here. A very remarkable group of the *Undulatæ*, which may be referred generally to the *T. producta* of Lycett,* but which also has affinities with *T. literata*, Y. & B., and with *T. V.-costata*, Lyc., is another proof how local are the forms of this genus—so abundant in the shallow waters of the Jurassic period—and how difficult it is to find names for them all.

At the village of Hook Norton the party began to separate, the major portion returning directly to Chipping Norton, whence, after a hurried dinner, most of them went back to London in the evening.

On the Lancashire Coal-Fields.

By C. E. De Rance, Esq., Assoc. Inst. C.E., F.G.S., of the Geological Survey of England and Wales.

(Read February 1st, 1878).

At the close of the Carboniferous period the British Isles, in common with the neighbouring parts of Europe, were subjected to great lateral pressure, acting in a general N. and S. direction, which produced considerable terrestrial movements in the earth's crust, causing the strata to be thrown into a series of flexures, ranging in a direction at right angles to that of the pressure exerted. In France, Belgium, the South of England, and in Yorkshire, the direction of the axes of these flexures is nearly E. and W.; in Lancashire, in the hills of the Pendle range E.N.E. (E. 35 N.).

One of the greatest of these rolls or anticlinal axes now traverses the Yoredale Rocks and Millstone Grit separating the Lancashire and Yorkshire Coal-fields from that of Durham. These anticlinal arches, more or less traversed by fissures, were readily attacked by denudation, and it is due to this cause that anticlinals are found along the lines of valleys, while synclinals occur in hills forming lines of strength. It was by this denudation, at the close of the Carboniferous Epoch, that so large an area of Coal Measures were swept away.

* Monograph of British *Trigoniæ*, in Pal. Soc., p. 60.

WEST FYLDE AND BOLLAND.

1. Clitheroe and Skipton Anticlinal. (Longridge Fell, Fell synclinal.)	Roach Bridge—Darwen—Ribble—To Bolton Abbey, 35 miles.
2. Slaidburn Anticlinal	Lond Valley—Chipping—Whitewell.
3. Sykes ,,	Fylde or Brack—Fells of Bowland.

Mountain Limestone.—The base is seen resting on Silurian Rocks in the valley of the Ribble north of Settle, near Malham Farm. At Clitheroe the Wotton beds are not brought to-day by the anticlinal, and the thickness without these is no less than 3,250 feet.

The limestones of the Forest of Pendle are of great value for their lime-producing qualities, both the lower black bituminous varieties and the upper grey beds, the former being the most desired when whiteness is an object, the whole of the colour being expelled by burning.

Shales with Limestone.—These series consist of an alternation of shales, thin limestone, cement stone, and thin ironstones, giving ries to springs containing sulphuretted hydrogen gas; one of these occurs at Clitheroe, and has a bath-house attached. The thickness of this series is not less than 3,225 feet.*

Lower Yoredale Grit.—This bed resembles the Gannister beds of the Coal Measures in appearance and hardness, is often absent, but when present it invariably forms the base of the Bowland Shales, so named by Professor Phillips, and plays an important part in the scenery of the Forest of Pendle, the steep slopes of which are all composed of the disintegrating shales of this age, reaching a maximum thickness of 700 feet. The commonest fossil is *Posidonomya Gibsoni;* Goniatites and Fish remains occur, as well as seams of ironstone, which give the shales an appearance of Coal Measure, which have led to many fruitless borings.

Upper Yoredale Grit is well seen in the quarries at Longridge Fell, near Preston, which are very extensive, the grit reaching a thickness of not less than 1,000 to 1,200 feet. Overlying

* To render this paper useful to those who may wish to traverse the district, I have largely quoted thicknesses and other details from the Memoirs of the Geological Survey, especially the work done by Mr. Tiddeman, and have also laid Mr. Binney's in the Transactions of the Manchester Geological Society, and Prof. Hull's papers in the Quarterly Journal of the Geological Society, under contribution.

the Upper Yoredale Grit, which contains impressions of plants, occurs a bed of shale 200 feet in thickness, on which rests the Kinderscout Grit, forming the base of the Millstone Grit series, which is divided into four great divisions by three thick beds of shale, and these beds are often again subdivided by interculated shales often of considerable thickness. These subdivisions, though useful for purposes of identification in Derbyshire, Lancashire, and South-Western Yorkshire, are local and mere divisions of convenience, the whole of the Millstone Grit, physically and biologically, forming one formation.

