' 'coralloid,' 'oolitic,' 'botryoidal,' 'egg

* *Trans. Inst. Min. Eng.*, vol. xxiv (1902), p. 370.

† R. Howse, *Trans. Tyneside Nat. Field Club*, vol. iii (1858), p. 235.

‡ *Trans. Geol. Soc.*, Ser. 2, vol. iii, pt. 1 (1829), p. 37; see also E. J. Garwood, *Geol. Mag.*, dec. 3, vol. viii (1891), p. 433; and Dr. G. Abbot, *Report Brit. Assoc.*, (1900), p. 737; *Quart. Journ. Geol. Soc.*, vol. lix (1903), p. 51.

and cup,' and others infinitely varied, besides the spheroids, that is required, and this probably experiment only will in time provide." The recent interesting conclusions derived from the examination of coral rocks does not seem to help here, as both the lime and magnesia in the Durham beds appear to have existed in the original deposits.

The interesting brecciated beds so well exposed along the coast between Frenchman's Bay and Marsden are of various types. Besides the vertical pipes and V-shaped fissures filled with angular fragments, we have whole beds of brecciated rock occurring over considerable distances. The Breccia-gashes were first described by Prof. Lebour,* and the detailed structure of the brecciated beds has recently been studied by Dr. Woolacott,† who gives evidence to show that a general movement of the nature of a horizontal thrust has taken place in a direction between north-west and south-east. The fauna of the Magnesian Limestone is well known and need not be enumerated here; it contains invertebrate forms characteristic of the Zechstein of Germany, the bulk of which appear to be closely allied to Carboniferous forms. The majority of the fossils are found in the middle group of the limestone, and well-known fossil localities are Humbledon and Tunstall Hills near Sunderland, and Claxheugh on the river Wear. Well preserved specimens of *Schizodus*, *Pleurophorus*, and *Turbo* also occur, forming the nuclei of the concretions round which the carbonate of lime underwent segregation during the consolidation of the rock, while the shells appear to have been dissolved out of the porous matrix when they were not so protected. The fauna generally is considered to show dwarfed development under unfavourable conditions, due to the accumulation of the deposits in a shrunken inland gulf or "Caspian" Sea stretching eastwards into Germany, in which evaporation exceeded precipitation, conditions which were intermediate between those under which the marine Artinskian type was developed on the one hand, and the continental or Autunian type on the other.

The beds which succeed the Magnesian Limestone in South Durham, consisting of red sandstones and sandy clays, are about 1,000 ft. thick; by some authors the lower beds of this group, which contain layers of magnesian limestone, are classed as Permian, while the officers of the Geological Survey include the whole series in the Upper Trias.‡ The chief interest of the deposit consists in the valuable salt beds which it contains, one of which reaches a thickness of 100 feet. The strata were evidently deposited in a shrinking lagoon area where "Caspian" conditions prevailed, and are devoid of fossils.

* *Trans. N. Engl. Inst. Min. and Mech. Eng.*, vol. xxxiii (1884), p. 165; also *Geol. Mag.*, dec. 3, vol. ii (1885), p. 513.

† *Mem. Univ. of Durham Phil. Soc.*, No. 1 (1909).

‡ Sir A. Ramsay, *Quart. Journ. Geol. Soc.*, vol. xxvii (1871), p. 241; Prof. G. A. Lebour, in the Victoria "History of Durham" (Geology), p. 21.

POST-CARBONIFEROUS INTRUSIVE ROCKS.

The *Intrusive rocks* of post-Carboniferous age consist of the great basic sheet known as the *Whin Sill*, together with a series of basic Dykes of later date.

