THE CLEVELAND IRONSTONE.

J. J. BURTON, F.G.S.

'CLEVELAND Ironstone' is a term very loosely used and understood. When one hears the expression 'the discovery of Cleveland Ironstone' it is generally applied to the Ironstone which has had or is having a commercial use, but in dealing with the subject from a geological, rather than from an industrial point of view, the whole aspect of the question is changed, as seams too thin to be worked profitably, or too poor in quality to be worth smelting, are as interesting and important, and present problems as difficult of solution, as the main seam which is the one principally worked for iron-making purposes. Indeed, to obtain a clear view of the subject, the geologist must dismiss from his mind all questions of commercial value, and apply himself to a study of the whole series of Ironstone deposits over the Cleveland area and beyond, whether the deposits are formed in the Lias or the Oolitic formations, as they are all so closely interlinked that to ignore any portion of the deposits may lead to very erroneous conclusions.

We must therefore enquire what and where deposits exist; how they came there, and from whence the ferruginous material was obtained.

Before we deal with these aspects of the question however, brief reference should be made to one or two matters of human rather than scientific interest.

The discovery of the main seam is usually associated with the names of Bolckow and Vaughan, and the date about the year 1850; but this, like many other popular beliefs, is a myth, although to that firm belongs the credit of being the first to use it on a large scale. It is however recorded by the late Sir Lowthian Bell that Ironstone from Robin Hoods Bay was sent to the Tyne between 1745 and 1800, and that soon after 1800 Ironstone was obtained from the beach between Scarborough and Saltburn and used by the Tyne Iron Company. In 1811, Wm. Ward Jackson sent six or eight *cartloads* from the Normanby Estate to the Tyne; and thence forward every few years there are numerous records of the existence of the main seam on the coast, and also inland. Although the early users of the stone do not seem to have made any mention of the fact, they must have been well aware that the stone they gathered from the beach at the foot of the cliffs must have come out of the cliffs themselves. It is probable, however, that mining the stone was not then practised because the profit on the gathered and transported stone left too little margin for any more costly method of procuring the supply. My own opinion is that the discovery and use does not commence within the last century and a half, but dates back 2000 years or more if we do not confine our survey to the main seam only, which was perhaps the least suitable for use by early races of men. Implements of war and husbandry were used by the Britons, and as local material was used whenever it existed, it seems probable that many a lusty blow was dealt by bill-hooks of local iron wielded by the Brigantes inhabiting Cleveland. The crude but efficient methods they adopted would doubtless be applicable only to the ores of Oolitic formation, which are found plentifully throughout the dales ; and not to the Lias stone.

The local ores may or may not have been used by the more highly civilised Roman conquerors. It is probable that their greater knowledge and their better system of inland transport would lead them to the use of hæmatite ores principally, but that they did manufacture iron is pretty clear from the fact that a few years ago a Roman bloom of that metal was found near Hexham.

The Chartularies of many abbeys shew that the monks were mine-owners, and the chronicles prove them to have been Ironmasters.

It is clear therefore, that any investigations must be into the whole of the iron-bearing strata, whether we regard its existence from an industrial and historical point of view, or from that of geology only.

The local ore is found in nodules in the upper portion of the Lower Lias.

In Middle Lias.

In The Dogger.

In the Ellerbeck bed of Goathland, Egton, Ingleby and Snilesworth.

In the Grey Limestone.

In the Upper Estuarine Series in Fylingdales,

In the Cornbrash in Newton Dale and Ryedale, and

In the upper part of the Kellaways rock on the moors about Danby.

The various seams, however, are not continuous throughout the area, and seams which are continuous in section at one place, are in other places split up into bands with shales of varying thickness between, so that the problem of formation becomes very complicated, and is further intensified by the different lithological and chemical characteristics of the various seams, and of the same seam in different areas. Take for instance Eston on the north side, the main and Pecten seams are one ; at Upleatham they are split into three with one band of shale ; at Staithes into seven with six bands of shale. At Hawkser it is difficult to assign any of the seams of shale and Ironstone to any corresponding seams at Staithes, although the separating distance is only 12¼ miles.

I have prepared a series of diagrams drawn to scale vertically, which illustrate this diversity, and it should be noted that the diagrams deal only with the Ironstone series of the *Spinatus*-zone of the middle lias.

If we examine any one of this series of either shale or ironstone, or indeed almost any of the ironstone beds, we find, in more or less abundance, fossils of many forms of marine life; and as most of the shell remains consist of carbonate of lime, often in an altered condition, we are forced to the conclusion that the deposit of iron-bearing strata cannot have been formed in the condition in which it now exists, and indeed that no iron solution could have contemporaneously permeated the beds as they were laid down. The very abundance of shells throughout the whole zone negatives any idea that there was a ferruginous sea existing when and where the ironstone beds were deposited.

Many writers have carefully considered the question of the nature of the original deposit and in almost all cases they have arrived at the conclusion that the beds were of carbonate of lime. The evidence is not absolutely beyond question, as there are difficulties not easily explained, but by a process of eliminating every other imaginable idea of the original condition of the beds, it seems fairly well established that they were at first an impure limestone.

This is known as the replacement theory, and if it is correct, we have only advanced one step, as the origin of the interstratified limestones and shales has to be sought, and then the question as to how the lime has been substituted by iron, and whence the iron was derived must be answered.

Limestone has many sources. *First,* the Chemical. Carbonic acid from the atmosphere combines with rain water, and as it permeates the surface of the earth, the solution is strengthened by decaying vegetable matter. This weak solution of Carbonic acid dissolves certain mineral constituents of the soil, and, in particular, lime. The lime-charged water issues as springs, loses part of its Carbonic acid by evaporation of the solvent medium, and deposits the lime as a carbonate. A very similar action takes place between Carbonic acid and iron. The chemically formed limestone, however, is comparatively small in extent.

The second source is the accumulation of abandoned 'house-boats' of organisms living in the sea. These house-boats are composed of carbonate of lime which the owners built by abstracting the material from the waters carried down to the sea by inland streams.

