MEMOIRS

OF THE

GEOLOGICAL SURVEY

OF

GREAT BRITAIN,

AND OF THE

MUSEUM OF PRACTICAL GEOLOGY.

THE IRON ORES OF GREAT BRITAIN.

PART I.

THE IRON ORES OF THE NORTH AND NORTH-MIDLAND COUNTIES OF ENGLAND.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF
HER MAJESTY'S TREASURY.

LONDON:
PRINTED FOR HER MAJESTY'S STATIONERY OFFICE.
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In the annual Parliamentary Report of this year upon the Progress of the Geological Survey of the United Kingdom and this Establishment, I have already spoken of the inquiry into the composition of British iron ores as being of great national importance. I feel confident that this First Part of the Memoir on that subject, containing some of the analyses carried on in our metallurgical laboratory, under the able guidance of Dr. Percy, will satisfy the public as to one of the obvious uses of this School of Mines. The clear and accurate description, by our mining geologist, Mr. Warington Smyth, of the various rock formations in which the ores occur, forms a valuable portion of the Memoir.

Roderick I. Murchison,
Director.

Museum of Practical Geology,
Jermyn Street, May 23, 1856.

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PREFACE.

In the Great Exhibition of 1851 there appeared a very extensive series of the iron ores of the United Kingdom, which were collected, arranged, and catalogued by Mr. Blackwell, of Dudley. To the ordinary spectator there could be nothing less attractive than that collection, although it truly represented one great element of the wealth, the power, and the prosperity of the country.

At the close of the Exhibition Mr. Blackwell generously presented the collection, upon the formation of which he had expended a considerable sum, to the Museum of Practical Geology, in order that it might permanently be preserved in a national institution, and be constantly accessible for inspection. But this is not all. Mr. Blackwell, conceiving that the practical utility of the collection would be greatly increased by the knowledge of the exact composition of the ores, munificently offered to place at the disposal of the lecturer on metallurgy the sum of 500*l.* towards defraying the expenses of an analytical investigation of all the more important varieties of ore in the collection. The offer was accepted, and the results are presented in this volume. The investigation has been conducted in the metallurgical laboratory of the School of Mines; and although it was commenced in February 1852, it is not yet quite completed. It should also be stated that Mr. Blackwell expressly stipulated that the results should be published; for notwithstanding he is himself extensively engaged in the smelting and manufacture of iron, he yet entertained no narrow-minded notion of exclusive personal advantage, and was willing that others should partake of any benefit which the knowledge resulting from such an investigation might confer.

Almost all the analyses have been conducted by Mr. Allan B. Dick and Mr. John Spiller, a few only having been made by Mr. Edward Riley, who received an appointment at the Dowlais Ironworks shortly after he had entered upon the investigation. The labour, as every chemist will observe on inspecting the recorded results, has been very great; and it required no small amount of enthusiasm and perseverance on the part of an analyst to devote himself continuously to the same kind of work during so long a period. As it is right that every man should receive the entire merit of his own labours, the names of the gentlemen above mentioned will be attached to their respective analyses.

There is no metallurgical problem of greater practical importance than the determination of the causes which occasion the differences in quality of the various kinds of iron, differences which have long been recognized by engineers familiar with the use of iron in the construction of bridges, buildings, and railways. Now it is certain that, exclusive of effects due to mechanical treatment, these differences in quality are of a chemical nature. It must be borne in mind, that chemically pure iron is known only as a curiosity even in a laboratory; and that all the substances to which the term iron is commonly applied are compounds, and frequently very complex compounds. But differences of chemical constitution in iron must depend upon differences of chemical constitution either in the ores, the fuel, or other materials used in smelting, or upon differences in the mode of conducting the process of smelting. It has been demonstrated that all these causes, either separately or conjointly, may be powerfully operative in determining the quality of iron; and it may be asserted that not the least influential are those which relate to the ores and fuel. It is hoped, therefore, that, so far as relates to the influence due to the ores, the present investigation will furnish decisive results of considerable practical importance.

Mr. Kenyon Blackwell, elder brother of Mr. Blackwell, who has had considerable experience in the smelting and manufacture of iron, and who has had the opportunity of acquiring a practical knowledge of the character of the British iron ores, undertook the selection and sampling of the ores for analysis. In every case, as far as practicable, a fair average sample of ore was taken; and as respects those varieties of ore which, occurring in contiguous measures, are gotten together in the mine, and which also are smelted together, the sample was prepared for analysis by triturating together an equal weight of each particular variety. Thus, for example, when reference is made in Analysis No. VIII. to the Nos. 305 to 310, it signifies that the specimen subjected to analysis was prepared by triturating the same weight of the ores from No. 305 to No. 310 inclusive.

It must be borne in mind, that in some varieties of iron ore certain substances may occur only occasionally, very irregularly diffused, as, for example, Millerite (sulphide of nickel) in the ore near Merthyr, or blende, galena, and copper pyrites in several of the Staffordshire ores. It is, therefore, probable that, notwithstanding the care bestowed in the selection of the samples, such occasional substances may yet have been absent in the specimens subjected to analysis.

In some cases it has been necessary to apply for additional specimens of ores in order to obtain as characteristic an average sample as possible, and we have pleasure in recording the promptness with which such applications have in general been attended to; but we are compelled to state that in other cases similar applications have been made in vain to more than one firm in Staffordshire, not from any disinclination, we suppose, to furnish them, but, as it would appear, from mere dilatoriness, and want of appreciation of the necessity of more accurate knowledge.

After all, it must be acknowledged that the value of an analytical investigation of iron ores would be very much increased by a corresponding investigation respecting the iron produced and the fuel and flux employed in the process of smelting. Such a work would require great skill and persevering labour, but would be certain to yield results of great practical value and high scientific interest.

Researches of a similar kind, with reference to the materials employed in the manufacture of cannon, have been during several years conducted by the officers of the Ordnance Department of the United States, and a handsome quarto volume of the results has been published by the United States Government in the present year.* It is proposed to carry out a more extensive series of analyses,

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* Reports of Experiments on the Strength and other Properties of Metals for Cannon. 4to, 1856.

" conjoined with exact mechanical tests;" and the officers engaged in this labour at Pikesville Arsenal truly observe, in summing up their Report, " The strongest argument in " favour of such an investigation is its own importance and " prospective advantages; for the manufacture of iron is " the basis and index of modern civilization, and every " effort tending to improve it is a matter of general " welfare."

John Percy, M.D., F.R.S.

Metallurgical Laboratory,
Museum of Practical Geology,
London, May 1856.

IRON ORES of the NORTHERN and NORTH-MIDLAND COUNTIES of ENGLAND (CUMBERLAND, DURHAM, NORTHUMBERLAND, LANCASHIRE, YORKSHIRE, and DERBYSHIRE).

GENERAL DESCRIPTION. (By W. W. SMYTH, M.A.)

IN no part of the world has the production of iron advanced with more rapid steps than in the north of England, nor is there perhaps a limited district where the ores and their resulting irons are more varied in character; and although some of the mines to be noticed in this paper have been long celebrated for the part they have taken in contributing to this important branch of British manufacture, others of them have sprung into existence, and attained to colossal dimensions, within a period so recent as to invest them with a peculiar interest.

The employment of the ironstone which occurs in the coal measures, has from very early times invited the establishment of iron furnaces in the coal field of Derbyshire and the south-western part of Yorkshire, and these works are most of them honorably distinguished for the good quality of the material which they produce. Farther north there existed in the neighbourhood of Newcastle, in the year 1828, but one iron work, consisting of two blast furnaces; whereas within the last few years the improved means of transit and the increasing demand for iron have created extensive establishments, situate chiefly on the western border of the coal field, and fed with ores from various and distant localities. More recently still, within half a dozen years, the discovery and application of the abundant stratified ores of the Cleveland district in Yorkshire, has led to the erection of groups of smelting works in the southern part of Durham, and near Middlesbro' in Yorkshire; and whilst in some cases the ore is conveyed for many miles by railway to the coal producing district, in others the fuel is transported in the opposite direction to the immediate neighbourhood of the iron mines.

It is proposed in the following pages to give a brief account of the mode of occurrence of the ores of iron which are chiefly employed in these districts; and it may be useful in the first place to impress upon the reader the very high importance of these establishments in the North of England, by setting before him a summary of the blast furnaces now in operation.

Name of Works.	Owners.	No. of Furnaces.	Furnaces in blast.
NORTHUMBERLAND AND DURHAM.			
Auckland		4*	
Bedlington	Bedlington Iron Co.	2	2
Birtley	Birtley Iron Co.	3	3
Clarence	Bell, Brothers	3	3
Consett	Derwent Iron Co.	14	14
Crookhall			
Darlington	H. Pease and Co.	2	2
Felling	Pattinson and Co.	2	2
Hareshaw	Hareshaw Iron Co.	3	
Hartlepool, near		2*	
Lemington	Tyne Iron Co.	2	2
Stanhope	Weardale Iron Co.	1	4
Tow Law		6	
Stockton	Stockton Iron Co.	3	3
Shotley Bridge or Bradley	Richardson and Co.	4	4
Walker	Losh, Wilson, and Bell	5	4
Wallsend	Carr and Co.	2	2
Witton Park and Etherley	Bolckow and Vaughan	4	4
Wylam	Bell, Brothers	1	1
YORKSHIRE.			
Cleveland District.			
Cleveland	Elwin and Co.	3	2
Eston	Bolckow and Vaughan	6	6
Middlesbro'	Ditto	3	3
Ormesby	Cochrane and Co.	4	3
South Bank	Samuelson and Co.	3	3
Tees	Gilkes, Wilson, and Co.	4	4

* Now building, January 1856.

YORKSHIRE—*continued.*

Coal Measure District.

Name of Works.	Owners.	No. of Furnaces.	Furnaces in blast.
Beeston Manor	Harding and Co.	1	1
Bierley	Hird, Dawson, and Hardy	4	3
Bowling	Sturge and Co.	5	4
Chapeltown	Newton, Chambers, and Co.	2	1
Elsecar	Dawes and Co.	3	1
Farnley	Armitage and Co.	2	2
Holmes	S. Beale and Co.	2	2
Low Moor	Hird, Dawson, and Hardy	5	4
Milton	Dawes and Co.	2	2
Parkgate	S. Beale and Co.	1	1
Thorncliffe	Newton, Chambers, and Co.	3	2
Thorpe Hall	J. and H. Haines	1	1
Wosbro' Dale	Field, Cooper, and Co.	1	1

DERBYSHIRE.