The *Great Whin Sill* is by far the finest example of a basic intrusive sheet in Britain, both on account of its extent and also on account of the contact metamorphism it produces. It traverses the Carboniferous rocks of Northumberland and Durham from the Farne Islands to the High Force in upper Teesdale, a distance of over 80 miles, and must underlie a considerable portion of South Northumberland and the greater part of Durham, an area estimated by Prof. Lebour at over 400 square miles. Its greatest development occurs at either end of its range, where it must in places exceed 100 or even 150 feet in thickness; elsewhere along its outcrop it dwindles to 20 feet, and is thinnest where it crops out along the western margin of the Pennine chain. On the whole, it follows the strike of the Lower Carboniferous rocks, into which it has been intruded, but it frequently shifts its horizon in that series. In Teesdale it lies near the local base of the Carboniferous series, but across Northumberland it shifts its horizon as much as 1,000 feet in short distances. (See Plate XX, Fig. 2.) Its outcrop can be followed in the accompanying map, where its general relation to the Eelwell Limestone is shown. In the north of Northumberland it forms the backbone of the Kyoee Hills, and stretching thence eastward by Bamburgh, rises from the sea to form the Farne Islands, the haunt of sea-birds and the chosen retreat of the old Northumbrian saint, to whose diligence in stringing rosaries the presence of crinoid plates on these basalt islets is attributed; where, as celebrated in local legend,

" St. Cuthbert sits and toils to frame
The sea-born beads that bear his name."

It forms the coast line for two miles between Dunstanburgh and Cullernose, where it underlies the Dryburn Limestone. When next seen north of Howick,* however, it has shifted its horizon to the Six-yard Limestone below. South of Alnwick it has descended considerably in the series, and cannot lie far above the Woodend or Four Laws Limestone near the base of the *Dibunophyllum*-zone. In the neighbourhood of Kirkwhelpington it occupies a considerable tract of ground, and has here divided into two parallel sheets, which again split into minor intrusions near Great Bavington.† The main outcrop runs thence through Great Swinburn to Broomlee Lough, crossing the North Tyne a mile to the west of Barrisford, and finally passes into Cumberland at Greenhead. In Durham it is only exposed in the upper Tees,

* See Plate XX, Fig. 1.

† Prof. Lebour, "Handbook, etc., of Northumberland and Durham," p. 95; also W. Topley and G. A. Lebour, *Quart. Journ. Geol. Soc.*, vol. xxxiii (1877), p. 405.

Photo by E. J. Garwood.

FIG. 1.—VIEW OF CULLERNOSE POINT, SHOWING THE COLUMNAR WHIN (W) INVADING AND CONTORTING THE CARBONIFEROUS GRITS AND LIMESTONE (C).

(Photo by E. J. Garwood.)

FIG. 2.—SNABLEAZES QUARRY, RATCHEUGH. SHOWING THE WHIN TRAVERSING FROM THE LIMESTONE ON TO THE OVERLYING SHALES.

where it forms the High Force and the columnar pillars of Cronkley Sear and Cauldron Snout just outside the county. It is met with, however, in various lead mines in Weardale, where it occurs in two layers, the upper intrusion being locally known as the Little Whin Sill.

The texture of the rock varies from place to place, being coarsest near the Yore Head and at Cauldron Snout, where crystals of augite an inch in length occur, while in places where it occurs as thin strings and veins it takes the form of tachylite. Usually it has the character of a mica diabase, but has been described from some exposures as an enstatite dolerite; it is noticeable, however, that olivine is typically absent. Where quartz is present it is intergrown with the felspar as micropegmatite. The rock has been fully described by Dr. Teall,* who points out its general resemblance to the Hett dyke in Durham and the High Green dykes in Central Northumberland.

For many years the intrusive character of the Whin Sill was disputed, and it was considered by such eminent geologists as John Phillips and William Hutton to be a contemporaneous lava flow.† Sedgwick, however, as long ago as the year 1824, favoured its intrusive character, which has been amply confirmed by Messrs. Topley and Lebour‡ in more recent times. Even up to the present day, as Prof. Lebour remarks: "Many miners still refuse to regard the Whin Sill as intrusive because of the supposed constant position (as they think) of the Tyne-bottom Limestone above it, arguing in a vicious circle thus: 'The Tyne-bottom Limestone is next above the Whin Sill at A, the limestone lying upon the Whin Sill at B or C must therefore be the Tyne-bottom Limestone also, and the Whin Sill has therefore not changed its horizon and is not intrusive.' An instructive example of bad logic and bad geology."§ In places on the coast of Northumberland, as at the Harkess rocks near Middleton,|| and between Dunstanburgh and Cullernose the rock is vesicular and amygdaloidal, but the same phenomena occur in many undoubtedly intrusive dykes. Mr. Clough is of opinion that in Teesdale, at all events, there is evidence of the assimilation by the Whin of the beds into which it has been intruded.¶ An examination of the chemical and microscopical characters of the Whin, however, does not bear out this theory, its composition being remarkably regular and the junction of the igneous and sedimentary rocks being microscopically sharp.