The third source is the destruction by denuding, but not necessarily dissolving forces, and the carrying away in suspension by streams of the denuded material, which has again been deposited.

To which of the three do the Cleveland beds belong?

The thin bands in some places; the ever constant evidence of a changing littoral in some parts of the area; the strong suggestion of estuarine conditions here and there, and the probability that shallow water prevailed where the seams are thickest, prove to my mind that the beds are not directly organic. Microscopic examination reveals nothing more than a comminuted fragment of a shell, perhaps as the nucleus of an Oolitic grain, and I am strongly of opinion that the beds were formed out of the debris of pre-existing limestone formations. The mixture of impurities of silica and alumina strengthens this view. The Permian, Triassic and Liassic period was one of great earth movements, and the older rocks to the west were being elevated and fractured. It is probable, if not certain, that much disturbance of a volcanic nature was in progress to the north-west, giving exactly those alternating conditions of stability and instability required for the rapid wearing down of pre-existing rocks, including Permian and Carboniferous formations, which are necessary for the building up of the Lias, and the ironstone series in particular. Mr. Stead, in his usual thorough manner, has investigated this subject, and has given the results in a paper read before the Cleveland Institute of Engineers in February, 1910, where he says he believes he found the original substance imprisoned in the vertebral column of a *Plesiosaurus propinquus*, occupying what was originally the spinal cord. It consisted of Oolitic mineral closely resembling the ironstone itself in every particular. The bone surrounding it was very dense, and it appeared to be possible that the substance inside, being surrounded by a dense non-porous envelope, might have been protected from the influence of percolating solutions, and would perhaps approximate in composition and character to the original deposit.

He gives the analyses of both the fossil bone and the imprisoned substance; that of the latter is:—

Ferrous carbonate	15.58% dried at 212° F.
Iron Pyrites	0.82
Alumina	7.00
Silica	19.80
Calcium carbonate	51.16
Calcium Phosphate	2 53
Magnesia	1.67
Organic matter, etc. ..	1.44
	100.00

The lithological character of the substance under the microscope closely resembles that of the Ironstone.

Dr. Sorby, Hudleston, Tate and Blake, and other authorities, all support the replacement theory. The substitution of iron for lime is quite a practical operation in nature's workshop, where the conditions are favourable. As already pointed out, a solution of Carbonic acid will take up a portion of iron from the rocks through which it passes. Bicarbonate of iron in solution, in open water, will, on coming to the surface, take up a molecule of oxygen, freeing the Carbonic acid, and forming Fe_2O_3. On this taking place it immediately combines with water and sinks to the bottom, where, if there happens to be any decomposing vegetable matter, the carbon it contains abstracts a molecule of oxygen from the Fe_2O_3, the abstracted oxygen molecule going to make up Carbonic acid and leaving the iron as FeO, and so the fight goes on indefinitely between the iron salts and carbon, with the one molecule of oxygen as the bone of contention. In this way are many lake deposits of ferruginous material formed. Some of the iron formed in Permian and later times may have been mechanically transported and deposited simultaneously with the limestone, but probably the greater portion of the iron found was carried down with the clays which now form the shale bands above the ironstone. These shale bands have been elevated, and have at some period of their existence, and perhaps, for considerable periods, been swampy estuarine beds, on which, in the warm Liassic seas, plant life would quickly form and decay. The iron in the shales would probably be a ferric oxide (Fe_2O_3), and as the carbonaceous matter produced Carbonic acid and acted upon the ferric salts, a bicarbonate of iron would be formed, which would percolate through the soft strata of the period. According to Dr. Irving, the calcium of the limestone rock would take up the strong acid of the iron salts, leaving Carbonic acid available for union with the iron as ferrous carbonate ($FeCo_3$, or Siderite). The change produced by percolations of ferrous carbonate through limestone is thus simply put by Dr. Stead, following Dr. Sorby:— $CaCO_3$ solid + $FeCO_3$ in solution = $FeCO_3$ solid + $CaCO_3$ in solution.

Dr. Stead gives the constitutional anaylsis of the Cleveland Main Seam as 44·97% of Siderite ($FeCO_3$) by weight

$$\left(\begin{array}{ll} FeO & 27{\cdot}91 \\ CO_2 & 17{\cdot}06 \end{array}\right. \quad \left. 44{\cdot}97\right)$$

The principal difficulty in the replacement theory is the fact that fossil shells occur which have not been converted into carbonate of iron and still remain carbonate of lime, and the question naturally arises, why, if the replacement theory is correct, were these shells not also converted into carbonate of iron?

No entirely satisfactory answer seems to be forthcoming, but as there are differences of both a physical and chemical character in various parts of the many seams of ironstone, shewing that the conditions prevailing at the time were not uniform, may it not also be that these same varying conditons may account for the substitution of iron for lime in one case and not in another? The time the changes took place is not known, and it is quite possible that the time between deposition and substitution was long enough to allow other changes, as for instance the shells may have crystallized into calcite, which is much less soluble than limestone—and "it is remarkable that nearly all the shells found in the Cleveland Ironstone beds mainly consist of calcite in distinct crystals differing entirely from the structure of similar shells of the present day, which if crystalline at all are only microscopically so."* There is the further possibility that some of them may have received a silicious coating, thus adding greater resistance to the attack by the carbonate of iron solution. It has been shown by several writers that the surface of some of the shells has been partly or wholly converted into carbonate of iron, while the interior still remains calcite, so that it may well be that at the infinitely slow rate of many of nature's processes the time has not been sufficient for a complete change, and that the work is even now in progress, rather than that it has been arrested.