Name of Works.	Owners.	No. of Furnaces.	Furnaces in blast.
Alfreton	Oakes and Co.	3	2
Brimington	Knowles and Co.	1	1
Butterley	Butterley Company	3	3
Codnor Park		4	4
Duckmanton	R. Arkwright	2	
Clay Cross	Clay Cross Co.	3	2
Morley Park	Mold and Co.	2	2
Newbold	S. Beale and Co.	1	1
Renishaw	Appleby and Co.	2	1
Stanton by Dale	Stanton Iron Co.	3	3
Staveley	Rd. Barrow	4	2
Unstone	Rangeley and Co.	1	1
West Hallam	Whitehouse and Co.	3	2
Wingerworth	Wingerworth Iron Co.	3	3

CUMBERLAND.

Name of Works.	Owners.	No. of Furnaces.	Furnaces in blast.
Cleator	Whitehaven Iron Co.	3	2

LANCASHIRE.

Name of Works.	Owners.	No. of Furnaces.	Furnaces in blast.
Newland Backbarrow Duddon	Harrison, Ainslie, and Co.	3	1

SUMMARY.

	No. of Furnaces.	Furnaces in blast.
Northumberland and Durham	63	50
Yorkshire	55	46
Derbyshire	34	26
Cumberland	3	2
Lancashire	3	1
Total	158	125

These smelting furnaces alone, irrespective of the mines, mills, and forges with which they are connected, represent, in mere erections and plant, a sum of half a million sterling.

The ores of iron raised in the northern counties, belong, geologically speaking, to three different formations, viz.

1. *The Carboniferous Limestone;* Weardale, Alston Moor, Haydonbridge, Whitehaven and Ulverstone.

2. *The Coal Measures;* Western edge of coal fields of the Tyne and Wear; coal fields of Yorkshire and Derbyshire.

45

3. *The Lias;* Cleveland district, in the north-east of Yorkshire.

The greater part of the blast furnaces employ, according to the facilities afforded by their position, ores derived from various localities; and it is therefore desirable, in discussing the materials from which iron is made in the establishments above enumerated, to group together the various ores under the divisions most naturally afforded us by the classification of the several rock formations.

ORES OF THE CARBONIFEROUS LIMESTONE.

Analyses have been completed of the following—

	Catalogue of 1851.	Analyses, page
1. Weardale Ores, Tow Law Iron Works -	—	55
2. Carbonate of Iron, Rispey, Tow Law Works	—	58
3. Hæmatite, Cleator, Whitehaven - -	424,426	60
4. do. do. - - -	427,429	61
5. do. Gillbrow Ore, Ulverstone, Lancashire.	—	63
6. Hæmatite, Lindale Moor, Ulverstone -	—	65

The principal mass of the carboniferous or mountain limestone* of the iron-producing districts under consideration, emerges from beneath the coal measures of Durham and Northumberland on the east, and is bounded by a steep declivity overlooking the vale of Eden on the west. It reaches a culminating point in the long mountain ridge of Cross Fell, and forms the vast tract of moorland, which near Alston extends for some 25 miles in width, and in the high desolate region adjoining the Scotch border, stretches across almost from sea to sea.

After an interval of some miles towards the west, the same formation rises again from beneath the new red sandstone of Penrith and the coal measures of Workington and Whitehaven, and lapping as a narrow belt round the older slaty rocks of the lake district, almost entirely encircles this the most beautiful region of England.

The structure of the central high land first mentioned, in which are situated the towns of Alston, Hexham, and Haltwhistle, differs materially from the contemporaneous formation which occurs farther south in England and Wales, and which consists principally of uninterrupted beds of limestone

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* For a detailed account of the structure of this important formation, see Westgarth Forster's Section of the Strata, 1821, and Phillips's Geology of Yorkshire.

to a vast thickness. In the north the actual limestone plays but a subordinate part, and alternates with strata of gritstone and shale, locally termed "hazle" and "plate." Certain ores of iron are interstratified with these beds; nodules of clay ironstone, the argillaceous carbonate, are met with in some of the bands of shale, the mode of aggregation being analogous to that of the similar ores of the coal measures. At Hareshaw, near Bellingham, towards the source of the North Tyne, four furnaces were erected some years ago, to smelt the clay ironstones which were obtained from the series of "sills" or beds intervening between the so-called "great limestone" of the Alston District, and the "second" or "little limestone" which lies about 60 feet above it. They produced excellent iron, but the expensive cartage of the ore, and the absence of railway or canal communication, were fatal for the time to the success of the establishment.

Near Haltwhistle and Nenthead the same "ballstones" have been worked at their outcrop.

Masses of brown iron ore (the hydrous sesquioxide of iron) appear in some instances to form regular layers, although their presence is probably in close relation to the veins of metallic minerals which in great numbers intersect the rocks in and around Alston Moor.

It is not until farther and systematic workings shall have been followed out that the true nature and extent of these apparent strata can be determined.

A bed of the carbonaceous iron ore termed "black band" was discovered a few years ago and worked till within a recent period, about one and a half miles north-west of Haydonbridge, near the Newcastle and Carlisle Railway; it ranged from two and a half to three feet in thickness, and being calcined on the spot, was proved at the Shotley Bridge furnaces to be a very valuable ore, but its cropping out on the west, and disturbances of the ground on the east, limited its exploration. Its true position in the series of the measures is not rightly understood, although it underlies a thick band of limestone, which may lead to the identification of its place; and it appears not improbable that a closer geological investigation of the neighbourhood might prove the existence over a larger area of this important substance.

The majority of the mineral veins or lodes of the Alston district, celebrated for their productiveness of lead ore, range nearly from east to west, intersecting the whole of the above-mentioned beds, but yielding their riches far more abundantly in certain strata than in others. Some of these lead veins, in a part of their course, are charged with brown iron ore instead of the usual veinstone of fluor spar and quartz and its concomitant lead ore. Thus the rich lode of Rodderup Fell where it crosses the valley of the Tyne, above Alston and is known as the Craig Green or Bracken Syke vein, is seen in the so-called "scar" limestone, as a vein of brown iron ore from 16 to 20 feet in width. Hitherto, however, from the remote position of the district, these repositories of an ore so well calculated to produce a good quality of iron have been very little explored.

Since the late extension of a branch railway to the town of Alston certain of the lodes, apparently producing nothing but this kind of ore, have been extensively wrought. Thus the Manor House vein has been opened very near the railway station, for the Shotley Bridge Company, and hundreds of tons have been raised from a very small area at the extremely low cost of 1*s*. 7*d*. per ton.* The vein is about 14 feet wide striking east and west, with a northerly dip, and throwing down the measures on its north wall about 12 feet. Its productiveness is increased by tongues or "flats" which penetrate to the distance of a few feet between the layers of the scar limestone which it here intersects.

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* It is worthy of note, that here, as in so many other localities, our forefathers had availed themselves of the occurrence of a rich ore to work it for their small charcoal furnaces; on the late opening of these works, remains of ancient galleries and a horse shoe were found, although the existence of old workings was not betrayed by any surface appearances.

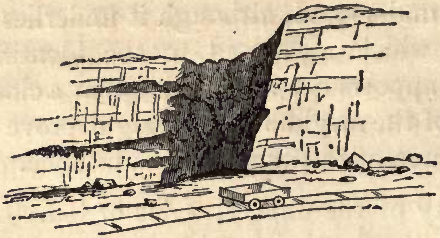

Diagram Section of Manor House Lode.

On the opposite side of the valley of the Tyne, the Park or Horse Edge vein has also lately been wrought, and considerable quantities of a similar brown ore are now being raised from the Thorngill vein where it intersects the "great" limestone.

To the west, on the northern shoulder of Cross Fell, and to the east at Kilhope, and in Weardale, the outcrops of similar iron veins present themselves. Crusts of manganesian botryoidal peroxide occur abundantly near the surface, varied by the delicate reddish brown tint of lepidokrokite. At the former locality some of the corals characteristic of this formation are found enveloped in and entirely fossilized in brown iron ore, a curious series of changes having probably operated on the fossiliferous limestone which at one time formed the walls or sides of the vein.*

In the eastern part of this region, another, the "sparry" ore, or carbonate of iron, makes its appearance abundantly in the lead veins, and is locally termed the "rider" or veinstone accompanying the ore which has been the chief object of search. At the mines of Allenheads, belonging to Mr. Beaumont, M.P., the sparry iron ore occurs both in the regular lodes and in the "flats" which insinuate themselves from them laterally into the limestone. Adjoining Weardale this character is still more pronounced, and in the neighbourhood of Stanhope burn the veins are so "ridered," so charged with this ore, that at a spot where several of them occur in close proximity, and interlacing "strings" additionally enrich

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* See specimens in the Museum of Practical Geology, wall case 49.

the ground, the whole surface has been removed from a large area by the Weardale Iron Company, and the rock absolutely quarried away, a considerable amount of lead ore being separated during the operation.

The ore No. 2, of which the analysis will be given, is derived from the Rispey vein in Rookhope, a lateral valley opening into Weardale. Here, as elsewhere in the district, brown peroxide is often mingled with the sparry ore, especially near the surface, where it sometimes spreads over a width of 30, 40, or more feet. There is little doubt that the brown ore is due to the decomposition effected by atmospheric or *anogenic* action, and that it was all originally placed *in situ* in the condition of a carbonate.

Remembering the high character of the iron which is produced from similar ores on the continent, more especially the celebrated "steel irons" of Siegen, and Styria, and Carinthia, it will be seen that the introduction of this ore into the British iron manufacture is a step of importance. Nor should it be forgotten, that till very recently it has been regarded as mere refuse during the working of the lead veins, and that larger quantities of it may reward farther research through these extensive moorlands.

Mr. Charles Attwood of the Tow Law works, to whom is chiefly due the merit of testing the value of the sparry ores, states that he employs much less of it than he could wish, in consequence of the comparatively scanty population, and of the greater expense of *getting* as compared with the brown ore, and that he reserves it for making the very best and highest priced irons.

When we look to the successive introduction of the various minerals which have filled these interesting veins, it is evident that the carbonate of iron has been one of the latest comers. Many of the specimens exhibit it investing as a crystalline incrustation the previously formed crystals of fluor spar and galena, and the striking manner in which it is often found to coat only those surfaces which face in a particular direction is well worthy of attention in the study of these obscure phenomena.* In other cases fragments either of the rocky sides of the fissure, or of a pre-existing vein, have been cemented together by the carbonate as a paste, and hence it ensues that whether introduced subsequently, or as in many instances simultaneously with other ores, it is very difficult to separate it from portions of galena and zinc blende in preparing it mechanically for the smelting furnace.

