The Physiography of the Coal-Swamps.[1]

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THE subject of Coal Measures geology has been discussed piecemeal in innumerable papers and memoirs, so that an inquirer may well be appalled at the mass of facts and of often conflicting deductions with which he is confronted. Indeed, it is surprising to discover how fundamental are some differences of opinion which exist.

Among the questions in the answer to which doctors have differed there is, I imagine, none more fundamental than this:

Were coal seams simple aggregations of plant remains swept together by the action of water—a process of accumulation which the learned call allochthony; more simply by drift; or were they formed, like peat, by the growth of vegetable material in its place—the process of autochthony?

I do not intend to labour the answer to this question. Categorical arguments in favour of the growth in place origin of the coal-forming vegetation are on record, and they have never been as categorically answered. Many arguments in favour of the drift theory seem to me clearly to have arisen from confusion between cannel and true coal. This distinction is again fundamental. True coal-seams are characterised by:—

(1) Wide extent.
(2) Uniformity of thickness and character over extensive areas.
(3) Freedom from intermingled detrital mineral matter.
(4) Constant presence of a seat-earth or rootlet bed.
(5) Entire absence of remains of aquatic animals within the seam.

Substitute affirmatives for negatives, and negatives for affirmatives, and the characteristics of cannel are as truly set forth.

THE ABERRATIONS OF COAL-SEAMS.

Having got our coal-swamp clothed with vegetation, and the coal-forming materials accumulating, let us next consider the various interruptions of continuity and the aberrations to which it is liable. These interferences may be either contemporaneous with the accumulation of the materials, or, as one may say, posthumous.

Prominent in the category of contemporary interferences must be put the phenomena of split-seams. A split-seam is the intercalation into the midst of the coal of a wedge of sandstone, shale, or the like, in such wise that the seam becomes subdivided by intervening strata into two or more seams. The most notable split-seam in Britain is the famous Staffordshire Thick Coal. Jukes showed that this magnificent seam, 40 feet thick at its maximum, is split up into a number of minor seams by wedges of sedimentary strata which aggregate, in a distance of 4½ miles, a thickness of 500 feet. The explanation offered by that sagacious student of coal, Bowman of Manchester, might find here a typical application. Bowman supposed that a local sag occurred in the floor of the coal-swamp, resulting in the drowning of the vegetation and interrupting the formation of peat until the hollow was silted up and a new swamp flora re-established.

I now turn to a form of split-seam of extraordinary interest, which has received comparatively little attention from geologists though mining engineers must surely have a special comminatory formula to express their sentiments thereon. The first example that came under my notice was encountered in the eastern workings of the Middleton Main Seam, at Whitwood Colliery, near Wakefield. Thin intercalations of shale and other sedimentary materials, appearing at different horizons in the seam, were found to thicken gradually to the east concurrently with the gradual dwindling of the lower part of the seam. An exploration was then carried out. The bottom coal was followed, but it was found that though the underclay continued the coal disappeared, and was wholly lost for a short distance before it reappeared. The top coal rose over a steadily thickening shale parting, and disappeared into the roof of the workings, but boreholes proved that it was present above a parting which was, at the maximum, 29 feet thick. At the farther end of the heading the top coal came down and the integrity of the seam was restored. Two other transverse explorations have proved the same general arrangement on the same scale of magnitude and one or both margins have been traced for a long distance, enabling the interruption to be mapped continuously for about 8 or 9 miles and intermittently much further.

My first impression was that this was just a simple case of Bowman's "sag," until I observed that in every traverse the *upper element of the seam was arched while the floor was flat.*

Several analogous cases came under my notice before an explanation of this anomalous arching was reached. The explanation was found to lie essentially in the differential shrinkage undergone by peat-stuff in the process of forming coal, and, on the other hand, by any sand or mud which may have been deposited so as to replace a part of the peat.