The Kinderscout or Fourth Grit is well seen in the mass of elevated moorland country raised by faults, between the Wigan and Burnley Coal-fields, especially at the western edge at Withnell Moor, where it has been bored into in a fruitless search for coal to a depth of nearly 1,000 feet, the Yoredale-shale being reached. The Grit here forms a peculiarly valuable building stone, which is largely quarried, underlying a conglomerate, formed of pebbles of white vein quartz. A fault traversing the quarry with an easterly down-throw, brings in the Yoredale-shale at the foot of the Fell to the west, which is cut off by a large fault, with a westerly down-throw, bringing in the Lower Coal Measures, containing workable coal-seams and fire-clays. The Kinderscout Grit, on the Moor above, contains numerous impressions of plants, chiefly *Stigmaria*, and some thin coal-seams, a few inches thick, testifying the proximity of land during the deposition of the strata.

The Sabden Valley Shales overlie the Kinderscout Grit, and in the country lying around the county boundary of Yorkshire and Lancashire, measured by Mr. Tiddeman, are 2,000 feet in thickness, and contain many wedge-shaped masses of Grit resembling the Kinderscout.

In the Ribble near Ribchester and at Roach Bridge, under the Permians of the Darwen, these shales contain ironstones with fossil *Goniatites*, *Posidonomya Gibsoni*, fish, and *Calamites*.

At Sales Wheel on the Ribble, thin limestones with Encrinites occur. Similar beds, with *Goniatites*, Encrinites and Brachiopoda, are described by Mr. Tiddeman on the top of the Kinderscout of Hole Brook, a tributary of the Darwen.

The Sabden shales at Shorebrook, lying below Noon Hill, east

of Rivington, contain numerous fossils, *Goniatites spiralis*, and two thin coal-seams.

The Third Grit overlying the shales is generally fine-grained, but occasionally forms a conglomerate, as at the fine cliff known as "the Ratchers," at Belmont, near Bolton. Sometimes the Grit is divided into two or more beds by thick shale, occasionally containing fossils, marine shells, and land plants.

The Shales lying at the base of the Haslingden Flags contain the "Brooks bottom," or Holcombe Brook series of Mr. Binney, containing two or three coal-seams associated with numerous plants, many of which occur in the shale overlying the Feather-edge Coal, and in the Lower Coal Measures, as do also the shells *Aviculopietee papyracea*, Sow, *Goniatites Listeri*, Mant., &c.

Beyrichia arcuata, Bean., *Spirorbis Carbonarius*, Murch., *Discina nitida*, Phill., also occur.

In the district south-east and east of Manchester, at Mottram, Brooksbottom, and Glossop, a coal from two to three feet in thickness occurs in this horizon, and is extensively worked under the name of the *Mottram* or *Simmondsly* Mine; everywhere that the seam is thick and valuable, the Feather-edge Coal, which should lie 60 to 70 yards above it, is either absent or very thin; whilst north of Rochdale, where the latter is thirty inches thick, and of good quality, the Mottram seam is valueless on Horwich Moor.

Haslingden Flags or Second Grit.—The shales lying between the first and third grit, over a considerable area, contain beds of fine grained micaceous flagstone and freestone, of great value for building purposes. On the surface of the flags annelide tracts, ripple marks, and rain drops may often be noticed, as well as carbonaceous partings.

The flags are generally divided by a thick bed of shale, the lower bed is largely quarried at Haslingden, the upper bed at Entwistle and Edgworth.

In the shale associated with these flags at Rivington, during the excavations connected with the Liverpool Waterworks, I noticed the black shales to be charged with fragmentary portions of *Calamites Suckowii*.

Rough Rock or First Grit.—The uppermost, or "first" bed of Grit is generally conglomeratic, hard, and coarse, but is sometimes

free from pebbles, and soft enough to be dug for sand; it is then, locally, called "Sand Rock," the thin coal occurring in it being termed the "Sand Rock Coal." Near Rochdale this coal-seam has a peculiar fracture, which has caused it to be named the "Feather-edge" coal,* the shales accompanying it yielded 18 species of fossils,† of which at least 9 (or 50 per cent.) occur in the overlying Lower Coal Measures. Of these 18 species, 13 are plants, and three shells of Marine Mollusca; amongst the former are *Calamites Suckowii*, *Pecopteris arborescens*, *Sigillaria hexagonia*, &c.; amongst the latter, *Aviculopecten papyracea*. Indications of this flora and fauna, with a few additional forms, occur at *three* intervals below this horizon, in the Millstone Grit Series:—(1) In a bed of shales in the second Grit; (2) in the bed of shales between the second and third Grits; and (3) in that between the third and fourth Grits. One can hardly resist the conclusion that a land-surface, on which these plants grew, must have existed throughout the whole of the Millstone Grit period, and down into the true Lower Coal Measures, and from which surface the plants migrated, as from time to time the shallow sea bottom, through the temporary stoppage of subsidence and subsequent deposit of sand, became land, more or less covered with freshwater, at the bottom of which, here and there, seams of coal from one inch to two feet in thickness were deposited.