The alteration effected by the Whin at its junction with the sedimentary rocks affords a good illustration of the contact

* *Quart. Journ. Geol. Soc.*, vol. xi (1884), p. 640, and *Proc. Geol. Assoc.*, vol. ix, p. 575.

† "Geol. of Yorkshire" (1836), part ii, p. 78; *Trans. Nat. Hist. Soc. North. and Durh.* vol. ii (1832), p. 187.

‡ *Quart. Journ. Geol. Soc.*, vol. xxxiii (1877), p. 406.

§ G. A. Lebour, Victoria "History of Durham" (Geology), p. 6.

¶ See Garwood in "A History of Northumberland," vol. i, pp. 13 and 359.

¶¶ *Geol. Mag.*, dec. 2, vol. vii (1880), p. 433.

alteration produced by a basic intrusion. Specimens collected by the writer from the various beds in contact with the Whin throughout its length show that the greatest metamorphic effects occur, as might be expected, where the intrusion is thickest, namely, near Cullernose (Plate XX, Fig. 1) and in Upper Teesdale. The pure limestones have been altered to saccharine marble and the sandstones hardened to vitreous quartzites, the greatest alteration, as regards the production of new minerals, being found in the impure limestones and calcareous shales in which garnet, augite, idocrase, wollastonite, epidote, hornblende, felspar, chlorite and sphene occur. Microscopic sections were examined by Mr. W. M. Hutchings, who gives a full and careful description of the alteration produced in the different sedimentary rocks.* Many of the shales are crowded with secondary needles of rutile, while both garnet and idocrase sometimes contain small crystals of spinel. On the whole, the most interesting alteration products occur under Falcon Clints, where the metamorphism has extended to a bed of shale 75 feet below the Whin, in which pea-like bodies up to half an inch in diameter are developed.†

The exact geological period at which the Whin Sill was intruded is difficult to determine. It is not seen in contact with any formation newer than the Carboniferous, and we can therefore merely state, on direct evidence, that it was intruded in post-Carboniferous times. Two views appear to be held, one that the intrusion took place during the Permian, and the other that it occurred in Tertiary times. Although direct evidence is wanting, there are certain facts which appear to be suggestive in this connection and which point to the earlier of these dates as the probable period of intrusion. There is strong evidence of the inception of a monoclinal fold along the present axis of the Pennine chain in early Permian times, as shown, first by the marked discordance with which the Permian rocks rest on the various members of the Carboniferous series,‡ and secondly by the remarkable difference in the character of the Permian deposits on either side of the Pennine chain. In the second place, the thinning out of the Whin Sill to the west along the edge of the Pennine escarpment, where it approaches the Pennine fault, appears to the writer a very significant fact; thus between Cauldron Snout and High Cup Nick the sheet has diminished from over 100 to some 50 feet in thickness, and thence towards the Eden valley it is seen to be thinning rapidly at a rate which would cause its total disappearance before reaching the valley, and no trace of it has been recorded from the west side of the Pennine fault. That it was intruded previous to the rupture

* *Geol. Mag.*, dec. 4, vol. v (1898), pp. 69 and 123.

† *Geol. Mag.*, dec. 4, vol. ii (1895), p. 122.

‡ Thus they rest on the base of D1 at Kirkby Stephen, on the Millstone Grit near Appleby, and on the Coal Measures near Ingleton