Let us imagine a stream being diverted at flood time across a bed of peat and scooping out for itself a hollow channel which subsequently becomes filled with sediments, and afterwards the formation of peat continues, the peat plants creep out, and presently envelop the whole mass of sediments. When the beds consolidate there will obviously be very different contraction between the sands, muds, and the coal-stuff. The sands will scarcely contract at all, the muds will contract a good deal, the coal-stuff will contract very greatly.

Let us now return to the consideration of the plano-convex lens of "dirt" occupying a position between the upper and lower elements of the split-seam at Whitwood. On the sag explanation it should be convex downward, yet in this as in all other cases I have investigated, it is convex upward. The explanation is simple. Let us make our mental picture of the infilled channel in the peat a little more specific in detail. Let us suppose that the peat was 40 feet in thickness when the river commenced to cut its

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course across it; the channel we will say was, like most channels, deeper in the middle than at the sides, and in the middle actually cut through to the seat-earth. Then the channel silted up completely, so that a cast of its meandering course in sands or mud reaching 40 feet in thickness at the maximum, but much thinner at the margins, was formed; then the upper bed of peat formed to a further depth of 40 feet. The conversion of the peat into coal would reduce it to two beds, each, let us say, 2 feet in thickness at the maximum, enclosing the sediment with a proportionately smaller thickness in the eroded peat on either margin of the channel. The sedimentary mass would have the transverse section of a plano-convex lens, the convexity being downward, but when the peat under the edges of the sediment is condensed to one-twentieth of its original bulk the base becomes almost flat, and the unconsolidated mass of sediments adjusts itself thereto. Thus the curve, originally at the base of the mass, reproduces itself in the top of the mass, which was originally quite flat and now is curved. The lens of infilling has reversed its curvature.

When a seam is deeply eroded the only too familiar phenomenon of a "wash-out" is formed.

The most common abnormality is the occurrence of belts or patches of "proud coal" in which the seam swells up to twice or thrice its normal thickness—sometimes, though not always, by repetition of the whole seam or of the upper part, either by shearing or by overfolding.

It has been suggested that all the violent displacement and over-ridings are brought about by tectonic agency, and that they are thrust-planes. The localisation to a single stratigraphical plane should suffice to discredit this explanation. An amplification of the same explanation ascribes the displacements to a thrust with a movement from S.E. to N.W. and a common cause to the cleat or cleavage of the coal which is normally directed to the N.W. It suffices to refute this to remark that the wash-outs I have explored in the Yorkshire coalfield are aligned in four principal directions, so that if superposed they would give what may be called the Union Jack pattern, *i.e.* N.E.—S.W., N.W.—S.E., N.—S., and E.—W.

Moreover, if these so-called "wash-outs" are not due to the erosive effects of contemporaneous or sub-contemporaneous streams, but to flat-hading faults, any coal displaced should be presently found again without any loss whatever. That swellings and duplications of the seam occur we have already noticed, and such phenomena have been pointed to as evidence that there is "no loss" of coal in connexion with the so-called wash-outs. But losses and the gains by duplication do not, in fact, balance. A simple and convincing case is a wash-out in a thin seam, in which, by taking measurements of the thickness of coal present and the breadth of the barren area, I have been able to show that a gap with no coal for 210 feet is compensated for by only 35 feet of excess on the margin.

SEISMIC PHENOMENA IN THE SEAMS.

While the displacements and duplications are totally unlike those produced by faults, there are cases in which the seam appears to have been subjected to a stretching tension and to have broken under the strain. Along the zone of such a stretch great confusion is commonly found. Masses of sedimentary materials, of the coal seam, and slabs and seams of cannel commonly occur, besides a curious argillaceous substance unlike any natural rock with which I am acquainted. In its unstratified structurelessness it suggests a kind of consolidated sludge such as might be produced by violently stirring or shaking a quantity of not too liquid mud. Where the seam abuts against this stuff it presents usually a nearly vertical ragged edge, its bright and dull layers preserving their characteristics quite up to the contact.