Dr. Sorby made some interesting experiments on the action of chloride of iron on calcite, which are given in *The Naturalist* No. 597, 1906, where he says:—"Since writing my original papers I devoted much attention to the production of artificial pseudomorphs, especially including those in which carbonate of lime is replaced by carbonate of iron. Crystal of calcite or portions of Iceland spar were sealed up in tubes with a neutral solution of iron protochloride and heated to various temperatures. Kept for a few weeks in the boiler of a high pressure steam engine, at a temperature somewhat under 300° F. replacement was somewhat rapid, and pseudomorphs were formed as hard as any similar natural product. Kept much longer in a boiler at a temperature varying up to 212° F. the replacement was slower, and the pseudomorphs much more tender. I sealed up a piece of Iceland spar in a glass tube so full of the chloride that there was a mere trace of air left, and after keeping for a few years the replacement was so small that I came to the conclusion that it did not take place at the ordinary temperature, but on re-examining after thirty-six years, though the amount of replacement was small, there could be no doubt about its having occurred. This shews the importance of such long continued experiments, and proves that the changes met with in the Cleveland Ironstone may have taken place at the ordinary temperature of the rocks."

* Dr. J. E. Stead, *loc. cit.*

Of course these experiments were made under conditions which were intended to produce results in a lifetime and cannot be compared with the weak solutions and unlimited time with which nature works, but the results obtained support the suggestion that the replacement action in the ironstone beds may not have entirely ceased, although we are unable to detect the means by which it may still be carried on.

The chemical side of the question has been so fully dealt with by others that it is unnecessary to go further into it now. If, however, it is clear that the conversion of limestone into ironstone is possible, there is still to be considered the source of the iron which has replaced the lime.

Iron is one of the most universally diffused substances in the composition of the crust of the earth, and during the enormous period of time which has elapsed since the envelope round the unknown condition of the interior became solid matter, many and often repeated cycles of chemical change must have taken place. Iron has been segregated and again diffused under the changing conditions which have taken place.

The New Red Sandstone, for instance, has taken up a thin pellicle of iron as a covering to the grains of sand of which it is composed. Springs have in their wanderings through the interior taken up from the rocks and soil large quantities of iron in solution, and left it as a solid deposit in streams and lakes. Earth movements have produced faults and cracks and fissures, and by friction have generated great heat; and mineral veins and iron bearing lodes have resulted. Lavas from volcanoes and dykes have spread over, in, and under the surface, and these contain vast quantities of iron.

From sources of this character all the iron necessary for the Cleveland beds might have been obtained.

It seems probable also that the physical conditions in later liassic times were such as would permit us to contemplate the derivation of the iron from these sources.

On the sections and the map on which I have drawn the lines of the sections, it will be seen that at Eston the main seam is the thickest, and that as we proceed east and south, clay shales and ferruginous shales take the place of the ironstone; and if the section had been continued south and south-east as far as the beds are recognisable, to say, beyond Thirsk, the same thinning of the seams and replacement by shales would be seen. These records of the material carried down by Liassic streams indicate very clearly that when the Eston main seam was under water the shore line of the ancient sea was not very far distant and that there must have been streams carrying out the finely divided wreckage of land areas, east and south, in suspension.

It is generally admitted that the area of the Penines north and west was, at this period of geological history, dry land, and probably rising, creating a slope to the east, which is exactly the condition necessary for the formation of the Lias deposits of Yorkshire. It was also the area, as was that of the South West of Scotland, where the greatest disturbance was going on and seismic and plutonic forces were most active. So that in the region from which the streams probably ran were those physical features, natural forces and lithological conditions necessary to explain the source of the mineral constituents of the Cleveland Ironstone.

It must, however, be conceded that for a full explanation of the whole series it is necessary to assume that deposition was not continuous, but intermittent or interrupted, and that there were many alterations in land and sea level, but I think we are fully justified in reasoning from effect back to cause, and in saying that such oscillations of land and sea level did take place during the whole of that period. The same action must have been repeated time after time.*

(*To be continued*).

'How birds make love,' is the title of an article in Part 27 of Cassell's *Nature Book*, by Mr. Oxley Grabham.

Mr. J. Arkle refers to the forms of *Cœnonympha* in various northern counties in *The Entomologist* for March.

In *The Scottish Naturalist* for March, Mr. W. Eagle Clarke describes A New Racial Form of Song-thrush from the Outer Hebrides, with the name *Turdus musicus hebridensis*.

On the strength of specimens found at Radcliffe-on-Trent by Professor Carr, Mr. K. J. Morton, in *The Entomologist* for March, writes on 'An Addition to the List of British Plecoptera: Reinstatement of *Chloroperla venosa*.

In a note on 'The Origin of Septarian Structure,' by Dr. A. M. Davies in *The Geological Magazine* for March, he refers to the fact that this structure is due to *expansion* of the nodules, and not to contraction as is usually supposed.

From an article by the curator, Mr. F. Williamson, in *The Museums Journal* for March, we learn that 'Rochdale now possesses an Art Gallery and Museum which compares very favourably with those of many much larger towns and cities.'

The *Museums Journal* announces the death of Robert Cameron, who was for many years honorary curator of the Sunderland Museum, and 'was in advance of his time in the broad views he took of the potential value of museums in the general scheme of education.' He was in his eighty-eighth year.

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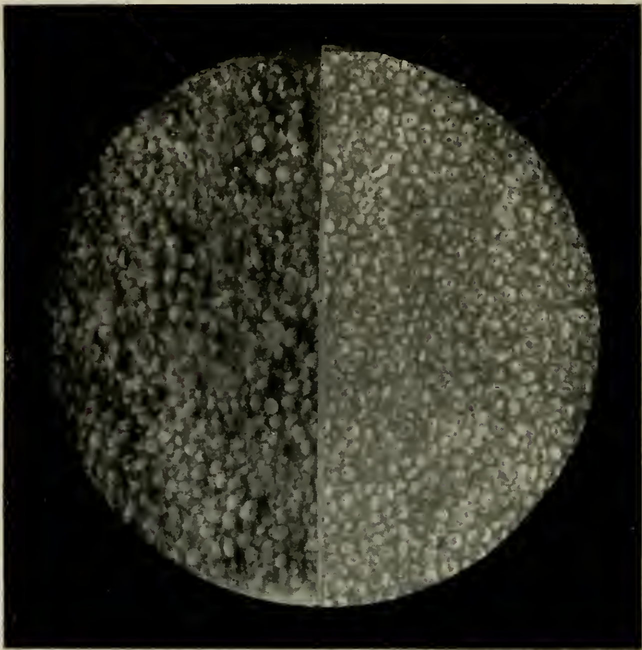
* The question arises, was the iron in the interbedded shales, or in the Estuarines of the Upper Lias and Inferior Oolite? I think in the interbedded shale, as there is not much evidence of leaching in the Upper Lias, and the iron and the limestone does not shew that diminishing ratio of iron to lime in the lower beds that one might expect if it had to pass through and leave some of it in the upper beds.