The hæmatite (red iron ore, sesquioxide of iron) of Whitehaven, occurs in the carboniferous limestone near the outcrop or surface edge of the slaty rocks upon which that formation rests. The greater part of the excavations from which it is extracted are subterraneous, and so extensive is often the mass of iron ore in which the workings are carried, that it is difficult in such situations to obtain a clear idea of the nature of this important deposit. But at a place called Todholes, near Cleator, an open work has for some time been in operation, which throws great light on the subject. A slight anticlinal axis has brought the iron ore to within a small distance of the surface, and the superficial covering of 15 to 20 feet in thickness, which contains very numerous angular fragments of gray limestone in its lower portion, being removed, the red iron ore is worked as a quarry. The floor of the deposit is a white and red mottled shale, almost of the nature of a fire clay, and is evidently a bed belonging to the limestone series; bore holes have been sunk in it to a depth of 30 or 40 feet without meeting with any other material. The surface of this shale is very uneven on a large scale, although the actual planes are smooth, and frequent sudden depressions or ridges throw it up or down for a few feet, disturbances which appear to be regularly followed by the superimposed hæmatite. Between the shale and the iron ore there lies, very generally, a band of conglomerate, from 3 to 8 inches thick, of small pebbles of white quartz. The mag-

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* See specimens in the Museum of Practical Geology, wall case 30.

nificent bed of hæmatite which then follows, varies from 15 to upwards of 30 feet in thickness (rarely, as in Big Rigg Moor, as much as 60 feet), and is for the most part a dense mass of red ore subdivided by irregular and nearly vertical joints. Small cavities rarely occur, adjacent to which the ore assumes those botryoidal forms commonly termed "kidney ore," so well known in mineralogical cabinets, and which exhibit this mineral in a high state of purity. In such parts of the mass, rock crystals frequently occur, and calcareous spar and arragonite appear to be the substances which were last crystallised in the hollows.

Section of Hæmatite at Todholes.

1. Drift with limestone fragments.
2. Impure limestone "roof."
3. Hæmatite, 20 feet thick.
4. White "shale floor."

With a general parallelism to the floor of the deposit, two and sometimes three bands of greenish black shale, from 1 to 8 inches thick, are distinctly interstratified with the iron ore; and the presence of these partings, with the overlying roof of impure limestone which makes its appearance on the dip, leaves on the mind almost a conviction that the hæmatite occurs as a true bed.

And yet it is difficult to remain satisfied with the view of the regular contemporaneity of the ore with the limestone strata. In other mines of the district the presence of a definite and nearly vertical boundary along one side of the workings is more nearly akin to the phenomena of a vein, and it is very possible that a systematic examination of the whole group of localities might lead to the assigning of a later date for the introduction of the iron ore into chasms and hollows which had been formed in the already consolidated beds, and thus bring the nature of the repositories of Whitehaven into coincidence with the more clearly marked ores of Ulverstone.

There seems occasionally to be a second bed, in a somewhat higher position, which rests upon a limestone floor; but hitherto so small an area has supplied the requirements of a single mine that the physical structure of the district is very imperfectly understood, both as regards the extent of these unrivalled deposits and their exact position among the members of the mountain limestone.

A shaft which has recently been sunk at High House near Cleator, through a greater depth of cover than usual, yields the following section:—

	Ft.	In.
Dark Shale - - -	156	0
Coarse Grit, called "Millstone" Grit	36	0
Shales - - - -	30	0
"Whirlstone" - - -	12	0
Shales - - - -	54	0
Red Limestone - - -	7	0
Shale - - - -	1	8
Hæmatite pierced to depth of -	32	0
	328	8

When the ore is worked as a mine, galleries are driven out from the shaft 14 or 15 feet in height, forming "rooms" with substantial pillars left between them; and after a certain area has thus been prepared, the pillars are "robbed," the roof falls, and the surface of the land commonly gives way. The depressions which ensue and often become pools of water, with the crushing action on the neighbouring workings, render the last stages of the operation somewhat insecure, and necessitate special caution.

A small proportion only of the ores of the Whitehaven district, is smelted on the spot. The coal of the neighbouring field is ill suited for smelting purposes; and the admirable coke of the Newcastle district has to bear so expensive a carriage that but one ironwork, that of the Whitehaven Hæmatite Iron Company, has, for some time past, been in action. This establishment, situated near Cleator, is placed close upon the edge of the coal field, and possesses three blast furnaces, smelting no other ore than that of the district, which the company purchases from its neighbours. Hot blast is employed, and a certain quantity of shale has to be added to the usual materials, in order to supply in conjunction with limestone the requisites for a slag.

IRON ORE MASTERS OF THE WHITEHAVEN DISTRICT.

1. Ainsworth and Co., *Cleator.*
2. John Stirling, *Todholes.*
3. Messrs. S. and J. Lindow, *Bigrigg Moor.*
4. Anthony Hill, *Bigrigg* and *Crowgarth* mines.
5. Hesket Iron Ore Company, *Hesketpit.*
6. Richard Barker.
7. Henry Attwood and Son, *Woodend* and *Berks* mines.
8. Messrs. Tulk and Ley, *Agnes* and *Yatehouse* mines.
9. Parkside Mining Co., *Parkside* and *Goosegreen* mines.
10. S. W. Smith and Co., *High House* mine.

The quantity of hæmatite ore sent from Whitehaven by sea and by railway amounted in the year ending the 25th March 1855 to 192,312 tons, besides what was smelted in the three furnaces of the Iron Company at Cleator.

On the north side of Morecambe Bay the promontory of Low Furness, between the slate hills which rise at the back of Ulverstone and the New Red Sandstone forming the site of the venerable ruins of Furness Abbey, is composed of the carboniferous limestone, covered up for the most part with drift or "till."* Over an area about six miles long and four broad, red hæmatite has been worked in numerous localities, and in some of them from a very early period. Neither the underground workings, however, nor the phenomena visible by daylight enable one to arrive at a very satisfactory conclusion as to the character and origin of these vast masses of rich ore.

At Stainton, south-east of Dalton, where two mines are in work, the excavations have left open a yawning chasm of 20 to 30 feet in width, ranging about North by East, with walls of gray limestone inclining slightly to the south-west. The appearances are so closely akin to those of a regular lode, that although the depth reached by the shaft is 60 yards, there seems good reason to expect the ore to continue in depth.

Less distinct are the features of the deposits in the Lindale district, and west of Dalton. Among the more remarkable for extent are the Lindale Moor mines, worked to a depth of about 70 yards, but to a width sometimes almost as great. Huge excavations are thus formed in a mass of solid ore "as large," according to the saying of the district, which recals the comfortable status of the Furness churchmen, "as a tithe barn." The result has been the collapse of the surface of the ground into a deep gully for a quarter of a mile in length. The direction of the fissure is north-west and south-east, and it was asserted by the manager that he had found slaty rock to form the northern wall, limestone the southern. It is remarkable that in this and several of the neighbouring veins, a portion only of the ore, and generally adjacent to one wall, is of the compact character exported for smelting purposes, and thence termed "blast ore." A great part is often filled with "raddle," a light and less coherent aggregate of ex-

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* For a sketch of the geology of this district, see a paper by Mr. Binney, in the 8th volume of the Manchester Literary and Philosophical Society's Memoirs, 1848.

tremely delicate filmy scales of micaceous iron, soiling the finger on the slightest touch, and sometimes enclosing small portions of the more compact kind; it is sold as "puddling ore," for the purpose of forming the bottom of puddling furnaces, at a higher price than the "blast ore."

Close upon the boundary of the Silurian rocks (the Coniston or Furness grits of Sedgwick), at Whinfield Farm, are the mines of Carr Kettle and Gillbrow, in which the ore-bearing deposit takes a parallel course, at the distance of only a few yards from the former. And the circumstances both of limited length, great width, direction, and material of the deposits are similarly repeated at Whitriggs, Crossgates, and Eure Pits.

On the north of the town of Dalton, at Rickett Hills, Elliscales, and Mousell, the hæmatite has been worked in several isolated repositories, described as of a "dish shape," in which the excavation has been stopped on all sides by limestone; several of these, whose boundaries have been ascertained, run from 50 to 60 yards in width, and 15 to 20 yards deep, having no cover over them but the "diluvium," or drift. At Mousell some open works now in activity present a mass of the soft ore above described, varied occasionally by harder portions which often have a fragmentary appearance, and more rarely by interspersed patches of a white slightly coherent sandstone. No regularity of arrangement is observable, no resemblance to the character of a lode, except in an occasional piece of limestone wall, which suggests as much the idea of the side of a channel eroded by water as of a vein fissure. Numerous smooth faces or heads, exhibiting the striæ which are generally ascribed to attrition, intersect the mass of iron ore near its boundary, proving the fact of disturbances or settlements after its first consolidation.

Between Dalton and the western coast, another very remarkable tract of ore is worked at the Park and the Roanhead mines. Limestone surrounds its irregular margin, but rather in the form of two slightly connected basins than of a vein. The hæmatite is often of an extremely fine and crystalline character, the fibres of its spheroidal mammellated aggregates being sometimes more than 6 inches in length.*

What with the richness of the ore and its extent, this place has few rivals in the world; you may proceed 4 or 500 feet in either direction in one solid mass of this valuable substance, and nothing has yet been seen of the bottom of it.

The natural cover of the deposit is a loose sea-sand overlaid by some yards of till or thick clay; and the incautious entrance into old workings, or a sudden fall of roof, have several times liberated the quicksand saturated with water, and produced ruinous results. A sudden incursion of this kind, the day before I visited Roanhead in January, 1856, may be cited as an example of the accidents to which these mines are subject. The blow of a pick into some old workings had formed a small opening, which, whilst the men in headlong flight barely escaped to the shaft, burst forth in a huge torrent of sand and water, choking in a very few minutes the galleries of the mine, breaking the pumping machinery and precluding access to all the lower workings. During the night the surface of the ground cracked and rent in various directions, the roadway and part of an adjoining field sunk in, and the crush having then abutted on solid material, it became possible with safety to commence to repair the disaster.

In the ordinary process each stage of the working is 9 feet high, and one horizon is entirely cleared out before the next beneath it is commenced; the roof is meanwhile partially supported by strong timber framing, so that when several such stages have been exhausted, the place of the ore is occupied by a certain quantity of refuse and by a collapsing forest of Baltic pine. No precautions can long save a shaft, except of the smallest dimensions, placed in such a subsiding mass. An attempt was made at Stainton, not long

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* See specimens from Roanhead in Museum of Practical Geology, wall case 48.

since, to work by means of a shaft 24 feet long by 12 feet broad, in opposition to the experience of the miner; it soon began to yield, various devices were employed to keep the closing walls apart, but in vain; the whole fabric went down together, and has left scarcely a wreck behind.

It is but a few weeks since a "run" of this kind took place at Cleator, and an unfortunate man was overwhelmed by the falling ground. In vain the miners laboured, for days together, with the gallantry they always display in endeavouring to rescue even the mutilated body of a comrade, in vain the managers aided with all their means, the crush only became more hopeless. The attempt had to be abandoned, and the burial service was read at the surface over the spot where the poor fellow lies buried far beneath.