The explanation I have offered is that all these disturbances which complicate the already complex features of wash-outs are the effect of the lurching of the soft alluvial materials by earthquake agency. Every predicable subterranean consequence of earthquake action upon unconsolidated alluvial deposits, such as the Coal Measures were, can be seen in the Yorkshire Coalfield. The lurchings, the rolling and heaving of sand-beds, the shaking to pulp of the muddy deposits, the rending and heaving of the peat, cracks in the peat, and cracks infilled with extraneous material passing through the strata; and lastly, though actually the first clue to the explanation, masses of sandstone in the form of inverted cones ("dog's-teeth," "paps," or "drops"), descending on to coal-seams, which I interpret as the deep-seated expression of the sand-blows that are the invariable accompaniments of earthquakes in alluvial tracts.

An earthquake sweeping across an alluvial plain beneath which lay a thick bed of water-charged peat overlain by laminated clay, and that in turn by sand and an upper layer of mud or clay, would throw the peat and its watery contents into a state of severe compression which would result in the bursting of the immediate cover of clay and the injection of water into the sand, and, probably, a large quantity of gas, converting it thus into quicksand. This in turn would eject water in the form of fountains through the upper muddy or silty stratum, producing sand-blows and craters on the surface. When the disturbance subsided sand would run back down the orifice into the funnel above the peat. These are the "drops." They are commonly flanged down the sides, showing that they were formed upon a line of crack. An earthquake not infrequently gives rise to permanent deformations of soft deposits either by the lurching of the surface and the production of permanent wrinkles, or by subterranean migration of quicksand so as to produce, here a sag or hollow, there a ridge or bombement. Mr. Myron Fuller's admirable account of the effects of the New Madrid earthquake of 1816 as observed one hundred years after the event, is full of the most interesting and suggestive observations, not the least so those upon the sand-blows and sand-filled fissures containing lignite—the sand having come up from a bed lying at a depth of not less than 80 feet—the elevated tracts, and the new lakes produced by subsidence.

THE "CLEAT" OR "SLYNES" OF COAL.

One feature of coal-seams I must discuss before I conclude, though it will not at first appear clear that it can be brought within the title of this address —I allude to the cleavage or cleat or slynes of coal. If we look at a piece of coal this cleavage is very conspicuous, for, lying at right angles with the bedding, it gives the straight sides to the fragment. It is obviously not like the cleavage of slate, *a texture*, but it is a series of well-developed joints.

It is a vital element in the cleat problem that it is as well developed and as definite in direction in a flake of bright coal the $\frac{1}{100}$th of an inch in thickness as in a tree-trunk. While I was preparing this address I procured a slab of shale from the bed underlying the uppermost bed of the Millstone Grit. It bore numerous imprints of goniatites and a leaf of Cordaites, which, in its present condition of bright coal, varies in thickness from about $\frac{1}{50}$th down to $\frac{1}{150}$th of an inch in thickness. It is traversed by an even and regular cleat at intervals of about $\frac{1}{100}$th of an inch, disposed at an angle of about 35° to the length of the leaf. With great care it was possible to replace the slab in its original position and to determine the orientation of the cleat to be N.W.-S.E. This is not nearly the extreme of tenuity reached by well-cleated plant remains. I have specimens that are mere shiny films, and cannot, I should judge, exceed $\frac{1}{500}$th of an inch, yet they show well-defined and regular cleat. Further, it should be noted that the production of cleat was subsequent to the erosion of stream channels as well as to the production of phenomena on the margins of the wash-outs. Every pebble and flake of coal found in the displaced masses in these stream-casts has the cleat well developed, and in strict parallelism with the cleat of the adjacent undisturbed seam.

I have directed attention to the fact that cleat is quite independent of the joints traversing the shales and sandstones of the associated measures; whence I draw the inference that the cleat must have been produced prior to the jointing.

The reason for this early development of a joint system is easily found—the original peat, in passing into lignite, acquired a brittle consistency and a consequent disposition to joint. Indeed, the change of consistency is the effect of chemical change and loss, whereby the peat substance contracts. Hence when our Coal Measures were first laid down they would consist of a series of incoherent sands and muds, and this uncompacted condition may have persisted for a very long period, even surviving considerable tectonic disturbances. The peats, however, would be subject to changes entirely innate: the gradual loss of volatile constituents, or at least the resolution of the carbon compounds into new groupings and the conversion of the mother substance of the coal into lignite. In this condition the coal-substance would be brittle and liable to joint in response to the tensile strains set up by the contractility of the mass.