No. 1.—Top bed, Liverton Ironstone.
Fractured surface (dark) on left; polished surface on right. Magnified 5 diameters.

No. 2.—Top bed, Liverton Ironstone.
Polished surface; oblique illumination. Magnified 30 diameters.

THE CLEVELAND IRONSTONE.

J. J. BURTON, F.G.S.

(PLATES VIII., IX. AND X.).

(*Continued from page 168*).

In some cases the accompanying diagrams are based on the Geological Survey measurements, in others the Survey records have been corrected in the light of more recent observations, and in several instances they are the result of information given to me by mines' managers, or recently taken by myself.

In the section of the main seam of ironstone at Eston (*A*), the Main and Pecten seams, although divided by a line, are continuous in section, that is, there is no shale parting between them ; but in the section to the east, at Court Green (*B*) less than two miles away, these two seams have become separated by a band of Dogger and a band of shale. In an eastward direction, as depicted on successive diagrams, the shale band thickens, not on any very clearly defined principle, but in a somewhat irregular manner, until finally the Pecten seam becomes so split up into thin bands of shale and ferruginous material that it is impossible to define its upper and lower boundaries with any certainty.

Without dealing with the subject in any commercial sense it is noteworthy that just where the Ironstone seam was first opened out on an industrial scale, the bed is not merely the thickest and the richest in iron, but the Pecten bed really forms part of it and was worked along with it. This cannot be done anywhere else in Cleveland.

On the map is an irregular line commencing at Eston (marked *A*), and ending at Hawsker (*H*). Between these two points all the sections on the first portion of the diagram were taken, and the positions of the several sections are indicated by letters corresponding with those heading the columns on the diagram.

On the map is also shown a line beginning at the same point (*A*), and proceeding in a southerly direction to Ingleby (*J*), and thence in a direction west-south-west to Swainby.

Intersecting the southern line at Roseberry (*I*), is another line more or less easterly to *L2* and thence north-easterly until it cuts the line from Eston at Staithes (*F*) thus forming an irregular triangle. The position on the map of the different sections shown on all the diagrams is indicated by corresponding letters.

It has been shown that the ironstone thins out and becomes split up along the most northern line. Taking the base of the triangle, starting at Eston (*A*), Roseberry Topping is shown $3\frac{1}{2}$ miles distant. In that short distance there has been a great alteration in the strata. The main seam has thinned down from 11 feet to $5\frac{1}{2}$ feet. The Pecten seam closely resembles that at Hummersea, which is nearly 11 miles distant from Eston. Any differences may be due to the difference in the mental attitude of different observers, in allotting this to Ironstone, that to shale, or to the difficulties attending accurate measurement. Still proceeding southwards to Ingleby (a distance of $5\frac{3}{4}$ miles from Roseberry), the Pecten seam (if correctly located and described, and I am taking the figures from the Survey records) bears no kind of relationship to the section which I have had taken at Roseberry, and is very puzzling and difficult to explain. Some other measurements and observations which I have recently made between the two points, while not explaining, appear to throw some light on the subject.

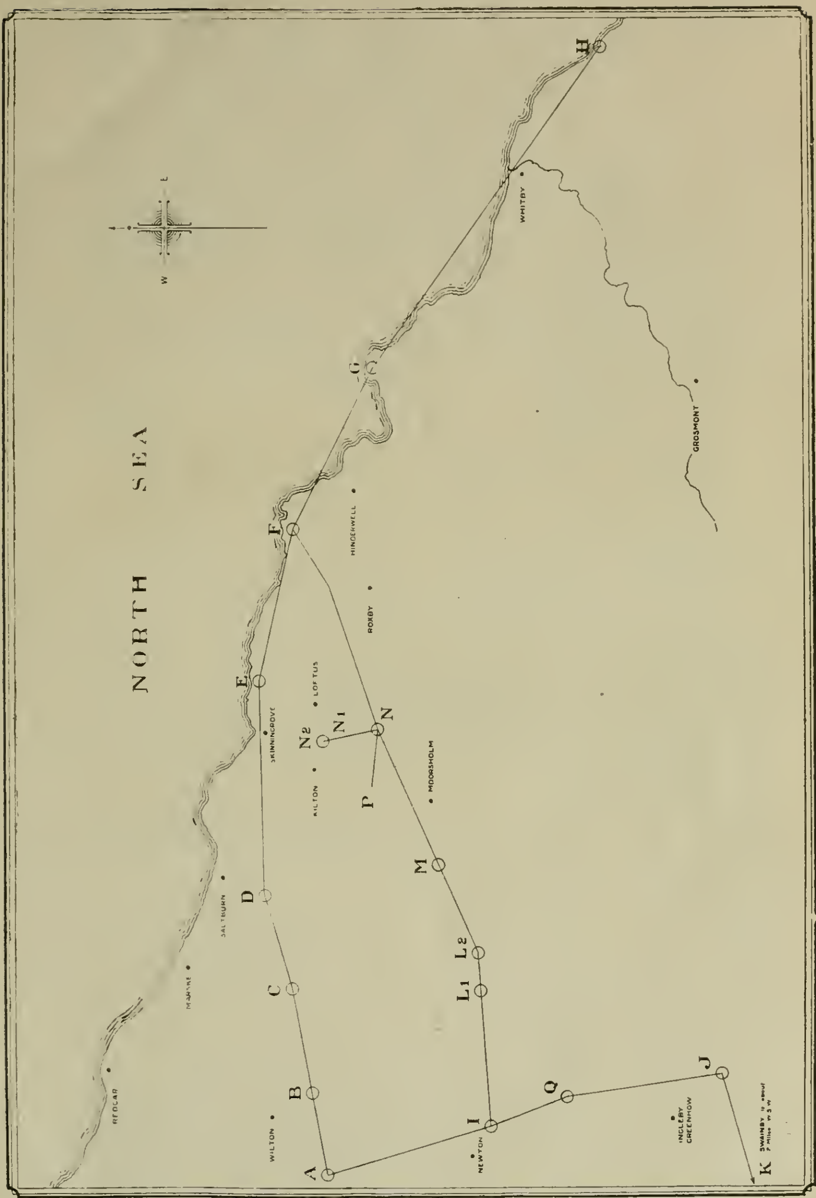
At Cockshaw, about $1\frac{3}{4}$ miles south of Roseberry, the Pecten bed has become nearly all shale, with only two thin bands of ironstone; below it is a band of 3 ft. 2 in. of shale. At Roseberry this same shale bed is split into two, differing quite distinctly from each other; or, as the section is not at present very easy to explore, should it turn out that any of the shales above or below the two thin bands of ironstone at Cockshaw belong to the Pecten, then the difference between Roseberry and Cockshaw is, if anything, still more marked. Inside the mine at Roseberry, close to a fault, the whole character of the Pecten bed becomes altered; there are three thin bands of shale amounting in total thickness to only eight inches, and the ironstone bands have a total thickness of 3 ft. $3\frac{1}{2}$ ins. Local variations evidently occur, shewing that the conditions existing at the time the strata were being formed must have been variable. Perhaps in this instance faulting and deposition and possibly denudation were progressing simultaneously, but the main point is that in distinctly local areas there are given variations in the character of the beds.