The shafts of the district, whether thus placed, or more securely at some distance from the ore, are much better fitted with apparatus for raising the mineral than in most of our metalliferous mines; steam engines, and in many instances the "water balance" are adapted to this purpose, and the waggons are drawn in cages running against slides. It would be impossible, without devoting much time to the subject, to speak critically of the other arrangements for the practical underground operations.

Very large quantities of the Ulverstone ore are shipped for the supply of Staffordshire, South Wales, and other districts; considering its quality, it brings but a low price, viz., from 11*s*. 6*d*. to 13*s*. 6*d*. per ton.

The usual rate of royalty paid to the "lords" is 1*s*. 3*d*. per ton of 21 cwts. And when we compare this with the very low dues, often only a third of that amount, taken by the lords of the newly discovered Cleveland and Northampton ores, it would appear that, accidentally, a check is given to the production of a good ore, a premium is placed upon the extraction of inferior ores, and—if with due diffidence it may be said—upon the consequent deterioration of iron.

The effect is moreover heightened by the high rates charged by the new railway for the conveyance of the ores over very short distances; although in this respect Ulverstone has taken precedence of the Cleator district, from which the ore is still conveyed by carts along the ordinary roads.

A small amount of the Ulverstone hæmatite is still smelted with charcoal at the furnaces of Newland, Backbarrow, and Duddon, one of which only is in blast at a time: and this forms the only relic left in England of the old mode of production, so completely has the introduction of coal swamped the use of vegetable fuel.

The following are the workers of mines in the Furness district:—

Harrison, Ainslie, and Co., *Lindale Moor, Whitriggs, Gilbrow.*
Schneider, Hannay, and Co., *Park, Mousell, Whitriggs, Old Hills, Newton.*
C. S. Kennedy, *Roanhead.*
Rawlinson, Jos., *Crossgates, Carr Kettle, Rickethills.*
H. Kennedy and Co. or Ulverstone Mining Co. } *Lindale Cote, Eure Pits.*
Brogden and Co., *Stainton, Adgarley, Bolton Heads.*
Fell, Messrs., *Stainton.*
Ashburner, Geo., *Elliscales.*

The total quantity of hæmatite exported from the Ulverstone district amounted in 1854 to no less than 354,685 tons, making with the amount raised near Whitehaven, and that used in the neighbourhood, a grand total of 579,924 tons as the year's production of these two important sources of our richest iron ores.*

In other parts of the northern counties, hæmatite occurs in less important deposits, especially in certain veins in Derbyshire, but since their produce is not included in the present series of analyses, we may omit their detailed description.

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* These details are extracted from the statistics of iron and coal compiled by Mr. R. Hunt, F.R.S., and published in the Memoirs of the Geological Survey. Longmans, 1855.

IRONSTONES OF THE COAL MEASURES.

The ores which are interstratified with the other rock layers in all the coal fields of Britain are, to the uninstructed visitor, among the least attractive specimens of the mineral kingdom. Gray, brownish, or black lumps and nodules, they present none of the symmetry of crystallization, no transparency or brightness of colour, to invest them with external interest. But it is mainly to these commonplace-looking ironstones, to their good qualities, and to the fortunate manner in which they occur associated with the beds of fossil fuel, that the manufacture of iron owes the gigantic strides which it has made within the last half century, and to which Great Britain must ascribe her remarkable pre-eminence in this amazingly important branch of industry.

Although the clay ironstone (argillaceous carbonate of iron: *Sphärosiderit* of the Germans) occurs more or less in all our coal-bearing regions, it is developed in certain among them in too small a quantity to render it capable of profitable extraction. In some of them it is the only ore which is employed for smelting, whilst in others it is used in conjunction with richer ores conveyed from a distance, and in some few instances forms so small a proportion of the total material which is treated as to hold but a low rank in importance.

Of the northern districts included in the present paper, Northumberland and Durham fall within the latter category. On the western or outcrop side of that coal field, the numerous furnaces of Consett, Tow Law, and others, were erected in localities where a certain supply of the clay ironstone was obtainable from the lower portion of the measures, principally beneath the beds of coal which are worked for export, and above the millstone grit. The courses of "stone" occur in close proximity to those coal seams which within the last few years have risen into great importance from their excellent coking properties, but their development is so partial that although when near the outcrop, at the Consett Works, west of Gateshead, they formed at first a chief part of the raw material required, their extraction has now ceased, and at the distance of a few miles, around the Marley Hill and Pontop Collieries they are said almost entirely to have thinned out. At Tow Law, which is placed farther south, in a similar position as regards the outcrop, these ironstones are still raised. The lowest important seam of coal in the series is here worked for the furnaces, varying from four to six feet in thickness (where it is not split or subdivided), and called the Beaumont, *alias* the Harvey Seam.

This region of the best coking coal, which extends from Wylam in the northern to St. Helen's Auckland in the south-western part of the field, has been within the last six years brought into an interesting relation with the north of Yorkshire. Its indigenous iron ore was so insufficient in quantity that ruin seemed to impend over some of the large works established there; but the spreading of the great railway net, and the almost contemporaneous discovery of the ores of the Lias in Cleveland totally changed the scene. No longer need the workers of the coal measures to repine over the paucity of their nodules; the admirable coke which they produce is exported to manufacture iron at Middlesbro' in Yorkshire, and the returning trains carry back large quantities of that ore which is obtained so cheaply as to bear the expense of transit without difficulty.

In the Lancashire coal field argillaceous ironstones occur in several parts of the coal measures, but not in such abundance as to have led to their extraction for smelting purposes.

YORKSHIRE.

The coal field of Yorkshire may be considered, especially in respect to its iron manufacture, as admitting of division into two parts, the northern or district of Bradford, and the southern which ranges from Leeds by Barnsley to Sheffield and Rotherham.

Bradford District.—In the former portion the lower part of the strata is developed to a degree of importance not seen in the south, by the occurrence of the beds of coal and ironstone which have given rise to the establishments of Low Moor, Bierley, and Bowling, celebrated for the production of the best irons made in Britain, and to that of Farnley, which is following in the same steps. The castings from these works are largely employed for special purposes where strength and tenacity are required, as for mortars and sea-service guns; their wrought iron, the quality of which is attested by its bringing nearly twice the price of ordinary English iron, has the peculiarity of a granular structure, with a uniform, small, and brilliant grain which closely resembles the character of the Swedish bars.

It is an important fact that coal-measure ironstones are alone employed in this district, and principally from two ranges of strata called the *White Bed Mine* and the *Black Bed Mine* respectively; a third, the *Brown Rake*, was also formerly worked. Neither their quality nor their abundance have much contributed to the celebrity of the North Yorkshire iron, as the result of analysis and comparison with other coal fields will show. The superiority appears to proceed from the care and attention bestowed upon the various processes, and from the admirable character of the seam of coal, termed the "better bed," which lies beneath the ironstone, and attains a thickness of only 1 foot 8 inches to 2 feet; it differs, however, from ordinary seams in its remarkable freedom from iron pyrites and other impurities, and is exclusively used for smelting, refining, and puddling. You may pass through the thick smoke of the coking heaps or ovens without the least inconvenience from the sulphurous gases, which in the coking of most coals are so freely liberated.

An average section of the measures is as follows, the numbers prefixed relating to the series collected by Mr. S. H. Blackwell, and enumerated in the Catalogue of the Exhibition of 1851:

	Cat. 1851.
White bed Ironstone, Bierley. Analysis No. 7.	300 Top flats.
	301 Low flats.
	302 White balls.
	303 Middle balls.
	304 Low measure.
Black bed Ironstone, Lowmoor, in 18 beds. Analysis No. 8.	305 Top balls.
	306 Flat stone.
	307 Middle balls.
	308 Rough measure.
	309 Low measure.
	310 Basset stone.

	Ft.	In.		Ft.	In.
Royds or Black bed Coal	1	4	to	2	3
Various measures Roof of coal, black shale with numerous fish remains, and small white nodules of ironstone				120	0
"Better bed" Coal	1	4	to	2	0
"Floor" of indurated clay with small scales of white mica					
Various measures				150	0
Flagstone, exported for London pavement, &c.					

These ironstones, as usual with their class, are exposed for many months to the weathering action of the atmosphere, in order to free them from the adhering shale; they are then calcined previously to smelting, and unusual care is taken to pick out every kind of refuse or impurity.

The higher band, the *white bed*, is characterized by the pale drab colour which pervades most of its courses, although enclosed in a darker shale or bind. The *black bed* is of the blackish gray tint more usual with clay ironstones, and occurs in detached nodules of various sizes, but, taken as a whole, smaller than those commonly worked in the coal fields.

The extension of these rows of nodules and their accompanying coal seams over other portions of Yorkshire is a question of much interest, when we know how persistent some similar beds are over very large areas. But the quality of coal in the same seam will often vary within a small distance; and ironstones, either by running smaller, or by their courses being separated by a thicker band of shale, may become unworkable; several trials already made in search of the Lowmoor series have proved this deterioration, and although it may be predicated that the same strata may be followed up on the dip, far beyond where they are at present known, it is by no means certain that they would retain the qualities which have given them celebrity.

Southern Yorkshire.—The ironworks of this district are situate between the North Midland Railway and the line of high ground which, abounding in gritstones and flags, marks the outcrop of the lower portion of the coal measures. A beautiful district by nature, the West Riding of Yorkshire has not yet been despoiled of all its picturesque character, and specially in the iron-bearing part are the hills well clothed with wood, the valleys deeply cut and adorned by rapid streams. From the banks of the river Dun which flows past Sheffield, rise in bold masses the Wharncliffe rocks, which may be followed along the outcrop in a north and south direction, dipping with the rest of the measures towards the east, and forming the base of that portion of them which yields the ironstones and coals of the tract under consideration.

From Park Gate, near Rotherham, over Lord Fitzwilliam's fine property of Wentworth, to Tankersley, and on to the west of Barnsley, may be traced in succession many of the more important bassets of ironstone, the value of which, added to a particular method of working, has imparted a strange aspect to the surface, which is reflected in the well-executed shading of the Ordnance map.

Wherever the courses of ironstone nodules come up to within a short distance of the surface they are vigorously attacked by the small shafts termed *bell pits*, disposed in great numbers along the line of strike, at a distance of a few feet only each from the other, and arranged like the vines of Virgil,—

"All in regular order, with intervals each like the other;
"Not for the empty mind to approve the symmetrical aspect,
"But that to all alike the earth may distribute her treasures." *

The result of the *belling*, and the open work which not uncommonly accompanies it, is to leave long lines of irregular holes and pits, often so considerable as to unfit the land for agriculture, and to induce the planting of belts of trees. The ironstone *bind* or shale appears not to be prejudicial to their growth, and the strips of plantation thus offer to the eye, even from a distance, a clue to the arrangement of the strata beneath the surface.