There are questions of very deep import concerned with the geographical direction of the cleat. The first reference to this interesting topic is, I believe, in a work, close upon a century old, by Edward Mammatt, entitled "Geological Facts to elucidate the Ashby-de-la-Zouch Coalfield," published in 1834. His fourth chapter, headed "On the polarity of the strata and the general law of their arrangement," contains these remarkable passages: "Polarity of the strata is a subject which hitherto has not been much considered. The extraordinary uniformity in the direction of the slynes and of the partings of the rocky strata seems to have been determined by the operation of some law not yet understood. . . . . Wherever these slynes appear, their direction is 23° West of North by the compass, whatever way the stratum may incline. The coal between them has an arrangement of lines all parallel to the slynes, by which it may be divided. This is called the *end* of the coal."

In a paper in the *Geological Magazine* I commented on the fact that little had been written on the subject of cleat since Jukes's "Manual of Geology" (1862), in which he quotes a Nottinghamshire miner's remark that the slyne faced "two o'clock sun, like as it does all over the world, as ever I heered on," a generalisation to be remembered.

John Phillips corroborates the statement so far as concerns the coalfields of Northumberland and Durham, where he says it "runs most generally to the northwest (true)." The same direction, he says, prevails in Yorkshire and Derbyshire and also in Lancashire.

I have suggested a reason why coal should acquire a joint system anterior to, and independent of, that of the associated measures, but, while providing a jointing-force, that theory furnishes no explanation of the directional tendency of the cleat. This tendency must have been supplied by some directive strain —not necessarily of great intensity, but continuous in its operation.

In 1914 and since I have collected a great body of data regarding the direction of the cleat in coals and lignites in many parts of the world.

Cleat observations in the Northern Hemisphere show an overwhelming preponderance of a N.W.-S.E. direction in coals and lignites of all ages from Carboniferous to Pleistocene and from regions so remote as Alaska, Spitsbergen, the Oxus, Nigeria, and China. This direction persists through every variety of tectonic relations, but seems most regular in the largest and least disturbed fields.

Jukes's miner's astonishing statement that "the slyne faces two o'clock sun . . . all over the world" involves more than is at first glance apparent, for, as a friend has pointed out, that two o'clock sun must shine from a quite different compass-bearing in the Northern and Southern Hemispheres. Yet the data I have collected confirms generally the miner's declaration in the Southern Hemisphere as well as the North, though exceptions occur that may possess a deep significance.

Many of the southern coals have no definite cleat, but in such as do display a regular system there is a distinct predominance of the N.E.-S.W. direction, which has a curious inverse relationship with the N.W.-S.E. direction of the Northern Hemisphere.

I feel persuaded that the cause will be found in some relation to influences, tidal or other, dependent upon the earth's planetary rôle.

There is a negative aspect of the cleat question which brings it more clearly within the ambit of an inquiry into the physiography of the coal-swamps. I allude to the absence of cleat that characterises anthracite the world over. Upon this absence of cleat are attendant features that have been regarded as indicative of conditions prevailing during the formation of the coal, and hence clearly within my terms of reference.

In the Memoir of the Geological Survey on the Coals of South Wales, it is pointed out that the anthracite condition, instead of being accompanied by a high ash-content—which is what might be expected if the ash ratio were determined simply by the reduction in the non-ash—is shown statistically to bear the reverse relationship. That is, the more anthracitic the coal, the lower the ash. From this it is argued that the anthracites of South Wales were formed of plant-constituents different from those contributing to the steam and house coals. This proposition gains no support from the study of the plants found in the associated measures, nor does it explain why the coals of other fields, composed in their various parts of very diverse constituents, do not exhibit the anthracite phase. But the ash question needs to be approached from another point of view. The ash of coal may, as I have shown elsewhere, be composed of three entirely distinct and chemically different materials. There may be (1) the mineral substances belonging to the plant-tissues; then (2) any detrital mineral substances washed or blown into the area of growing peat; and, finally, the sparry minerals located in the lumen of the cleat.