Along the most southerly line of sections there are numerous local changes, but broadly speaking the ironstone in the main seam becomes less rich in iron and the impurities, chiefly silicia and alumina, become more pronounced as we proceed eastward. Along with this change there comes the cleaving of the ironstone into a top and bottom block, with a band of Dogger or shale between them, and just as in the converging line of sections on the coast, the band of shale thickens towards the east.

Some of the local variations are curious. Thus in Spawood Mine, the Western side of the most southerly workings (*L*) shews a thicker band of shale and a thinner bottom block of ironstone than the eastern side (*L2*) 1,300 yards along the line

No. 3.—Top bed, Liverton Ironstone.
Oolitic grains; insoluble portion left on boiling with strong Hydrochloric acid.
Magnified 30 diameters.

No. 4.—Top bed, Liverton Ironstone.
Same as No. 3, after crushing. Note the grain at right hand lower corner in which the Oolitic layer has fallen off, leaving a second layer exposed.
Magnified 30 diameters.



Map of the Cleveland Area, showing the positions of the Sections.

of section, which is entirely contrary to what might be expected judging from experience elsewhere. Again, in the case of Stanghow (*M*) the bottom block of ironstone is lithologically so much like the middle band that it is difficult to distinguish the one from the other as they appear in the seam.

I have drawn a subsidiary line of sections from Liverton Shaft (*N*2) for 1½ miles South to *N*. The rapid alteration in the main seam along this line is remarkable. Thus the two feet of the middle dogger, which was very ferruginous, and was worked with the stone, at the shaft becomes split into 1 ft. 2 in of shale and 10 in. of dogger, 638 yards to the south, and is a very silicious shale 1½ miles from the shaft.

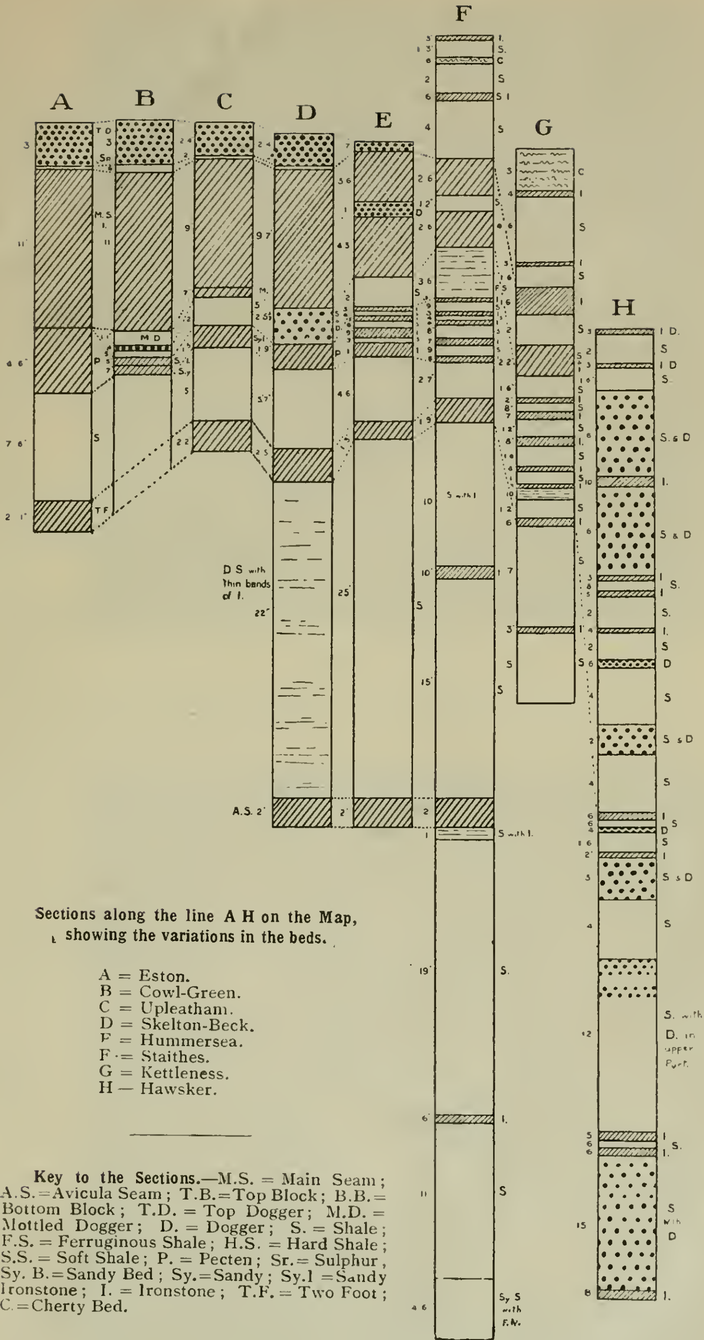
From this last point is a line due west to the present position of the workings in Kilton pit, and the mines manager kindly gives me the section (*P*) which gives the middle band as