The beds of coal and of ironstone frequently change their appellation in passing from one part of the district to another, so that it becomes difficult to identify them in distant localities without a very accurate study. The Rev. Mr. Thorpe has published a valuable aid in this direction in his Section of the Yorkshire coal field, where he has united the result of the sinkings and borings over a very large area.

The more important of the ironstones employed in the West Riding are interstratified in about 1,000 feet thickness of measures, which intervene between two well-marked beds of coal, the *Barnsley thick* coal and the *Silkstone*, and are known as the *Swallowwood*, the *Lidgate*, *Tankersley*, *Thorncliffe Black Mine*, *Thorncliffe White Mine*, and *Clay Wood Mine*.

An average section in the Wentworth district of the ironstone-bearing part of the coal measures, is as follows:—

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* "Omnia sint paribus numeris dimensa viarum,
"Non animum modo uti pascat prospectus inanem,
"Sed quia non aliter vires dabit omnibus æquas
"Terra."

VIRGIL, *Georgics*, lib. ii.

			Ft.	In.		Ft.	In.
COAL, Low Wood, Hobbimer, Elsecar or Barnsley			6	0	to	9	6
Various measures, with several small coal seams						180	0
Swallow Wood Mine, Milton.	311 Flats. 312 Balls. 313 Bottom measure.						
COAL, Swallow Wood, or Strafford Main			3	4	to	6	0
Measures						130	0
Lidgate Mine	314 Flats. 315 Balls. 316 Bottom measure.						
COAL						1	0
Measures, near Milton						30	0
COAL, Lidgate						2	4
Measures						120	0
COAL, Tankersley thin						1	10
Tankersley Mine, or *Joan.*	317 Top measure. 318 Middles. 319 Bottom measure.	12 to 15 in. ironstone.				6	0
Measures						66	0
COAL, Heward or Top Flockton			2	0	to	4	0
Measures very variable in thickness						140	0
COAL, Fenton's thin (good smithy coal)						2	0
Thorncliffe or *Old Black Mine,* Parkgate.	320 Balls. 321 Holing measure.	11 in. of ironstone.				4	0
Branch COAL						1	6
Measures						75	0
COAL, Parkgate, Thorncliffe thick, or Manor			4	10	to	7	10
Thorncliffe White Mine, or *Cowley Lane ironstone.*	322 Flats. 323 Balls. 324 Holing measure.						
Measures						72	0
COAL, Thorncliffe thin, or Furnace			2	6	to	3	0
Measures, including three thin seams of COAL from 6½ to 18 inches each						140	0
Clay Wood or *Black Mine,* Parkgate.	324 Balls. 325 Brown George. 326 Whetstone.					0	5½
Shale measures						36	0
COAL, Silkstone, Bromley, Sheffield, or Black Shale						4	0

Of the ironstones which have been selected for analysis No. 9. (or 320, 321, in the Illustrated Catalogue) is the *Thorncliffe* or *Old Black Mine*, of which about 1,500 tons are yielded by one acre. Some of the larger nodules often exhibit cracks formed by contraction which have been filled up with brown spar, the carbonate of lime, magnesia, and iron.

No. 10. (Illustrated Catalogue 322, 323*a*, 324*b*,) the *White Mine* of Parkgate, which yields about the same quantity, was formerly worked on a large scale by the Messrs. Walker, at the Holmes, and is still used by Messrs. Newton, Chambers, and Co., at Thorncliffe.

No. 11. (Illustrated Catalogue 324, 325, 326), the *Clay Wood Mine*, a brownish gray ore, produces 1,500 or 1,600 tons per acre, and, with No. 9, are the chief ironstones employed at the Thorncliffe ironworks.

The *Tankersley* or "Musselband" ironstone yields on the average about 2,000 tons to the acre, although as much as 3,400 tons has been exceptionally produced. It is so called from the great number of fossil shells (*Unio*) which characterize it, and it is probable that in a supplement the analysis of this ore also will be given.

DERBYSHIRE.

The coalfield of Derbyshire being the extension southward of that of Yorkshire, it is easy to trace many of the same seams continuously over a very large area; and a reference to the maps prepared by the Geological Survey will most distinctly prove this point, by exhibiting, unbroken from the valley of the Don to the southern extremity of the coal district, the outcrop of the two principal beds above alluded to. They change their names in different parts of the county, but are best known under the appellations of the *Top Hard* and *Black Shale* or *Clod coal* respectively; and between these two, as in Yorkshire, all the more important measures of ironstone are situate.

The beds of ironstone are somewhat more capricious than those of coal; a few of them maintain a valuable character throughout the length of the county, but many of the rows of nodules, or so-called *Rakes*, which are largely worked in certain districts, are found to thin out or deteriorate within a comparatively short distance. Thus, a series of strata far below the above-mentioned "Black Shale" coal, although hitherto considered of no account in the greater part of the county, are sufficiently improved at the southern end of the coal area as to have given rise to very important workings near Stanton-le-Dale.

The following general section of the portion of the Derbyshire coal measures in which most of the ironstones occur, includes the beds or seams worked at all the important localities:—

			Ft.	In.
Yard Coal			3	6
Measures, various			90	0
	Measure and Balls rake (Staveley)	327–34.		
Measures, apparently thickening southwards			75	0
Coal, Main or Top Hard (Staveley, Swanwick, &c.)			6	0
Measures			84	0
Coal, Dunsill, or Oldgreaves			4	0
Measures			100	0
Coal, Waterloo			4	0
Measures			20	0
Coal, Cannel			1	4
Measures			27	0
Coal, Tunnel			1	5
	Buff, or Cement rake, Alfreton.	341 Top measure. 342 Balls. 343 Bottom measure.	9	0
	Pinder Park rake, Staveley.	338 Red measure. 339 Balls. 340 Cockle.	6	1
	Brown rake, Butterley. 2,500 tons per acre.	344 Balls. 345 Top measure. 346 Bottom measure.	4	6
Measures			29	6
	Black rake, Butterley. 5 courses, 2,000 tons per acre.	347 Top measure. 348 Bottom measure.	4	6
Bind			1	4
Coal, Ell, Chavery or Allwoods			3	0
Measures			39	0
Coal, Main Soft, or Handley Wood			5	0
Measures, with	*Poor rake,* Alfreton *Blue rake,* Butterley	349 *a* and *b*. 350.	87	0
Coal, Lower or Deep Hard			5	0
Measures			69	0
Coal, Piper, or Three bedded			2	3
Measures, with	*Spring* or *Ridding's rake,* Alfreton, 341. *Old Man's rake,* Butterley, *and* *Whetstone rake,* Butterley.		96	0

		Ft.	In.
Dog-tooth rake, Staveley. 2,000 tons per acre.	352 White measure. 353 Sugar-plum measure 354 Marble measure. 355 Balls. 356 Snail-horn.	8	4
Called *Wallis's rake* at Butterley.			
COAL, Dog-tooth, near Chesterfield		3	0
Measures, with *Brown measure,* Clay Cross, 357 (2 ft. 10 in.)		39	0
COAL, Furnace or Tupton		4	6
Measures		15	0
Three-quarter Balls. 5 courses, at Clay Cross.	360	10	8
COAL, Three-quarter or Lees		2	0
About the same place, *Nodule rake,* Morley Park, 1,600 tons per acre.	358 Cinder measure. 359 Balls.		
South of Clay Cross this is called *Dog-tooth rake.*			
Measures		27	0
Black Shale rake, 4 to 7,000 tons per acre. Near Chesterfield divided into top and bottom measure by 12 ft. of bind.	361 Whetstone. 362 Chitter. 363 Cheeses. 363*a* Bear. 364 Top blues. 365 Lower blues. 366*a* Old man. 366*b* Old woman.	16	0
	367 Smooth chitter. 368 White balls. 369 Flampard. 370 Red measure 371*a* Dun. 371*b* Beams. 372 Roof measure. 373 Bottom balls.	21	0
Striped rake, Kirk Hallam, 2,500 tons per acre.	374–5, 6.		
Shale, &c.		3	6
COAL, Yard or Roof		2	8
Shale and thin coals, averaging		10	0
COAL, Black Shale or Clod (Sheffield seam)		5	0
Measures		37	0
Green Close rake, Morley Park.	377 Balls and bottom measure.		
COAL, and "Bat" or Black Shale		5	0
Hollyclose rake, Morley Park.	378.		
Measures with *Black or Ketlands rake,* Morley Park, 3,000 tons per acre.	379–84	216	0

		Ft.	In.
Baconflitch rake, Alfreton.	385 *a* & *b*.		
Yew-tree rake, Morley Park.	386.		
Coal		1	6
Measures		66	0
Coal, Kilburne, Buckland-hollow, or Honeycroft		5	0
Clunch		3	0
Honeycroft rake, Stanton. 6,000 tons per acre.	387 Chitters. 388 Tufty balls. 389 Barren beet. 390 Grindstone measure. 391 Grinder's wife. 392 Big balls. 393 Bottom flats. 394 Brick measure.	45	0
Measures, without "rock" or sandstone		252	0
Civilly rake, Stanton. 4,000 tons per acre.	395 Ratchell measure. 396 Chance balls. 397 Bottom measure. 398 Chitters. 399 Coal measure.	60	0
Coal, Furnace		2	3
Dale Moor rake, 3,000 tons per acre.	400 Clunch balls. 401 Roof measure balls. 402 Roof measure. 403 Over bottom. 404 Bottom balls.	21	0
Measures		96	0
Coal, Bottom, resting almost immediately upon the coarse grits, commonly called Millstone grit		2	0

Among the beds thus enumerated, those which lie above the Top Hard coal have not been very generally worked, and are thus difficult to identify in isolated localities. This applies especially to the measures called the *Brierly Bank rake, Inkersal,* and *Measure and Balls rake* of the northern part of the field, and the numerous bands of ironstone detailed in the carefully executed sections of the Butterley Company in the southern portion of the district.

The total thickness of coal measures in the above section is 1,600 feet; and to this may be added about 400 feet for the ground, containing also several seams of ironstone and coal, which caps towards the east the more important portion which we have detailed. A few comments on some of the beds are appended, taking them in the descending order of the section.

Below the Tunnel coal, and about 50 feet above the well-marked and continuous seam called the Main Soft coal (largely worked at Shipley, Babbington, &c.), occur some of the more productive measures, the *Pinder Park* of Staveley, and the *Ruff* or *Cement rake* and *Brown rake* of Alfreton and Butterley.

The *Dog-tooth rake* (Chesterfield) is one of the most important in the field, and remarkable from the fact of one or more of its beds being almost entirely made up of fossilized bivalve shells, the *Unio* of many authors, more recently termed *Cardinia* and now *Anthracosia.*

A section of the beds accompanying it at Unston, near Dronfield, was well exposed in the *bell pits* by which it was worked, and in adjacent pits.

GRAY SHALES WITH IRONSTONE.