which produced the present fault can hardly be disputed, but this fault is, we know, post-Triassic and probably post-Liassic, and may be, in part, of Tertiary age. The thinning out of the sheet as it approaches the present line of the fault, however, still requires to be accounted for. Such a thinning takes place along the whole face of the Pennine escarpment, and points clearly to some impediment to the continuation of the flow of the molten material towards the west. If we accept the suggestion that the Pennine fault originated in a monoclinical fold in Permian times, the presence of such a fold would account for the facts just alluded to and would point to the intrusion of the Whin Sill at this period; for the vertical limb of the fold now represented by the line of the Pennine fault would constitute a region of increased pressure, while to the east of it the arch of the fold would form an area of diminished pressure. The eastern area would therefore be in a condition favourable to the intrusion of molten material on account of the relief of pressure resulting from the formation of this anticlinal arch, while the western margin of the arch, forming the middle limb of the monocline, being an area of intense pressure, would effectually limit the intrusion to the east side of this line of pressure now indicated by the Pennine fault. One further piece of evidence in favour of the pre-Tertiary age of this intrusion may be mentioned, namely, the fact that the Whin Sill is cut by Tertiary dykes which traverse the two counties, among which may be mentioned the Cockfield—Armthwaite dyke which cuts across the Whin Sill in the neighbourhood of the High Force. It seems probable then that the intrusion took place in connection with movements in the Pennine area in Permian times.

Whin Dykes.—In addition to the Whin Sill, numerous basic dykes occur running in a general east and west direction. Many of these are almost certainly of Tertiary age; to others a post-Carboniferous, but pre-Permian age has been assigned by some writers, on the purely negative evidence that they are not seen cutting the Magnesian Limestone. Dr. Teall has suggested that one or two, namely, the Hett and High Green dykes, may be connected with the Great Whin Sill on account of their structural resemblance to that rock sheet. Prof. Lebour divides them into two series, one running east and west or south-east and north-west, the other north-east and south-west.*

Dr. Teall, who, in 1883, described in a classic paper the more important of these northern dykes, divides them into four series:†

1. (a) Cockfield, Cleveland and Armthwaite dyke.
- (b) Acklington dyke.

* "Handbook, etc., of Northumberland and Durham," p. 85.

† "Petrographical Notes on some North of England Dykes," *Quart. Journ. Geol. Soc.*, vol. xl (1884), p. 209., Plates XII and XIII. Also *Proc. Geol. Assoc.*, vol. ix (1886), p. 575, and "British Petrography." See also Sir A. Geikie, "Volcanoes."

2. The Hett and related dykes, including the "Sill" in the Brownly and Page-Bank Collieries.
3. (a) The Hebburn dyke.
       (b) The Tynemouth dyke.
       (c) The Brunton dyke.
       (d) The Seaton and Hartley dykes.
       (e) The Morpeth dyke.
4. The High Green dyke.

Dr. Teall remarks: "Groups 1 and 3 resemble each other in chemical composition and specific gravity; as also do groups 2 and 4." The former have about 56% and the latter 52% Si O₂. The Hett and High Green dykes are, to a great extent, holocrystalline, and may be classed as diabases and altered dolerites. The remainder are described by Dr. Teall as augite andesites.

The Cockfield—Armathwaite dyke, the Tynemouth dyke, and the Kielder Head dyke show prominent porphyritic felspar crystals, which are absent from the other dykes. One interesting point is the almost complete absence of olivine; with one exception, the dykes examined show either no trace of olivine or it is doubtfully represented by pseudomorphs. The exception is the Morpeth dyke, which, where it crosses the Wansbeck, contains typical fresh olivine as well as serpentine pseudomorphs. Space does not admit of a detailed description of these dykes, but one or two of their more interesting features may be mentioned.

The Cleveland—Cockfield—Armathwaite dyke is the longest dyke in England, extending as it does for a distance of 110 miles from near Maybeck, six miles south of Whitby, to the neighbourhood of Armathwaite in Cumberland, though shifted more than once by cross faults. Throughout its course it is characterised, according to Dr. Teall, by the same petrographical characters. In the Cleveland district it is intrusive in Lias and Oolite strata and alters the surrounding rocks. It varies in width from a few feet in some portions of its course to 300 yards at Bolam, where it spreads laterally in the form of a sill. At Cockfield an interesting section shows the dying out of the dyke upwards into the Coal Measure shales, which have been raised into a dome above it. It has been suggested that it is connected with the intrusion of the Great Whin Sill, but, as Dr. Teall points out, the microscopic evidence and its field relations are against this hypothesis. The rock is often spoken of in Teesdale as "Old Roger."*

Of the other Durham dykes, the Hett and Hebburn dykes are the most important. They differ in structure, the former resembling the Whin Sill while the latter agrees with the majority of the Northumberland dykes and also with the Cockfield dyke.