The normal thickness of the Rough Rock is about 100 feet, but it often suddenly thickens, as from Blackburn to Hoghton Towers, where, as stated by Mr. Hull,‡ it expands from 100 to 450 feet in thickness. Supposing this expansion to have taken place at the base of the Rough Rock, or in other words, that it commenced to be formed in the area where it is thickest, before its deposition commenced where thinnest, it appears not improbable that the base of the Rough Rock where it reaches a maximum development may be synchronous with a portion of the Haslingden Flags, underlying the Rough

* Described by Mr. E. W. Binney, F.R.S., in "Trans. Geol. Soc. Man.," Vol. i.; by Professor Hull, F.R.S., in "Mem. Geol. Sur.," "Geology of Oldham," and in "Geology of Bolton-le-Moors."

† See List of Fossils by the late Mr. J. W. Salter, F.G.S., in "Memoir on Oldham."

‡ Mr. Hull "On Thickness of the Carboniferous Rocks of Pendle Range." Quart. Journ. Geol. Soc., p. 323. Professor E. Hull, F.R.S., gives the thickness of the Millstone Grit Series at Blackburn at 5,000 feet, at Burnley at 6,500 feet. Quart. Journ. Geol. Soc., August, 1868.

Rocks, where thinnest, especially as the Flags appear to be thin, or entirely absent, wherever the Rough Rock attains a maximum development. In fact, though the Millstone Grit as a *whole* maintains a general average thickness in any special area, its members in *detail* appear to be ever changing places in relative consequence with each other. Thinning out, intercalating, and wedging into one another, in a manner proving the shallowness of the sea, the existence of currents laden with different materials, and the proximity of land causing pebbles ever and anon to be rolled against the coast, which, when deposited, formed the conglomerates of the first and fourth Grits.

The Rough Rock is generally traversed by planes of current-bedding dipping W.S.W., and S.W., those found in the Kinderscout Grit also generally dip westward, proving that the currents, which caused the false bedding and brought the materials, in all probability, flowed from the east and north-east during the whole of the Millstone Grit period, or at least that part of it, when the land was below the sea-level. In many respects, there is a resemblance between the "Sands and Gravels," of the Glacial Middle Drift, and the Millstone Grits they so often overlie; there is the same species of alternation of fine sandy with coarse sandy beds, the same occasional presence of conglomerates in the one, and of shingle beds in the other, in fact both sand and shingle is often so consolidated in the Lancashire "Middle Drift," by the infiltration of water, charged with carbonate of lime and iron, as to resemble the Kinderscout Grit so closely, as to make it difficult to tell a hand specimen of the one from the other. And there is the same phenomenon of excessive current-bedding, but the dip of the false-bedding in the Drift is to the E.S.E., or exactly in the opposite direction to that in the Millstone Grit. Thus the easterly extension of the Middle Drift, is cut off by the Penine Chain, and it is doubtfully synchronous with any deposit, in the low country, on the opposite side of the ridge, while the currents, which brought the materials of the Millstone Grit westerly, passed over what is now the Pennine Chain, for then of course the "Anticlinal Fault" had not come into existence.

Above the Rough Rock occur the Lower Coal Measures, or Gannister beds, consisting of a series of micaceous sandstone, evenly bedded, rippled and embrooked, often resembling those of

the Lower Keuper Sandstone shales, and thin beds of coal, locally known as "Mountain Mines," from their generally occurring in hilly situations.