	Ft.	In.
Dog-tooth measure	24	0
Bearstone, or band of cone-in-cone structure	0	9
Shales	9	0
Blueish bind with two courses of ironstone	4	0
COAL	1	2
Hard floor, with Stigmariæ abundant, very similar to "Gannister"	1	0
Fire-clay	4	0
COAL	1	9

The fossil shell which occurs so abundantly in this ore as greatly to affect its chemical composition is in many districts preserved with the utmost sharpness, and is referred by Mr. Salter to the species *Anthracosia agrestis* (Brown), *acuta* (Sow.), and appears to be identical with that from the Blue vein, Ebbw Vale, South Wales. It will be seen from the Analyses XVI. and XVII. that a great difference exists in the composition of different bands of this "measure;" and that in Nos. 354 and 356, the first of which is a perfect mash of shells converted into crystalline carbonate of lime, the per-centage of phosphoric acid, of organic matter, and of lime is greater, whilst that of iron is considerably less.

This shell, *Unio* or *Anthracosia*, probably of several species, is found more or less abundantly in all the ironstone beds, from the top of our section down to the Black Shale rake. In the lower measures it is much more scarce, or is even altogether wanting, although in some of the very lowest it again appears more numerously. The *Anthracosia bipennis*, which occurs in No. 330, the Measure and Balls rake, is found also in the Low Moor ironstone, and at Mold in Flintshire. We cannot but marvel at the wondrously prolific condition of the water in which these creatures lived, evinced as it is by banks of innumerable shells, piled upon one another, often to several inches in depth, and extending over many miles in area.

On the prolongation of these beds to the southward much confusion arises in consequence of the same name being given by the miners to any ironstone of similar structure; and thus the measure situated at the same distance above the Furnace coal at Codnor Park, Butterley, as the Dog-tooth at Chesterfield, and very full of the same bivalve shells, is termed *Wallis's rake*, and is separated by only a few feet of bind from a measure above it called the *Whetstone rake*. Wallis's rake appeared to be a great favourite with the men, being eulogised as the best ironstone in England, and asserted to contain an impossible proportion of iron.

Below the Furnace coal, the *Three-quarter balls* form a very productive working at Clay Cross. Several of these lower ironstones contain besides bivalve shells the remains of calamites and other coal plants, very commonly forming the surface of the nodule, and completely changed into ironstone. It is probably the same measure which, occurring south of Clay Cross, and especially at Butterley, about 10 feet below the Furnace coal, is called the *Nodule rake*, though by some it is termed the *Dog-tooth*. In both are numerously found small tubular hollows left by the rootlets of Stigmaria, and not unfrequently filled with zinc-blende.

The most remarkable of all the ironstones of the district is the so-called *Black Shale rake*, or *Striped rake* of the south, which occurs at a varying distance above the Black Shale or Clod coal. Its fullest development is met with between Dronfield on the north and Butterley on the south, and nowhere is it so well seen as at Hady, near Chesterfield, where it has long been actively worked for the Staveley iron furnaces. At this place it consists of two banks of gray shale, of 15 and 21 feet thick respectively, loaded with numerous rows of nodules, and having between the two 12 feet of unproductive shale. Each separate measure is well known to the workmen by distinctive character and by name; and as the Black Shale ironstone is not less interesting to the miner than as an unique specimen of this kind of accumulation to the geologist, a detailed section of it is here attached.

	Ft.	In.
Whetstone, lean or poor measure, not got	0	1
Shale	1	6
Single balls, do.	0	0½
Shale	1	6
Double chitter, do. brown rough nodules	0	2
Shale	3	0
Cheeses, good measure	0	1½
Shale	2	0
Bearstone, capped with cone-in-cone, lean, rough texture	0	1
Shale	2	3
Blues, upper, good and rich, flat nodules	0	1
Shale	1	3
Blues, lower, do. do.	0	1½
Shale	2	0
Old man, good; nodules often thick, average	0	2
Shale	1	6
Old woman, or *sheeting,* good; flat nodular	0	1
Total of top measure	15	11½
Intermediate Bind, with an irregular bed of ironstone, 18 ins. from bottom	12	0
Smooth chitter, a lean measure, brown and rough	0	2½
Shale	3	6
Flampard, a very rough, granular-structured stone; lean	0	3
Shale	2	0
Red measure, good; cleavage planes, with white coating	0	1½
Shale	3	0
Chance measure, lean	0	0½
Shale	1	6
Dun lining, do., black, with small crystals of pyrites	0	1
Shale	1	0
Dun measure, good; thick black nodules	0	2
Shale	2	0
Over lumps, good; cracks coated with white powder	0	1
Shale	1	0

	Ft.	In.
Nether lumps, good; cracks coated with white powder	0	1
Shale	1	6
Overbottoms, do.	0	1½
Shale	1	6
Roof measure, do. rough and black	0	1½
Shale	1	6
Bottom measure, do.	0	1
Shale	1	6
COAL smut, 2 ft. 3 in. above the roof COAL.		
Total of lower measure	21	½

Among the above, the "Cheeses" are remarkable for the symmetrical cracks caused by contraction in the interior. These are mostly filled with a carbonate of lime containing some iron and magnesia, and, where an open space has been left, crystals of zinc-blende are also present.

The "Old man" and "Old woman," gray stones of very compact texture, and with a fracture tending to conchoidal, exhibit numerous cracks of the same description, which, besides a similar mixed carbonate, present abundant crystals of zinc-blende, and isolated crystals of galena (sulphide of lead) in well-defined crystals combining the faces of the cube and octahedron. Copper pyrites and iron pyrites also occur occasionally in the same manner, sometimes even in the partial hollows left around the cast of a fossil shell; and it need scarcely be pointed out what an important bearing on the formation of mineral veins is afforded by the presence, under such circumstances, of the metallic sulphides. It is, moreover, remarkable that they occur more abundantly in the vicinity of the small faults which traverse the measures and which would appear to have been the channels for the passage of waters holding these substances in solution.

The working of this ironstone, when it gets beyond the reach of open work or bell pits, is conducted on a peculiar plan. A number of shafts are sunk at small distances asunder, commanded by one steam-engine, which, by means of a large horizontal drum and chains, may be made to wind the material from above twenty shafts at once. Along the sides of the levels of communication, which are driven in the lower measures, stalls or "holes" are opened, at the most about seven yards by nine in area, with but a few feet of wall between them. The lower ironstones are first extracted, and the waste shale or bind, being thrown under foot, suffices so to raise the floor that the men are kept continually near the roof of the upward advancing excavation; and, if the ground be strong enough, one stall may be "holed" into the other. Upon this system the upper range of measures is first extracted; and, when the ground has sufficiently settled, the lower range is commenced upon.

As regards the ironstones in the next 300 feet below the Black Shale, they are not worked over a very large area, being almost confined to the district of Alfreton and Morley Park. Those from the latter locality are mostly of a pale drab colour.

Below the excellent seam of coal called the Kilburn, occurs a band of ironstone, the Honeycroft, which runs continuously from Buckland Hollow, near the Ambergate Station, to Stanton, where it is very productive. No. 388, the "tufty balls," contains fossil shells and remains of fish, with calc-spar and zinc-blende lining the cavities. 388 and 390 have a much rougher texture than the rest.

In the *Civilly rake*, which occurs above the Furnace coal, Stanton, 395, the "Ratchell measure" is a rough textured stone, containing minute scales of mica. 396, the "chance balls," exhibit cracks lined with crystalline barytes of white and pinkish hue.

The upper measures of the *Dale Moor rake*, the lowest known in the Derbyshire coal-field, Nos. 400, 401, light drab stones in colour, are remarkable, especially the upper one, for the number of remains of plants, particularly of rootlets of *Stigmaria*, which they enclose. 402–3, 4, are black, rough-textured, large nodules; and No. 404, the "bottom balls," is especially remarkable for the discovery of a great number of well preserved entire fishes, generally from four to seven inches in length. They belong to the genera *Palæoniscus* and *Platysomus*, and it would appear that the workings at Stanton had at one time reached a shoal of them, so numerous were they in one comparatively limited spot.

From the fact that the beds so close above these fish nodules exhibit abundant remains of plants, it would appear highly probable that the fishes were left in a shallow pool at low water, or were by some similar means cut off from escape seaward, and having thus soon perished were covered up and entombed in the irony mud which was brought down by fresh water, and which, whilst yet soft, aggregated around their bodies into lenticular nodules.

The great number of courses in these lower ironstone measures, coupled with the considerable thickness of the shales in which they occur, rendered it advisable to work them by opencast on a very large scale. The workings, which have supplied for several years the Stanton furnaces, were opened at a short distance to the south of that establishment, and were continued downwards in the very moderate dip of the strata, till the face of the quarry, becoming 40 or 50 feet in height, was hazardous to the men employed upon it. The ore was drawn up an incline by a stationary engine, and the bind or shale thrown back to fill up the vast cavity.

IRONSTONE OF THE LIAS.

Not more than eight years have elapsed since attention was accidentally directed to loose masses of a ferruginous substance which were strewn over the beach on the north-eastern coast of Yorkshire; and experiments made at the furnaces of Messrs. Bolckow and Vaughan, near Bishop Auckland, proved it to be worth smelting as an ore of iron. Yet some little time elapsed before it was observed that these loose blocks had fallen from the higher ground, in which a massive bed of the same material might be traced by its outcrop for miles and miles along the escarpments of the Cleveland Hills.

On the coast line, and again at a small elevation above the flat land which extends from Redcar to Middlesboro' on Tees, there crops out to the surface a solid stratum of no less than 15 feet thick of an ironstone which, although said to contain on an average about 30 per cent. of iron, presents such an appearance as readily to account for its value being so long overlooked. Situate about the middle of the lias formation, in a position corresponding to the "marlstone," it would easily pass muster for an ordinary sandstone with only its external surfaces more or less rusted by the peroxidation of iron. It is, in fact, a sometimes massive, at others interlaminated with shaley bands, deposit of a greenish or gray colour, divided by a system of nearly vertical joints, having a structure generally oolitic, and in the spherules of which Mr. Bowerbank recognizes, under the microscope, concentric coatings. It contains numerous well-known fossils of the marlstone, especially *Belemnites* and *Pecten æquivalvis*, many of which are in a very fine state of preservation.

This remarkable seam extends over a region of some hundreds of square miles, although with a gradually diminishing thickness as it is traced southward to Gainsborough and then to Thirsk, where it appears to thin out. It is capped by sandy shales containing scattered nodules of ironstone, and ultimately, above the *Marlstone series* to which it belongs, by the upper lias shale, so well known along the Whitby coast for its fossils, jet, and the application of some of the beds to the manufacture of alum.

The upper lias shale, although 200 feet thick on the coast, is much less towards its western limit; and thus in the Thirsk district the marlstone is succeeded, within a very small distance, by the lower oolite series, which there acquires practical importance from containing several bands of workable ironstone.