Although these three dykes, together with the Tynemouth

* G. A. Lebour, Victoria "History of Durham" (Geology), p. 23.

dyke, cross the Permian escarpment, they are nowhere seen cutting through the Magnesian Limestone.

Of the Northumberland dykes, the Tynemouth or Coley Hill dyke presents some of the most interesting structural features. The porphyritic felspar crystals are seen under the microscope to be composed of grains of anorthite surrounded by a peripheral zone which extinguishes at a different angle to the centre and forms the crystalline outline of the mineral. Amygdules are plentiful and present several interesting features. The vesicles are, as a rule, filled with a mixture of quartz and calcite, but frequently a portion of a vesicle is occupied by an opaque paste representing a portion of the ground mass.

Another noticeable feature is the arrangement of the lath-shaped felspar crystals tangential to the periphery of the vesicles, a feature shown also by the Hebburn dyke. These vesicles seem to have been formed by expansion of gas bubbles while the ground mass of the rock was still plastic, but subsequent to the formation of the lath-shaped felspars. After condensation or escape of the gas, a portion of the still plastic mother-liquor occupied a portion of the vesicle, while later still it was filled up by calcite and quartz introduced in solution.

The High Green dykes constitute a series of parallel intrusions in the neighbourhood of Elsdon, Otterburn, and High Green. They contain considerably more igneous matter than the Whin Sill itself,* and pass westwards into Scotland at Kershope Head and Kielder Head. The Elsdon dyke near Grassless Burn is over 300 feet wide. Portions of these dykes occur along fault lines. The southern High Green dyke is 250 feet thick in Cross Hill, and shows columnar jointing and spheroidal weathering, which is locally known as *Whin Sill*. As pointed out by Dr. Teall, the structure of these dykes closely resembles that of the Whin Sill. The Acklington dyke, which is conspicuously vesicular and amygdaloidal, stretches across Northumberland, starting from Bondicar on the coast, cutting the Cheviot andesites near Shillmoor, and extends westward into Scotland, where it is apparently connected with the series of Tertiary dykes. Dr. Teall also points out its close structural resemblance to the rock forming the Cleveland dyke.

With regard to the date of intrusion of these dykes, the evidence available does not admit of any exact statement beyond that they are post-Carboniferous. Of two, however, namely, the Cleveland and Acklington dykes, the age can be more definitely fixed. The Cleveland dyke, being intrusive in Lias and Oolite rocks, is pretty certainly of Tertiary age, since no igneous rocks of pre-Tertiary but post-Liassic age are known in Britain. The Acklington dyke, again, being continued into the Scottish series

* H. Miller, *Mem. Geol. Survey*, "Explanation of Sheet 8" (108, S.E.), p. 98.

of Tertiary dykes, most probably belongs to the group of Eocene or early Miocene intrusions.

With regard to the Cleveland—Cockfield—Armathwaite dyke as a whole, there is further evidence of its Eocene or early Miocene age. In the first place, it is later than the Whin Sill, since it cuts the latter in the district between High Force and Tyne Head. In the second place, it must have been intruded before the final period of faulting of the district, since its outcrop is shifted some nine miles to the north-west by the Burtreeford dyke from Ashdub to the bed of the Tyne near Pethersike Mine. As the earth movements which produced this large disturbance cannot be reasonably assigned to a date later than the Miocene, it follows that the Cleveland dyke as a whole cannot be later in date than Eocene or early Miocene.

GLACIAL DEPOSITS.

The Glacial deposits cover the greater part of Northumberland outside the Cheviot area. The only formations which stand up through this covering are hill ranges formed by Fell Sandstone and Whin Sill. In the north and north-east of the county the glacial deposits consist of (1) An Upper Clay, (2) Sands and Gravels, (3) A Lower Boulder-clay, and (4) Kames.

The *Upper Clay* is usually blue, but sometimes red, and is typically free from large boulders, but contains a few small rounded fragments of Cheviot andesite and Silurian greywacke. There is a large spread of this clay in the district to the south of the Tweed enclosing peat bogs. It occurs especially in the neighbourhood of the coast, and has been dug, for the manufacture of tiles, on account of its freedom from boulders. The Cheviot fragments and Silurian greywacke are found as far east as the Farne islands and as far south as the Yorkshire coast.