The following gives the general sequence, &c. :—

Billinge District.				Horwich District.		
	Arley Mine.					
	ft.	in.			ft.	in.
Middle Coal Measures ...	210			M. Coal M's. ...	858	
Lower Coal Measures Shales	850			L. Coal M's. ...	852	
Upper Mountain Mine...	2		=	40 *Yards Mine*	1	4
Fire Clay and Shales... ...	10					
Fire Clay Coal		10		Measures	114	
Shales and "bullions" ...	245					
Bullion Coal		8	=	*Upper Foot Mine.*		
Shales, Flags, &c.	46	1		Measures	36	
Gannister Coal	1	4	=	*Gannister Coal.*		
Measures	181	8		Measures	36	
5th Coal	1	3½	=	*Lower Foot Mine*	1	6
Measures	32.0					
Lower Mountain Mine	2.8	398		Lower Coal Measures	399	0
Lower Coal Measures	336.4					
Rough Rock	100			Rough Rock ...	126	1

From this table it will be seen that an accession of material occurs at the top of the Lower Coal Measures in the Horwich and Bolton section, the 210 feet of black shale, lying above the Upholland Flags of the Billinge column, being replaced by 858 feet of sandy flagstones, which in the district north of Heywood, occur underneath the Arley Mine itself, which forms the most natural base for the Middle Coal Measure series; a *physical break* is however sometimes seen between the black shales, and the underlying flagstones as the section near Bury, described by Professor Hull, where the Middle Coal Measures are unconformable, on the Lower Coal Measure, the latter having been distinctly denuded, the flagstone series having been reduced in thickness.

This physical break evidently represents a biological one; below it the Invertebrate fauna is characterised by the marine types *Goniatites*, *Aviculopecten* and *Lingula*, genera ranging upwards from the Mountain Limestone, and Yoredale Rocks, with many species in common, while in the Middle and Upper Coal Measures the majority of these species become extinct, and the Mollusca are confined to a few genera of bivalves resembling freshwater

mussels, with the one remarkable exception of the marine band discovered by Messrs. Green and Hull on the top of the Middle Coal Measures of Ashton Green.

The fossils were found in large concretions in shales, about 150 yards above the "Great Mine," of Ashton-under-Lyne, not the "great mine" which lies 33 yards above the *Black Mine*, the most valuable of the Oldham district, which occurs well down in the Middle Coal Measures.

Mr. Salter described the fauna of this band as comparable with that of the Shropshire Lower Coal Measures, yet wholly distinct, only one species occurring in common—*Aviculopecten papyraceus*, and this in a dwarfed condition, the usual Lower Cephalopod, *Goniatites* being replaced by *Nautili* and *Discites*. The *Nautilus præcox* of Salter has some affinities to Oolitic species. The most abundant shell was a new species of *Aviculopecten fibrillosus* of Salter.

To return to the Lower Coal Measures, it is worthy of note, that the shore-line conditions which brought about the conglomerates of the Millstone Grit, still existed at the time of the deposition of the "Woodhead Hill Rock," which occurs 70 or 80 feet above the base of the Lower Coal Measures, and forms the high ridges of Compton Moor, Bowstead, and Ogden Edges, and is a massive conglomerate, traversed by current bedding. This and the overlying Lower Coal Measures sandstones, as the Helpet Edge Rock, consist, like the Millstone Grit, of fragments of felspar, mica, and quartz, the detritus of granitic rocks. All these sandstones increase in thickness eastwards, and are more developed in Yorkshire than in Lancashire, and even west of the Pennine Chain, the change is very marked, thus the Helpet Edge Rock, between the 40 *yards Mine* and the *Bullion Mine*, is 130 feet in thickness, while at Billinge, west of Wigan, a few flags associated with 260 feet of shales alone represent the sandstone. In the latter section, overlying the Bullion Coal, occur 5 feet of black shales and bass, containing large nodules of argillaceous limestone, locally called "bullions," with *Goniatites* and *Aviculopecten*.

In the black shales forming the roof of most of the Mountain Mines, are generally *Anthracosia*, sometimes *Goniatites*, and more rarely *Aviculopecten*. The under-clay, especially of the *Gannister Coal*, is generally replaced by a peculiarly hard siliceous bed, locally

called "Gannister," full of roots of *Stigmaria*. In Horwich, west of Bolton, the Gannister is said to reach a thickness of no less than 35 feet, traversed by *Stigmaria*.

Beneath most of the coal-seams occur floors of white or grey soft unctuous clay, penetrated by roots and rootlets of *Stigmaria*, locally called "warrant," or "warren earth," above many of the coal-seams are trunks of *Sigillaria*, and *Lepidodendron*, especially above the Ince 4 feet coal, a fruitful source of accidents.