Dogger		9 in.
Shale	1 ft.	8 in.
Dogger		8 in.
	3 ft.	1 in.

but doubtless the dogger is sufficiently ferruginous to be worked as an ironstone.

When I first began to prepare these sections I had the expectation that I should be able to discover some general principle which would sufficiently explain the variations in thickness, quality, and nature of the deposit, but in this I have quite failed, as there are so many and such striking local exceptions to the rule which would seem to generally apply, that any deductions are now necessarily put forward tentatively and with diffidence.

If in the comparatively few sections which are obtainable inland, there are such unexplained differences; what may there not be in places yet to be opened up? Almost every writer since Bewick's time has drawn his conclusions from such premises as were available at the time, and generalized from limited areas of investigation; and each succeeding writer on the same subject has found it necessary to modify some of his predecessors' statements. One of the most cautious and reliable of men — the late C. Fox Strangways, made the same error when he said of the changes in the character of the main seam, 'These changes are so extremely regular that the thickness of the ironstone at any point may be calculated from the nearest known sections.' This is not quite borne out by facts, and therefore any opinions now expressed are merely based on a careful consideration of present knowledge. It does, however, seem from the evidence, even including the absence of regularity, that there is justification for the opinion



Sections along the line A H on the Map, showing the variations in the beds.

A = Eston.
B = Cowl-Green.
C = Upleatham.
D = Skelton-Beck.
E = Hummersea.
F = Staithes.
G = Kettleness.
H — Hawsker.

Key to the Sections.—M.S. = Main Seam; A.S. = Avicula Seam; T.B. = Top Block; B.B. = Bottom Block; T.D. = Top Dogger; M.D. = Mottled Dogger; D. = Dogger; S. = Shale; F.S. = Ferruginous Shale; H.S. = Hard Shale; S.S. = Soft Shale; P. = Pecten; Sr. = Sulphur, Sy. B. = Sandy Bed; Sy. = Sandy; Sy. I = Sandy Ironstone; I. = Ironstone; T.F. = Two Foot; C. = Cherty Bed.

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that the original deposit did not, if at all, extend westward much beyond the present escarpment. There must have been during the Middle Lias period much oscillation of land and sea levels and alternate encroachments, one on the other. As sometimes in mining there is found an entire "wash-out," and as some of the thinner seams are in places entirely absent, it seems clear that there were many shifting currents sometimes preventing deposits, and at other times removing those which had already been laid down. It seems probable that in the shallow waters of the period there were mud banks which were partly dry land, and that while deposits were being laid down elsewhere, there were no accumulations in such areas until some further change in level, or a fresh direction of current took place.

The detritus-bearing streams apparently came from the north-west, and there is room for the assumption that the black shales which so characteristically distinguish the Yorkshire Lias are the products of denuded coal measures of the West, and that such differences and interruptions in formation, as well as changes from shale to limestone as they undoubtedly reveal, are due to earth movements having changed the flow of the streams in the gathering grounds, the subject of denuding action.

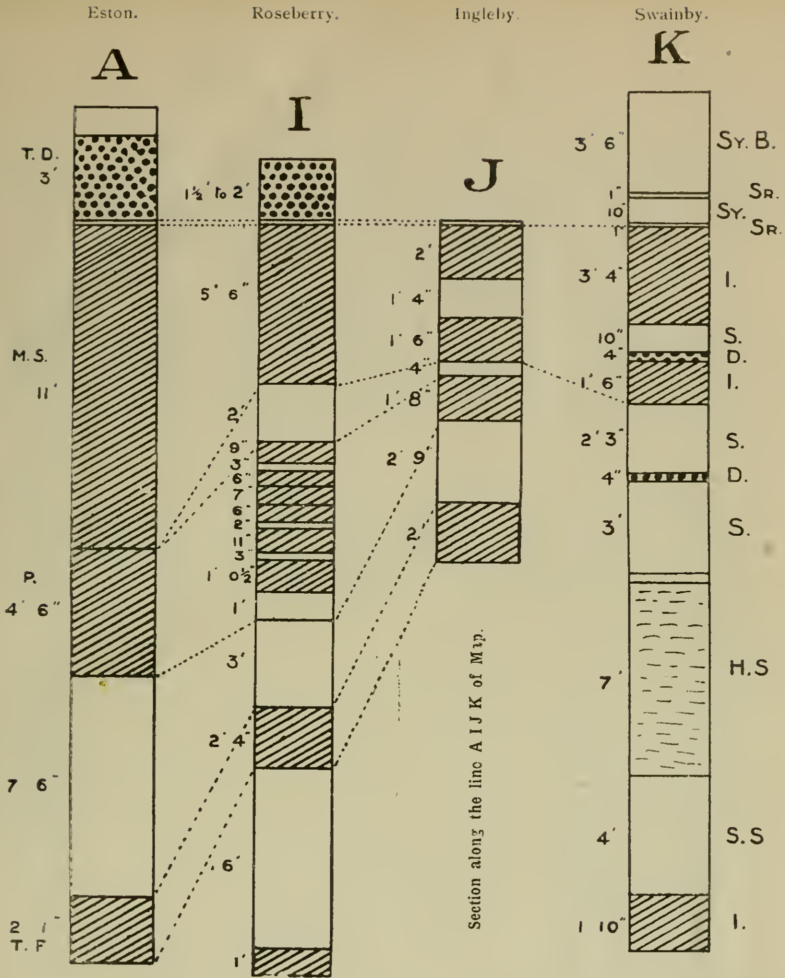
The area over which the ironstone seams extend, and the quantity of stone known to exist therein, is not much guide to economic values. But here again one must speak with caution, as mines which have been abandoned within the last 50 years because the stone was too poor in quality to be worth working, are now being worked profitably. The conditions of iron manufacture, the development of improved methods, the opening out of new supplies in foreign countries, the freight market, state regulation of bounties and tariffs, the contiguity of fuel and flux, all have an important bearing upon what Cleveland ore may or may not be possible to use. But the probability is that most of the workable stone in Cleveland lies within the area *A, I, F,* on the map. The northern outcrop of the main seam is on the coast east of Saltburn. From there the outcrop is by the Western escarpment round to the Kildale Valley; but the stone lying to the south of the line *I, L, F,* is poor in iron and high in impurities.