The *Sands and Gravels* appear always to lie below the Upper Clay, and may possibly represent an interglacial period. They are irregular in thickness and are often absent, in which case the Upper Clay rests directly on the *Lower Boulder-clay*. Even then the distinction between the two clays is usually very marked. A good section showing this difference is seen in the Birling quarry, near Warkworth.* Here the upper stoneless clay rests unconformably on the lower clay, which is full of boulders. The Upper Clay is prismatic, a feature characteristic of this deposit elsewhere in Northumberland. This vertical jointing is no doubt due to shrinkage after deposition, and points to accumulation in a very moist state.† This inference is borne out by the small size and rounded character of the pebbles it contains.

* See E. J. Garwood, "A History of Northumberland," vol. v, p. 12, and Plate.

† See E. J. Garwood, *op. cit.*, p. 13.

[Photo by E. F. Garwood.]

FIG. 1.—THE WHIN SILL AND THE ROMAN WALL.

[Photo by E. F. Garwood.]

FIG. 2.—CONTORTED CARBONIFEROUS SANDSTONE IN
BOULDER CLAY, TYNEMOUTH.

To face page 694.

The *Lower Boulder-clay* is much better developed in the western portion of the county than the Upper Clay. A boring near Wark shows a thickness of 102 feet, while south of Wooler the glacial deposits reach a thickness of 170 feet. The best section occurs on the bank of the Tyne below Tynemouth. Here, a few years ago, the view (Plate XXI, Fig. 2) was exposed which shows the surface of the underlying sandstone torn off and dragged westwards and folded into the Boulder-clay, indicating a movement from the east, which can only be attributed to the pressure produced by Scandinavian ice.

The *Kames* are chiefly found to the north and east of the Cheviots, and consist of false-bedded ridges of waterworn pebbles with occasionally scratched boulders. The latter, however, are decidedly rare. These Kames appear to be always the latest of the glacial deposits. They are often of considerable length, as, for instance, that at Wark, described by the Rev. P. Mearns;* others occur between Spindleston and Preston, while the Bradford Kame stretches for two miles.

These deposits are as a rule unfossiliferous, but in the north bank of the Tweed, opposite Yarrow Slacks, recent marine shells, with fragments of derived belemnites, were collected in the boulder-clay by W. Gunn, 75-90 feet above O.D. A good section showing the relation of these deposits is seen on Holy Island. This section was described by G. Tate in 1849. Referring to the clay, he remarks: "This deposit is separated into parts by singularly interposed stratified fine sands, in which layers of Carboniferous matter mark the lines of stratification; above the clay is a loose mass of gravel, and of smaller boulders embedded in sand; and above this, again, is a bed of clay without boulders."† The presence of layers made up of coal fragments, noted above, is not uncommon in the Sand and Gravel Deposits of Northumberland; in some cases they are very conspicuous. They seem to point to deposition under water, which allowed the lighter coal fragments to drift beyond the mineral sediment and form a regular deposit. Whether this deposition took place as a submarine or as a lacustrine deposit it is hard to say; the presence of marine shells mentioned above, at a height of 90 feet above O.D., shows that local submergence may have occurred.

With regard to the general direction of movement of the ice during the period of maximum glaciation represented by the Lower Boulder-clay, we have fairly satisfactory evidence. In the north of the county, to the south-west of Belford, the striae run south and south-south-east, though sometimes, as above Chillingham, we find two distinct sets of striae, one running south-west

* *Trans. Berwick Nat. Club*, vol. v (1865), p. 224.

† *Trans. Berwick Nat. Club*, vol. ii, p. 354.

and the other south-east. Near Bamburgh and on the Farne Islands the direction is south-east. In the Scremerston district, first described by Ramsay, both the striæ and the drumlins run 10° south of east, while farther west in the Tweed district the drumlins run due east and west. These drumlins are very common in the north of the county, and form conspicuous features on the one-inch map, the average direction east-north-east being that of the ice stream which came down the Tweed valley. Several of the Kames stand up over 100 feet above the surrounding country, while some reach a mile in length.