The Seven Feet or Rams Mine of Bolton and Clifton, is the equivalent of the Ince 7 feet coal, and at a short distance beneath it, occurred the erect fossil trees, discovered in the excavations for the Manchester and Bolton Railway, preserved by Mr. Hawkshaw, and now in the Owen's College Museum, Manchester, first described by Mr Bowman.*

The sections that have been drawn by the Geological Survey across the South Lancashire and Burnley Coal-fields and the surrounding tracts of older Carboniferous rocks well exhibit the series of flexures or foldings that the rocks of the Pendle Range have thrown by lateral pressure. These flexures traverse the country in a series of wave-like curves, the axes of which travel in an E.N.E. and W.S.W. direction, and form the Sykes, Slaidburn, and Clitheroe, and Rossendale Anticlinal of Messrs. Hull and Tiddeman.

The lines of geographical valleys range through the anticlines, as the valley of Sykes, Slaidburn, and Clitheroe, while the synclines occupy the fells and hills intervening.

The curve of the Rossendale Anticlinal, ranging through the ancient forest of that name and through Anglezark Moor, is low and gentle, and north and south of it lie respectively the Wigan and Burnley portion of the Lancashire Coal-field, which lie in basins, true synclinals of deposition, forming geographical valleys at the present time.

An examination of the thicknesses of the strata lying between the well-marked and well-known coal-seams of the Middle Coal Measures enables the relative rate of movement, as well as its position and duration, to be ascertained, which was the first expression of the continued subsidence that brought about those

* "Proceedings Geological Society," Vol. iii., p. 270.

flexures which separated the Lancashire Coal-field into distinct tracts.

With a view of endeavouring to ascertain what Lancashire coal-seams or groups of seams could be identified in the Flintshire Coal-field, I compared the various valuable sections published by the Geological Survey—those of Mr. Dickinson, in the "Transactions of the Manchester Geological Society," and others—and soon found that local thickening of measures evidently constantly took place, and considerable changes in the thickness and character of the seams themselves, but that the published sections were isolated as to be almost useless, as a means of discovering definite laws of thickening in a given direction, or for the identification of the thinner seams.

Towards this object I commenced collecting in 1868 the journals of all the sinking pits in the West Lancashire Coal-field I could obtain—which through the kindness of the Lancashire Colliery Managers, is now a very large number—and selecting ten of them, occurring as nearly as possible at equal distances from each other, along a line crossing the coal-field from S.W. to N.E., taking the Arley Mine—the lowest, but most valuable coal-seam of the Lancashire Coal-field as a geological datum—and plotting the section upward from it, Plate 61 of the Geological Survey, drawn by my colleague, Mr. Strahan, is the result.

For purposes of comparison, I have divided the Middle Coal Measures of the Wigan area into six groups :—

F.—*The Ince group;* from the Ince Yard coal to Pemberton 5 feet.

E.—*The Pemberton;* from the P. 5 feet to the Wigan 5 feet.

D.—*The Wigan;* from the W. 5 feet coal to the Wigan 9 feet.

C.—*The Cannel and King;* from the W. 9 feet to the Yard coal.

B.—*Bone coal group;* from the Yard coal to the Orrel 5 feet.

A.—*Orrel group;* from the Orrel 5 feet coal to the Orrel 4 feet at Arley Mine.

Commencing at the left hand, or S.W. end of the section, and following the groups towards the N.E., group A is seen to be

constant in thickness, the movement of subsidence that caused the lowering of the surfaces of plant-growth below the surface of the water to have been uniform in amount over a large area. A well marked horizon of fossil shells (*Anthracosia robusta*) at Wigan, which at St. Helen's is associated with a 6-inch coal, and the hard rag lying above this "cockle-shell bed," in the Wigan area is absent. At Pemberton the rag is of considerable thickness, and is known as the "Burr," or the "Scotchman."

Group B is thickest at St. Helen's (Column II.), the sediment between the Orrel 5 feet and the Whiston Main (or Roger-coal = Yard Mine) being at its maximum, and here we have the first indication of the special *axis of subsidence* which led to the formation of the Wigan basin, which axis gradually travelled north-eastwards in time until in the Ince Group A, it rested on Worthington north of Wigan. And it is especially worthy of note that the most remarkable phenomenon affecting any of the Wigan seams occurs at this very period, namely the local absence of the Pemberton 5 feet coal in special tracts, which I believe represent islands rising above the peaty tracts in which the coal was formed.

At Prestot the distance between the Arley Mine and the Ince Yard coal is 1,400 feet, while at Worthington, near Wigan, it reaches 2,200 feet; the Measures have thickened 50 feet per mile for each mile traversed through a horizontal distance of 16 miles, the thickening in the first four miles amounting to no less than 82 feet per mile, and 60 feet for the next five miles, the average of 50 feet being produced by the last six miles, only increasing at 20 feet per mile. At Burnley the Measures have thinned 64 feet per mile down to about 850 feet.