As to the first, I have long considered that the coal was in large measure deprived by leaching of much of its mineral substances; it is otherwise difficult to account for the almost total absence of potash. The second—detrital matter—is probably present in some though not in all coals; the high percentage of aluminium silicate is probably of this origin. But the third constituent—the sparry matter—may, both on *a priori* grounds and upon direct evidence, be assigned a very important rôle in the production of the ashes in most coals. When a coal with a strongly developed cleat is examined in large masses it is at once seen that the cleat spaces are of quite sensible width, and that they are occupied most commonly by a white crystalline deposit which may consist of either carbonate of iron or carbonate of lime, and there are also in many seams crystals of iron sulphide—either pyrites or marcasite. These sparry veins may be as much as $\frac{1}{10}$th of an inch, or even more, in thickness, and they clearly constitute the principal contributors to the ash. It has been suggested that they are true components of the original peat, a proposition to which no botanist would assent, and it appears certain that the veins consist of material introduced by percolation from the overlying measures, subsequent to the production of the cleat. If that be so, it then will follow that the amount of the material present in coal must be in some direct proportion to the available cleat space, and if there is no cleat neither will there be any vein-stuff to contribute to the ash. It should be pointed out that ordinary bituminous coal broken into minute dice and washed so as to remove any heavy mineral particles is found to contain a percentage of ash quite comparable with that of an average anthracite. It is to be concluded, therefore, that the variations of the ash contents of a coal are no indication of the plant-constituent of the coal.

I have sought to show how the concept of the Coal Measures with their sandstones, shales, and coal-seams accords entirely with what we know of modern swamps and deltas, and that just as each Coal Measure fact finds its illustration in modern conditions, so we may, inverting the method of inquiry, say that no noteworthy features of the modern swamps fail to find their exemplification in the ancient.

Even what may seem the most daring of my propositions—the seismic origin of abnormal "wash-outs"—finds, I cannot doubt, a full justification in what has been *seen* in the Sylhet region by Mr. Oldham, and in the Mississippi valley by Mr. Fuller, or in what can be *inferred* as a necessary subterranean accompaniment of these surface signs of great earthquake convulsions.

The Royal College of Science for Ireland.

THE scientific public cannot but feel grave concern that the Royal College of Science for Ireland is at present closed, and its students are scattered in temporary accommodation. All interested in applied science will realise that this is a serious state of affairs, both as regards Ireland's industrial prosperity and scientific progress.

The College was founded nearly sixty years ago. It came into existence in 1865 as the result of a Treasury Minute of that year, which converted an existing institution—the Museum of Irish Industry and Government School of Science applied to Mining and the Arts—into the Royal College of Science. Sir Robert Kane—well known as the author of "The Industrial Resources of Ireland"—was appointed its first Dean.

The College was at first housed in premises in St. Stephen's Green, and as early as 1869 it had earned considerable reputation for itself as a school of science. Thus, the Commission on Science and Art in Ireland, of which Huxley and Haughton were members, reported in that year, that—"In the Royal College of Science, Ireland possesses an institution which in the number of its professorships and general course of study is more complete as a pure school of science than anything of the kind existing in England or Scotland."

In its earlier years the College was under the administration of the Department of Science and Art; but in 1900 it was placed under the control of the newly created Department of Agriculture and Technical Instruction, a department which was largely the outcome of what was known as the Recess Committee, of which Sir Horace Plunkett was chairman and Mr. T. P. Gill secretary.

Under the enlightened administration of this Department, the College was greatly developed and extended, particularly in rendering it of more direct service to the industries and needs of the country. In the early days of the College, chief attention was devoted to such subjects as chemistry, physics, mathematics, geology, mining, engineering, and manufactures. Under the Department, however, not only were these activities extended, but also considerable developments were made in connexion with agriculture, which is the staple industry of the country.