The transported blocks and boulders in the clay show that the summits of Cheviot, Hedgehope, and the neighbouring heights were never invaded by foreign ice, but formed a local centre from which the ice radiated, the rock fragments being carried or washed down in a general easterly direction. South of the Cheviots the movement was undoubtedly from the west. In the upper North Tyne valley boulders of Galloway and Criffel granite are common, together with Permian sandstone from East Cumberland and South-West Scotland; and according to Hugh Miller, also Lake District lavas, and Silurian rocks from Liddesdale. In Redesdale and Coquetdale two sets of striæ show that while ice flowed down the main valleys a general movement also took place at one period in an easterly direction, pointing to an incursion of ice from the west of Peel Fell into the Tyne valley. Near Rothbury the Simonside Hills are glaciated to their summits, showing that the ice here must have been at least 1,000 feet thick. In the Harbottle Hills, Darden Fell, etc., the striæ point a little north of east, while the hills on the south side of the Rede, north of Blakehope, show no signs of foreign ice.

In South Northumberland and South Durham the dominant factor was the Solway glacier, which, travelling eastward, split on the northern point of the Pennines, the northern portion flowing east down the Tyne valley, the other moving at first south up the Eden valley and then east over Stainmoor. The country east of the Pennines, between the Tyne and Stainmoor, gave rise to local glaciers flowing down their valleys, the South Tyne glacier being diverted to the east when it emerged from the shelter of the Pennines, while the lower portion of the Tees glacier was carried over into the Wear by the deflecting force of the Stainmoor ice. On the coast of Durham the ice flowed in a more southerly direction, and appears to have been at one time deflected more and more to the south and south-west by the Scandinavian ice. How far north this influence was felt it is difficult to say. No undoubted Scandinavian boulders occur north of the Tees, but the top layer of the glacial deposits at Tynemouth contains rounded pebbles of clear quartz and flint chips resembling those found in the Danish

(After H.M. Geological Survey Index Map, with Additions by E. J. Garwood.)

GEOLOGICAL MAP OF NORTHUMBERLAND.

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drift, and it is difficult to attribute to these any other than a continental origin.

Dr. A. R. Dwerryhouse has shown that numerous lakes were formed during the close of the glacial period in the southern tributaries of the Tyne by the south margin of the Tyne-Solway glacier, similar to those described by Prof. Kendall in the Cleveland district, while smaller tarns also appear to have existed in the tributary valleys of the Tees, as, for instance, Maize Beck.* Similar tarns appear to have been formed in the Cheviot area by glaciers sweeping round the south-eastern corner from the Tweed and the south-western portion of the district. (See P. F. Kendall and H. B. Muff, *Geol. Mag.*, 1901, p. 513.) With regard to the pre-glacial drainage of the district, Dr. Woolacott† has shown, by a study of the borings and sinkings made in the Northumberland Coalfield, that Northumberland and Durham stood at a higher level in pre-glacial times, and that the general drainage flowed east by means of the Tyne and Tees valleys. The greatest thickness of superficial deposits is 233 feet, and the greatest recorded depth of the valley floor below sea-level is 141 feet. As is well known, the Wear in pre-glacial times joined the Tyne through the lower part of the Team valley, the present course of the river below Durham not being developed till glacial and post-glacial times.

POST-GLACIAL.

The post-glacial deposits cannot be dealt with in detail here. They consist of the usual accumulations of *blown sand*, *alluvial deposits*, *peats*, and *raised beaches*. With regard to the latter, Dr. Woolacott‡ has recently added to our knowledge of those which occur on the Durham coast, and has come to the conclusion that a maximum elevation took place at Cleadon and Fulwell of 150 feet, while differential north and south movements giving a maximum gradient of 6 feet per mile occurred during elevation. Another interesting beach occurs on the Northumberland coast south of Cullernose, which rests on boulder clay, a few feet above sea-level.§

* A. R. Dwerryhouse, "The Glaciation of Teesdale, Weardale, and the Tyne Valley," *Quart. Journ. Geol. Soc.*, vol. lviii (1902), p. 572.

† "The Superficial Deposits and Pre-glacial Valleys of the Northumberland and Durham Coalfield," *Quart. Journ. Geol. Soc.*, vol. lxi (1905), p. 64.

‡ *Op. cit.*

§ E. J. Garwood, "A History of Northumberland," vol. ii, p. 336, and Plate, Appendix iv