The researches of Bischoff, Graham, and Playfair as to the nature of the explosive gases evolved by coal, show that in addition to containing from 66 to 94 per cent. of light carburetted hydrogen, nitrogen is always present, and sometimes amounts to 14 to 21 per cent. of the entire volume, which can alone be explained by "supposing that air has permeated the fissures of the coal, and, acting upon it, has been robbed of its oxygen, partly by union with hydrogen, and partly with carbon." The presence of carbonic acid points out that the process of decomposition is still going on in the coal, and that woody fibre not only loses carburetted

hydrogen in passing into coal, but by a process of oxidation, carbonic acid and water also.

The large quantity of protoxide of iron (4·73), found by Dr. Frankland to occur in the under-clay of a coal-seam, has an important bearing on the origin of coal.

The extensive peat mosses of West Lancashire which fringe the margin of the land and dip beneath the sea, with prostrate forests at their base, exhibit clear evidence of the obstruction of drainage at a period immediately antecedent to their destruction—possibly as suggested by Mr. Binney, by a bank thrown up by the sea—which threw the country behind into a state of morass and bog, which would prevent free ingress of air to the soil, and consequently to the roots of the trees growing in it, which cut off their supply of oxygen, which forms the essential constituent of the sap, and exists in larger proportions in the spiral vessels than it does in air.

The fallen leaves and branches would be placed in a position favourable to decay, not merely by the mere action of the air, which would be to a great extent excluded, but the organic matter would act upon the peroxides of iron in the soil, and rob it of its oxygen. After all the iron in the soil was reduced to peroxide, a complete barrier to the entrance of oxygen to the living roots would exist, for all fresh oxygen absorbed by the soil would be appropriated by the lower oxide, which on elevation to the peroxide would again yield it to the dead organic matter.

The trees would then be no longer able to exist, surrounded by matter poisonous to vegetable life, and cut off from an essential element for their sustenance, whole forests would easily be destroyed. In Lancashire, the water appears to have risen some two or three feet up the trunks of the trees, along which line, between air and water, great decay has taken place, and the trees have been abruptly broken by some agency acting along this line, before the growth of the peat, sometimes reaching a thickness of 30 feet, with which they are overlaid. As most of the trunks lie in one direction parallel to each other, with their heads towards the E.N.E. or E.S.E., it would appear probable that they were violently snapped off by a westerly gale.

That some such sequence held good during the formation of the coal-seams of Carboniferous times, is supported by the fact that the

Underclays are so charged with protoxide of iron as to preclude any possibility of vegetable life; that notwithstanding this these Underclays are almost invariably traversed in all directions by *Stigmaria* and other roots of *Sigillarian* plants; that the trunks of *Sigillaria* and other tree-like plants are constantly broken across at a short distance from the original ground surface on which they grew, and have been surrounded, and often surmounted by layers of coal, which consists of finely macerated vegetable matter, and has been deposited in a stratified form, and is often overlaid by well-marked seams of the shells of *Anthracosia*, as well as by shales containing drifted ferns.

The preservation of the woody fibre would be due to the absence of air, while the subsequent decomposition under conditions of considerable pressure, and of tolerably high temperatures, would bring about the elimination of carburetted hydrogen, carbonic acid, and water, which form the "fire-damp," so much dreaded by the collier of to-day.

The laws affecting the thickness of the Measures of the Wigan and Burnley Coal-fields do not apply to that of the coal-seams, the aggregate thickness being in—

Column	I.—94·7	feet	in 19	seams,	15	being over 2 feet.
„	IV—84·7	„	35	„	13	„
„	VII.—79·5	„	27	„	15	„
„	X.—52·7	„	19	„	14	„

The researches of Messrs. Herschel and Lebour on the thermal conductivity of rocks, have shown that the lighter and more porous the rock the greater its resistance to heat; the more compact and crystalline, the less is its resistance, granite and grit being at one end of the scale, shale and coal at the other.

Laminated and cleaved rocks have been shown by M. E. Jannettaz to resist the transmission of heat in the direction of the cleavage planes, only half as great as across them.

The varied character of the rocks making up the Coal Measures, shales, sandstones, and coals, with different degrees of conductivity, varying in amount in the same rock in different directions, will well explain the fact that the rate of increase of underground temperature is not absolutely the same in collieries, not far distant from each other, for when the strata are inclined and a

numerous series crop out at the surface, heat is more rapidly transmitted than across the planes of the bedding of the same strata where they lay horizontal.