Some of the thin seams are good ironstone, but the cost of working renders them of no value at present.

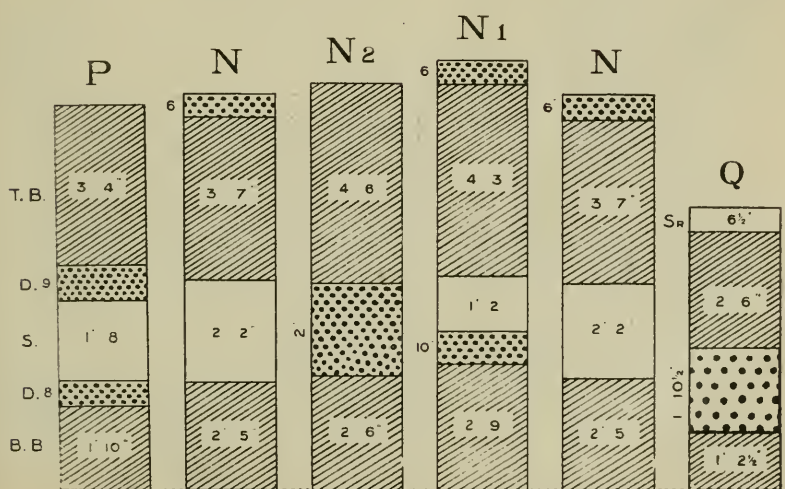
Two exceptions must be made. At Grosmont, near Whitby, the main seam, if at all recognisable, has become an attenuated band of about 12 inches thick, but the Pecten and Avicula beds each average $3\frac{1}{2}$ feet to $2\frac{1}{2}$ feet in thickness; there is a thin shale band in one or both seams, and they are separated by a thick bed of shale. Considerable quantities

No. 5.—Included matter in fossil bone.
Polished surface (flat) on left. On the right (showing relief) is the surface after etching with Hydrochloric acid. The dark portions represent hollows produced by the action of the acid. Magnified 30 diameters.

No. 6.—The same specimen as in No. 5, more highly magnified, showing silicification of the outer envelopes of two of the Oolitic grains. The dark parts in the photo were filled with Carbonate of lime. Magnified 50 diameters.



Section along the line A I J K of Map.



Section along the lines P.N. and N2 of Map.

were worked years ago, and the mines were again recently re-opened, and although now closed it is quite possible that with a lower carriage rate to the furnaces they may again be worked in the future, especially if the stone can be calcined where won.

In Rosedale, the Dogger proper, that is the bed lying on the top of the Alum Shale, reaches a peculiar development, and in places on the east side is, or rather was, as much as 14 feet in thickness of good ironstone, but although a good thickness is maintained the quality deteriorates so much that, in the words of the lessees, 'it is really no use.' On the west side the seam varies from about eight feet thick at the outcrop to five feet where work was abandoned in Sheriff's pit owing to water.

The useable stone gradually got narrower as the work extended, and the working place was only about 80 yards wide when left. The stone on the west side gradually 'nips out.'