The great lias bed is nowhere better developed than at Eston, near Middlesboro', where, as well as for some miles to the southward, it is now actively worked. Self-acting inclined planes have been carried up the lower slope of the hill and lead into the workings, which are conducted in a series of chambers and massive pillars, generally to the full height of the seam.

Had the landowners and their iron-making lessees been gifted by the Muses (too often scared away on the unfolding of the ledger) with a sense of the picturesque, some of these rubbish-strewn hill-sides of Yorkshire would have rivalled the chambered precipices of Egypt or Arabia Petræa. A great change in the appearance of the district has been brought about, but at present the alteration is not for the better. A very numerous population has been hastily accumulated around the base of the hills, and from the very mode of its being brought together, will require great efforts on the part of the managers and owners of works to mould it into a state of order and moral well-being.

Although of so few years standing, these iron mines now supply the ore to above sixty blast-furnaces; and thirty furnaces, besides establishments for the manufacture of wrought iron, have sprung up, in despite of the distance from coal, in and about Middlesbro'.* It may hence be estimated, that from this new source upwards of a million of tons of ironstone are annually extracted.

ANALYSES OF IRON ORES.

DESCRIPTION OF THE VARIOUS PROCESSES EMPLOYED, AND EXPERIMENTS IN PROOF OF THEIR ACCURACY.

(By A. DICK.)

Three principal Methods of analysis were employed, which, in the subsequent descriptions, will be denoted as Method No. I., Method No. II., or Method No. III., according as one or other was employed in the particular analysis. Any special modification will be mentioned in the account of the analysis in which it was employed.

DETAILS OF METHOD NO. I.—1. A portion weighed from the stoppered bottle containing the fine powder was digested in strong hydrochloric acid till no further action seemed to take place, and was boiled for about 15 minutes before dilution and filtration. The undissolved portion was thoroughly washed with hot distilled water, dried, ignited, and weighed, the usual precautions being taken to prevent absorption of moisture.

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* It is intelligible that the discovery of neighbouring coal should be regarded as a desideratum; but it says little for the spread of sound knowledge in the district, that at the present time a trial for coal should be in operation at Redcar, where people, more sanguine than prudent, are founding their hopes on the very shales, loaded with lias fossils, which, as has been pointed out to them by a geological neighbour, distinctly warn them to desist.

2. The iron in the filtrate was peroxidized, if necessary, by nitric acid or chlorate of potash; excess of ammonia was added, and filtration conducted rapidly.

3. The lime was precipitated from the filtrate as oxalate, converted into carbonate by ignition, and either weighed as such after evaporation with carbonate of ammonia, or else moistened with sulphuric acid, and, after expulsion of the excess of acid by heat, weighed as sulphate.

4. The magnesia was precipitated by phosphate of soda and excess of ammonia. Generally about 24 hours were allowed for the separation of the precipitate; it was then collected on a filter, washed with ammonia water, dried, ignited, moistened with a few drops of nitric acid, re-ignited, and weighed. The precipitate obtained by this method generally contains some flocculent matter which was found to be phosphate of alumina; the alumina having been retained in solution by the ammonia (2).

5. The precipitate (2), consisting of all the iron, alumina, phosphoric acid, and manganese (except a trace of the last which accompanies the lime), together with small portions of silica and lime or magnesia,—the former combined apparently with alumina, the latter with a portion of the phosphoric acid,—was dissolved in hydrochloric acid, then supersaturated with caustic potash, boiled in a platinum basin, and filtered. The filtrate was acidified with hydrochloric acid, boiled, after addition of some chlorate of potash to destroy the organic matter arising from the action of the potash on the filter, nearly neutralized with ammonia, and finally rendered alkaline with carbonate of ammonia. The precipitate was ignited and weighed; the phosphoric acid contained in it was determined by the tartaric acid process (see page 49), and subtracted from the previous weight to ascertain that of the alumina. The amount of phosphoric acid so determined is never exactly the correct one, owing chiefly to its containing a little silicate of alumina. The phosphoric acid was always determined by another experiment.

6. The precipitate produced by caustic potash was dissolved in hydrochloric acid, and the iron precipitated as succinate, collected on a filter, re-dissolved and re-precipitated by ammonia, ignited, and weighed. So obtained, it is never perfectly pure, owing to its containing a little phosphoric acid, combined apparently with lime or magnesia, and silica, combined apparently with alumina; neither of these combinations being decomposed by boiling with caustic potash. It was accordingly re-dissolved in hydrochloric acid, and filtered from a portion of the silica which becomes insoluble at this stage, and which was ignited and weighed. It may be here noted, that a very small quantity of silica cannot be separated from a very large quantity of iron by the ordinary evaporation process; so that the separation of this small quantity of silica could not be effected by evaporation of the original hydrochloric acid solution. The phosphoric acid contained in the precipitate was determined by the tartaric acid process; so obtained, it generally contains a small quantity of silicate of alumina. This phosphoric acid and silica subtracted from the original weight gave what was taken as peroxide of iron; though it no doubt still contained a very small quantity of other substances.

7. The filtrate from the succinate of iron was rendered alkaline by ammonia; a few drops of bromine were added, and it was left 24 hours. The precipitate was ignited at a bright red heat and weighed as $Mn^3 O^4$.

8. The insoluble portion (1) was fused with excess of the alkaline mixture obtained by decomposing Rochelle salt by heat, and washing out the mixed carbonates. The fused mass was dissolved in dilute hydrochloric acid evaporated to dryness, the residue moistened with strong hydrochloric acid, and left 24 hours;

it was then digested with hot water, filtered, and the silica ignited and weighed. Its purity was tested by dividing it into two portions, and treating one by hydrofluoric acid, and the other by caustic potash; any impurity was separated if the amount was weighable.

9. The filtrate (8) was rendered alkaline by ammonia, and filtered. The precipitate was either ignited and weighed, the iron being afterwards separated and subtracted from the previous weight, or else it was at once dissolved in hydrochloric acid, and subjected to the potash treatment described in (5) and (6), except that, since it contained no phosphoric acid, this part of the treatment was not needed.

10. The lime and magnesia in the filtrate (9) were determined in precisely the same manner as in the hydrochloric acid solution of the ore.

11. *Alkalies and organic matter.*—It was ascertained that nearly the whole of the alkalies was contained in the residue insoluble in hydrochloric acid. A weighed portion of the ore was digested in hydrochloric acid, the insoluble residue collected on a filter, and washed. The latter was then dried, till, by a little management, it could be collected together and removed from the filter without detaching a weighable amount of the fibre of the paper. It was then exposed in a platinum vessel to the vapour of hydrofluoric acid in Brunner's apparatus till decomposed. The product was evaporated with strong hydrochloric acid, the residue moistened with dilute hydrochloric acid, and the undissolved black matter collected on a small weighed filter, dried and weighed. As it generally contained a small amount of undecomposed inorganic matter, it was ignited and the ash weighed and subtracted. The filtrate from the organic matter was added to the original hydrochloric acid solution; the mixed solution was treated by the ordinary caustic baryta process for alkalies, which were weighed as chlorides.

12. *Sulphuric acid and sulphur.*—A weighed portion of the ore was digested in hydrochloric acid, the solution filtered and the sulphuric acid precipitated from the filtrate as sulphate of baryta, ignited and weighed. The residue was detached from the filter, mixed with carbonate and nitrate of potash, and fused in a gold crucible. The fused mass was dissolved in hydrochloric acid, evaporated to dryness, moistened with strong acid, diluted and filtered. From the filtrate the sulphuric acid was precipitated as sulphate of baryta, and from this the sulphur was calculated. It seems always to have occurred as iron pyrites ($Fe\ S_2$) in the ore. In tabulating the results accordingly, the iron required to combine with this sulphur was subtracted from the percentage of insoluble residue, as well as from the composition of that residue. It may be here noted, that when finely divided iron pyrites is boiled with strong hydrochloric acid and perchloride of iron, some of the latter is reduced and some sulphuric acid formed. It is important to remember this in the analysis of hæmatites.

13. *Phosphoric acid.*—A weighed portion of the ore was digested in hydrochloric acid, and the solution filtered. The filtrate was heated, (the iron reduced by sulphite of soda when necessary,) nearly neutralized with carbonate of soda, and excess of acetate of soda added. The liquid was boiled, and perchloride of iron added, drop by drop, to the hot solution, till the precipitate had a decidedly red colour. The precipitate was collected on a filter, washed with hot water, dissolved in hydrochloric acid, tartaric acid added, and, finally, excess of ammonia. The phosphoric acid was precipitated by addition of the mixture of sulphate of magnesia, chloride of ammonium, and free ammonia, 24 hours being allowed for the precipitate to separate. It was then collected on a filter, dissolved in hydrochloric acid, and some tartaric acid added to the solution. The phosphate was re-precipitated by ammonia,

collected on a filter, ignited, moistened with a few drops of nitric acid, re-ignited, and weighed.

14. *Water.*—A portion of the ore was weighed out, dried in the water oven, and re-weighed to determine hygroscopic water. It was transferred to a tube closed at one end; the other end was then connected by a cork to a small weighed tube containing chloride of calcium. Heat was applied to the tube containing the powder, and gradually increased to low redness. The majority of the ores suffer decomposition during this, with evolution of a gas arising from the decomposition of carbonates, which prevents, in most cases, the necessity of drawing any air through the apparatus. The tube containing chloride of calcium was then re-weighed to ascertain the amount of chemically combined water. In clay ironstones this is combined with the silicate of alumina or clay which they contain in admixture.

15. *Carbonic acid.*—The single flask apparatus was used; sulphuric acid was employed to decompose the carbonates in the ore.

16. *Metals precipitable by sulphuretted hydrogen from the hydrochloric acid solution.*—A weighed portion of the ore, varying from 200 or 300 grs. to 2,000 grs. was digested for a long time in hydrochloric acid. The solution was filtered off (the iron in the filtrate reduced, when necessary, by sulphite of soda), and a current of sulphuretted hydrogen passed through it. A small quantity of sulphur which always separated was collected on a filter and thoroughly washed. It was incinerated at as low a temperature as possible. The residue was mixed with carbonate of soda, and heated upon charcoal before the blowpipe; and any globules of metal obtained were dissolved and tested.

Sometimes the portion insoluble in hydrochloric acid was re-digested in hydrochloric acid and chlorate of potash added from time to time. The solution was then filtered off, and added to the original solution before reduction of persalts of iron.

DETAILS OF METHOD No. II.—A weighed portion of the ore was digested in hydrochloric acid, and the liquid filtered. The insoluble matter was fused as in Method No. I., dissolved in hydrochloric acid, and added to the original solution. The mixture was then evaporated to dryness to obtain the silica. In other respects the method of analysis was precisely similar to that described as No. I., avoiding only that part referring to the separate treatment of the matter insoluble in hydrochloric acid.