At Rose Bridge, the deepest colliery in England, the beds dip at a long angle some seven degrees, and are bounded by large and important faults, bringing beds of low conducting shale against the terminations of the strata, and the temperature is found to rise at no less than one degree for every 54·3 feet. The temperatures were taken with great care by Mr. Bryham, the manager, and have been published by Professor Hull—that of the solid rock, at the Arley Mine, at a depth of 808 yards being 93½°F., the total depth of the Colliery being 815 yards, or 2,445 feet.

The largest of these shafts at Rose Bridge is 16 feet in diameter, and is what is called in Lancashire a "Furnace Pit," the ventilation being effected by three furnaces, all of which return into the Arley Pit, and set in motion no less than 250,000 cubic feet of air per minute, consuming five tons of coal per day. The heat in the shaft is very great, and in passing the furnace one's hand intuitively leaves go of the cage rails to screen the face, and the knowledge that were the cage to be arrested in its upward movement, that the heat is more than 200°F. adds to the excitement of travelling through vertical space at the rate of nearly a mile a minute.

The system of ventilation by furnaces is replaced in the newer Lancashire collieries by "Guibal Fans" of large size, especially those at Abram and Pemberton Collieries.

At Garswood Hall Colliery, at Bryn, the gas is piped off from this coal, and taken up to the deck of the colliery stage, burns continually, and may be seen for many miles, the length and strength of the flame increasing, when the barometer is low, pressure released, and a larger quantity of gas enabled to escape. How large an influence barometric pressure has upon the escape of fire-damp is shown by the observations of Messrs. Scott and Galloway, which show that 48 per cent. of the colliery accidents of this country are due to this cause, generally occurring in the break after a long calm, and sometimes not until two days after the minimum is reached.

The structure of coal differs not only in different beds, but in different parts of the same bed, the variation being partly due to the nature of the different plants of which the coal is composed,

and partly to the degree of subsequent metamorphism that the coal has undergone.

Some coals, like the "Better bed" of Bradford, described by Professor Huxley, are entirely made up of Sporangia imbedded in their shed microspores; these sporangia have also been detected in some of the Wigan coals. In nearly all of these, vegetable organic tissue is visible under the microscope, some showing punctated woody tissue indicating the presence of conifers, and others exhibiting the scalariform tissue due to the Ferns and such plants as the *Sigillaria* and *Lepidodendron*. In the Wigan Cannel Coal vegetable structure is seen throughout the whole mass, which is the case with other cannel and gas coals. The exact causes which produce the peculiar condition known as Cannel Coal is still unknown, scales of fish, *Megalichthys* and *Rhizodus*, occur, and in the roof, fish remains are very common, as they are also in that of the Arley Mine.

The Wigan Cannel Coal was used early in the seventeenth century. Camden, speaking of its discovery at Haigh, near Wigan, states "that this neighbourhood abounds with that fine species of coal called *can* or *candle*. It is curious and valuable, and, besides yielding a clear flame when burnt, and therefore used by the poor as candles, is wrought into candlesticks, plates, boxes, etc., and takes a fine polish like black marble."

The method in which the various seams of coal, with their alternating beds of shale and sandstone, have been produced, is well exemplified in many sections in the Lancashire peat mosses, where trunks of large trees may be seen at the base of the peat, with their roots ramifying into the grey clays beneath, while other grey clays and sandy bands intersect the peat, and divide it up into distinct portions, just as the so-called dirt-bands traversing the coal are constantly observed to do. The amount of carbonaceous matter required to form a bed of coal is immense; Maclaren has calculated that one acre of coal three feet thick is equal to the produce of 1,940 acres of forest.

Sir Charles Lyell believed "that the plants which produced coal were not drifted from a distance, but nearly all of them grew on the spot, where they became fossil. They constituted the vegetation of low regions, chiefly the deltas of large rivers, slightly elevated above the level of the sea, and liable to be submerged beneath the waters of an estuary or sea by the subsidence

of the ground to the amount of a few feet. That the areas where the Carboniferous deposits accumulated were low, is proved not only by the occasional association of marine remains, but by the enormous thickness of strata of shale and sandstone to which the seams of coal are subordinate."

In Lancashire, the Upper, Middle, and Lower Coal Measures have a united maximum thickness of 8,000 feet, or more than a mile and a-half, exclusive of the underlying Millstone Grit. Such a thickness implies a constant flow of water carrying detritus from large islands, or continents to a given area through indefinitely long periods. The presence of so large a number of ferns would indicate a climate similar to that of New Zealand at the present day, and, as Mr. Bunbury has pointed out, the peculiarity of the Carboniferous climate consisted more in the equable temperature preserved in the different seasons of the year than in its tropical heat.