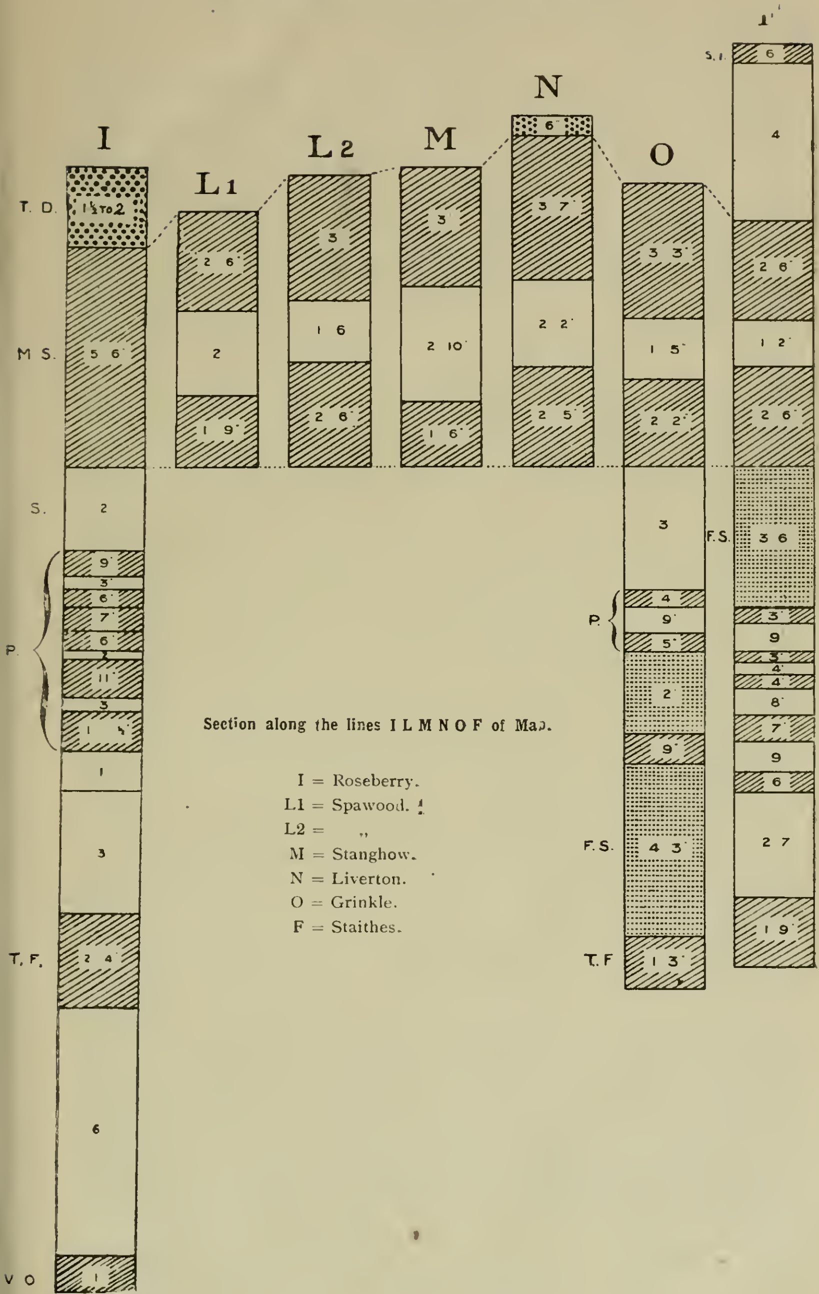
The Carlton Iron Company, Ltd., kindly gave me the above particulars, and their man, who latterly had charge of the Rosedale mine, adds, 'On the west side there is a gradual nip out all along the workings. We worked many places as low as 18 inches. The indications were that the ironstone was entirely disappearing and that the shale (a clayey material) and belmonite (a hard flinty material, not sandstone) would eventually join. There have been no proved indications in the Farndale Valley adjoining that a workable stone exists, although traces are found of an inferior stone at a lower level.'

Below the dogger, and in a hollow in the alum shale, the magnetic ore was found forming a lenticular mass about 70 feet thick in the thickest part.

Rosedale may be said to be practically worked out, and probably 8,000,000 or 9,000,000 tons have been obtained from that source.

The quantity of stone available has been very variously estimated by different writers. Joseph Bewick, writing in 1860, estimated the available quantity of workable ironstone at 4,820,659,200 tons, sufficient for 680 years at 7,000,000 tons per annum. He no doubt based his calculation on the Grosmont beds having a workable thickness over the whole of the Cleveland area. Mr. John Bell and Mr. John Jones jointly reporting to the Iron and Steel Institute in 1871, on the iron ores of Northumberland and Durham and the North Riding of Yorkshire, estimated the workable stone of the Cleveland main seam at 525,000,000 tons, basing their calculation on an area of about 27 square miles or say 17,500 acres, containing 30,000 tons per acre. They erroneously report that the seam worked at Grosmont is the main seam.

Mr. George Barrow, of the Geological Survey, in a paper read before the Cleveland Institute of Engineers in 1879,



Section along the lines I L M N O F of Map.

I = Roseberry.
L1 = Spawood.
L2 = ,,
M = Stanghow.
N = Liverton.
O = Grinkle.
F = Staithes.

gave the total quantity of workable stone in the main seam as 685,650,000 tons.

I have been at some trouble to make an independent estimate and I arrive at figures very closely agreeing with those of Mr. Barrow. According to my calculation the total area of workable stone in the main seam is 43·48 square miles, or 27,827 acres. The sp. g. is 2·86* which gives 3,467·89 tons per acre for every foot in thickness. Taking the average thickness of stone at seven feet, this gives 24,275·3 tons per acre. 27,827 acres by 24,275 tons gives 675,500,425, differing only from Mr. Barrow by about 10,000,000 tons. From the quantity thus ascertained must be deducted waste in winning, which will approximate 10 per cent. and leave the available quantity 607,950,383 tons, of which there has already been won about 270,000,000 tons, leaving unworked about 338,000,000 tons, which at 6,000,000 tons per year will last 56 years.

This leaves out of account the top seam, the Pecten seam, and the two foot seam, which together probably contain more stone than the main seam. It is all a question of cost whether they enter the field against imported ores or remain where they are for the edification of a future race of geologists.

The seams over considerable areas are full of local faults, and there are some of greater magnitude. The dips are variable, but the highest position above sea level is in the west. At Eston the outcrop is about 300 feet above sea level with a dip of 3 inches to the yard. At Roseberry it is about 750 feet above sea level with a gentle dip to the south-east. At Stanghow south it is 151 feet above sea level, with a dip of .815 inches per yard south-east. At Liverton south the seam is 218 feet below sea level.

The percentage of iron in the stone is fairly constant in given areas (although as already said, it gets decidedly worse eastward and southward), but it is very variable in distribution throughout the mass.

According to Dr. Stead, the porosity of the Raw Ironstone is 22 per cent. of the actual volume. From this one may conclude that there must have been a considerable amount of carbonate of lime dissolved and carried away in solution subsequent to the conversion of the major portion of the original limestone rock into carbonate of iron, as the shrinkage from substitution is insufficient to account for such a high porosity.

My thanks are due and heartily tendered to Dr. Stead for the loan of the blocks on Plates VIII.-X., and to the Mines' Managers who have kindly supplied me with the latest facts which have enabled me to prepare sections of the main seam up-to-date.

* Vide Dr. J. E. Stead.