The object of this Paper is chiefly to describe the general character of the West Lancashire Coal-field, but it may perhaps be unadvisable to omit all reference to the Manchester Coal-field, an isolated tract of Upper Carboniferous rocks surrounded on all sides by those of Triassic and Permian age, and occupying an area of four square miles, the general section being :—

	FEET.
Limestone series	600
From the Limestone to the *Openshaw coal* .	600
From the *Openshaw coal* to the *Yard coal* .	485

Below these strata lie some nearly 2,000 feet of barren ground, separating this field from that of Lancashire, consisting of reddish sandstones and shales.

At Bradford and Clayton, the "*Four Feet Mine*" occurs 108 feet above the Yard Mine, and perhaps may be taken as the base of the Upper Coal Measures, as it is believed to be the equivalent of the *Worsley* and *Pendleton Four Feet*.

In the Limestone series of Ardwick, the calcareous members of the Carboniferous are more fully developed than elsewhere in Britain, six beds occurring with an aggregate thickness of 15 feet of limestone, the lowest and thickest being six feet; the next above, a black-band ironstone, with *Anthrocomyn* of six inches.

The limestones contain *Spirorbis carbonarius* and fish remains, as *Ctenodus*.

At Patricroft, west of Manchester, the Upper Coal Measures have been penetrated in a colliery shaft, which passes through the Permian marls and sandstones, resting unconformably on 10 feet of Coal Measure shales, lying on two feet of calcareous hematite, forming a valuable iron-ore, containing 22 to 26 per cent. of metal with 40 per cent. of carbonate of lime, the iron varying from a carbonate to a peroxide. It occurs at 44 yards and 396 yards above the Worsley Four Feet seam, which has been sunk to in this shaft.

To sum up the sequence of events in West Lancashire, it appears probable that the Coal-fields of Wigan and Burnley were deposited in basins of subsidence, and lie in contemporaneous synclinals, the axis of subsidence in the western area coming first into existence at Preston and St. Helen's, and gradually travelled to the north eastwards in time, until it rested on Worthington, near Wigan.

That notwithstanding the enormous thickness of the Yoredale Series, Millstone Grit, and Coal Measures up to the base of the Arley Mine, were formed in a sea of no great depth, in which from time to time the sea bottom was either elevated so as to become a land surface, or else these barriers of sand or mud, at the entrance of inlets kept the sea out, while plant-growths came into existence on the higher grounds.

The sea not attaining any great depth, and the amount of deposition keeping pace with the rate of subsidence, the same depth was maintained, and the same marine organisms were able to exist throughout the whole period.

At the base of the Middle Coal Measures, a change takes place. Some erosion of previously formed beds occurred, the pauses in subsidence appear to have lasted longer, and occurred oftener, plant growth succeeding plant growth; thicker coal-seams were the result, freshwater conditions were more prevalent, though it is probable that the fish occurring were like the salmon, capable of living in sea water as well as fresh, and though the same species of fish are found in successive horizons, probably of freshwater origin, it is possible that the fish lived on in some outer area of salt water during the entire interval.

The Wigan cannel, occurring as it does at its maximum thickness precisely at the point where the subsidence was greatest, the nodal point of the curve of subsidence, formed as the researches of Mr. Binney have shown, of excessively comminuted vegetable matter, spores of Lycopodiaceous plants being common in it, and large fish-scales often occur in it, which would point to tranquil deposition of vegetable matter, which had long been macerated and submerged.

The deposition of the Coal Measures and formation of the coal-seams were followed by continued subsidence, which caused the Carboniferous rocks to be rolled into a series of flexures, the crests of which were denuded before the deposition of the Permian rocks, which rest upon the eroded edges of Upper, Middle, and Lower Coal Measures, various Millstone Grits, and the Yoredale-beds.

After the Permian era, a series of lines of faults ranging N. and S., followed by a still later one along N.N. Westerly lines.

Mr. Wilson's researches render it tolerably certain that subsidence of a curved surface inevitably results in the contortion of strata, while faults are its cracks, the result of the re-elevation of that curved surface.

The subsidence that brought about the E.N.E. synclinals of the Lancashire and Yorkshire district, the anticlinals of the Mendips and the Ardennes, was followed by an elevation at the close of the Permian Epoch, which brought about the Pennine anticlinal.