DETAILS OF METHOD No. III.—This method, owing to its greater simplicity and accuracy, was the one ultimately adopted. A weighed portion of the ore was digested in hydrochloric acid, and the liquid filtered. The insoluble matter was ignited, weighed, and treated in a manner precisely similar to that described under Method No. I.

2. The iron in the hydrochloric acid solution was peroxidized when necessary. The solution was heated, nearly neutralized with ammonia, then boiled with excess of acetate of ammonia, and filtered whilst hot. The precipitate was washed with hot water. The filtrate was received in a flask, and rendered alkaline by ammonia; a few drops of bromine were added, and the flask was tightly corked, to exclude air, and left 24 hours. The liquid was then heated, and rapidly filtered; the precipitate was ignited, and weighed, as $Mn^3 O^4$. The lime and magnesia contained in the filtrate were determined as in Method No. I. It may be here noted, that the ammonio-phosphate of magnesia obtained by this process is never mixed with any phosphate of alumina, owing to the alumina being completely precipitated as basic acetate.

3. The precipitated basic acetates (2) were dissolved in hydrochloric acid. The solution was supersaturated with caustic potash, boiled in a platinum basin, and filtered. The alumina containing some phosphoric acid was precipitated from the filtrate as in Method No. I. The phosphoric acid was separated by the tartaric acid process; the ammonio-phosphate of magnesia was always re-dissolved and re-precipitated, but still was seldom quite pure, containing generally a little silicate of alumina. Another determination was always made. It was ascertained that when this method was employed no phosphoric acid remained with the iron after treatment with potash. A little silica, however, did remain, but the quantity was small, and as nothing further was done with the iron after treatment with potash, this was lost from the analysis, a more accurate method for the determination of the iron being employed.

4. *Iron.*—Two determinations were always made by Dr. Penny's very accurate volumetrical process. The burette employed was graduated to cubic millimetres. Pure zinc was used to reduce the iron before adding the standard solution. When the ore contained both oxides of iron, precautions were taken to prevent the action of the air on the solution whilst the ore was dissolving.

5. All the other ingredients of the ore were determined in the manner described under Method No. I.

In all cases the actual weights of the substances obtained during the analysis have been given, so that corrections may be made should the atomic weights at present in use be altered at any future time. The atomic weights which have been employed are the same as those in the edition of Fownes' Chemistry, published in 1854, except in the cases of manganese and magnesium. The former of these has always been taken as 28·00; the latter, in the analysis by A. Dick, as 12·36.

Experiments on the Determination of Peroxide and Protoxide of Iron when they exist together in an Ore.—Extremely unsatisfactory results having been obtained by the use of Fuchs' process, some experiments were made with weighed quantities of the pure materials. The copper used was electrotype copper; the iron was in the state of peroxide prepared by precipitation and ignition. The hydrochloric acid was of known strength. The experiments were made in stoppered bottles filled by the liquid to exclude the air.

4·17 grs. of peroxide of iron were dissolved in twice the amount of acid required for complete solution, and poured into a stoppered bottle, containing a piece of sheet copper presenting about 3 square inches of surface. The stopper was tied down with caoutchouc, and the whole left at the ordinary temperature till the solution became nearly colourless. About 16 days were required. The copper was then washed, first with a hot solution of common salt, and afterwards with pure water. It had lost 3·26 grs., whereas it ought to have lost 3·29 had the whole of the produced chloride of copper been converted into dichloride. The bulk of the liquid was about an ounce and a quarter. Similar experiments with twice and ten times the amount of acid above yielded like results; as also did an experiment in which 30 grs. of chloride of sodium were used instead of excess of acid to dissolve the dichloride as it formed.

Similar experiments were made at 100° C. with like results, only that the change, which at the ordinary temperature takes many days, is effected in a few hours.

3·39 grs. of peroxide of iron, dissolved in twice the amount of acid requisite for solution, were treated exactly as above, except that the bottle was kept in a bath at 100° C. The solution became colourless in a few hours, and the copper was found to have lost 2·74 grs., whereas it ought to have lost 2·68 grs. A similar experiment in which five times the requisite amount of acid was employed, and another in which 20 grs. of chloride of sodium were employed, instead of excess of acid, also yielded results which were nearly accurate. It was found, however, that when this process was applied to the analysis of the ores it sometimes did not yield such accurate results.

Marguerite's volumetric method was used once or twice, but laid aside in favour of Dr. Penny's, owing to the trouble of preparing the solution, and keeping it of known strength. The solution of bichromate of potash employed was much weaker than that employed by Dr. Penny. To show the accuracy of this process, some of the experiments which were made for the purpose of testing it are given. They are quoted without selection, being just in the order in which they were made. The iron employed was fine iron wire. Quantity taken 4·025; found 4·050: taken 2·90; found 2·91: taken 4·29; found 4·285: taken 6·51; found 6·505: taken 4·10; found 4·07: taken 5·35; found 5·37: taken 4·77; found 4·77 grs. The mean error of the 7 experiments was rather more than 0·01 gr. of iron.

Experiments on the Determination of Phosphoric Acid.

To determine the accuracy of the process proposed by Fresenius, for separating phosphoric acid from iron and alumina by means of tartaric acid.

10·67 grs. of phosphate of baryta, prepared by adding ordinary tribasic phosphate of soda to chloride of barium and igniting the precipitate, were dissolved in hydrochloric acid. Excess of sulphuric acid was added to the solution, which was filtered, and the precipitate found to weigh 11·14 grs.

About 8 grs. of peroxide of iron, and 3 of alumina, both free from phosphoric acid, were dissolved in hydrochloric acid, and added to the filtrate. Tartaric acid and excess of ammonia were then added, and the phosphoric acid precipitated as ammonio-phosphate of magnesia. It was allowed 24 hours to separate, then collected on a filter, and washed with ammonia water. As it still contained some iron, it was re-dissolved, and re-precipitated by ammonia, after addition of some tartaric acid, about 24 hours being allowed in this as in all following experiments, for its separation. Weight of pyrophosphate of magnesia 5·35 grs.

Operated upon.	Calculated.	Found.
10·67 grs. of phosphate of baryta	=7·26 grs. of baryta.	7·32 grs.
	3·41 grs. of phosphoric acid.	3·41 grs.

This shows the accuracy of the process when the iron is not in very large excess.

To determine whether the process is equally accurate when a minute quantity of phosphoric acid has to be separated from a large quantity of iron, or of salts necessarily introduced during the process.

The source of phosphoric acid was a solution of ordinary tribasic phosphate of soda preserved in a stoppered bottle to prevent alteration.

Two determinations of the strength of the solution were made. In the first 130·43 grs. of solution yielded 1·515 grs. of pyrophosphate of magnesia. In the second, 336·25 grs. yielded 3·88 grs. of pyrophosphate of magnesia. Therefore 100 grs. of solution contained 0·74 gr. of phosphoric acid, by both experiments.

Effect of chloride of ammonium.—79·25 grs. of solution were diluted to about 5 ounces, and 400 grs. of chloride of ammonium added. The phosphoric acid was precipitated as before. Weight of pyrophosphate of magnesia 0·92 grs., equivalent to 0·74 grs. per cent. of phosphoric acid in solution. Chloride of ammonium, therefore, does not affect the accuracy of the process.

Effect of nitrate of ammonia.—94·07 grs. of solution were added to half an ounce of strong nitric acid supersaturated with ammonia. The phosphoric acid was precipitated as before, the bulk of the liquid being about 3 ounces. Weight of pyrophosphate of magnesia 1·105 grs., equivalent to 0·74 gr. per cent. of phosphoric acid. Nitrate of ammonia, therefore, does not affect the accuracy of the process.

Effect of tartrate of ammonia.—135·15 grs. of solution were added to a solution of 150 grs. of tartaric acid. The whole was supersaturated with ammonia, and the phosphoric acid precipitated as before. Weight of pyrophosphate of magnesia 1·55 grs., equivalent to 0·73 gr. per cent. of phosphoric acid. Tartrate of ammonia, therefore, does not affect the accuracy of the process.

It may here be observed that these salts, though they do not prevent the ultimate complete precipitation, exert an effect on the appearance of the precipitate. If to a solution of phosphoric acid a mixture of sulphate of magnesia, ammonia, and just as much chloride of ammonium as will prevent the precipitation of hydrate of magnesia be added, the ammonio-phosphate of magnesia separates at once and almost entirely (which may be proved by filtering a portion, and leaving the filtrate to stand) as a bulky gelatinous precipitate. In the course of a few days the precipitate assumes a crystalline appearance. The addition of salts of ammonia accelerates this change so much that it may be made to take place in a few minutes. No other salt of the alkalies (such as chloride of sodium), which has been tried, acts in the same manner. If, instead of precipitating the ammonio-phosphate of magnesia from a liquid containing little ammoniacal salts, it be precipitated from one containing a large quantity, the precipitate appears very slowly, is highly crystalline, and adheres strongly to the sides of the vessel.

Effect of sulphate of magnesia.—85·33 grs. of solution were mixed with 20 grs. of sulphate of magnesia, and 40 grs. of chloride of ammonium, and the phosphoric acid precipitated as before. Weight of ammonio-phosphate of magnesia 1·05 grs. equivalent to 0·78 gr. per cent. of phosphoric acid.

In another experiment, made under nearly the same conditions, 97·65 grs. of solution were employed, and 1·18 grs. of pyrophosphate of magnesia obtained, equivalent to 0·77 gr. per cent. of phosphoric acid.

In another experiment 65·95 grs. of solution were mixed with 30 grs. of sulphate of magnesia and an equal quantity of chloride of ammonium. The phosphoric acid was precipitated as before. The precipitate was washed with extreme care. Weight of pyrophosphate of magnesia 0·79 gr., equivalent to 0·76 gr. per cent. of phosphoric acid. The slight excess in these three results is probably owing to the enclosure of a little of the mother liquid between the particles of the crystals, which it is difficult to remove by washing, and which leaves a fixed residue on calcination; but as the ammonio-phosphate of magnesia was, in the following analysis, never thrown down from a liquid containing so much fixed salt, and was, moreover, invariably re-dissolved and re-precipitated before ignition, no error can arise from this cause.

Effect of the solution of peroxide of iron in tartaric acid and ammonia.—18·68 grs. of solution were added to a liquid containing about 70 or 80 grs. of peroxide of iron, tartaric acid, and excess of ammonia. To this a mixture of sulphate of magnesia, chloride of ammonium, and free ammonia was added, and the whole left for three days. It was then filtered, the precipitate dissolved and re-precipitated, tartaric acid having been added to the solution as usual. Weight of pyrophosphate of magnesia 0·14 gr., equivalent to 0·47 gr. per cent. of phosphoric acid. To corroborate this result, another experiment was made.

39·01 grs. of solution were mixed with an amount of the liquid containing tartaric acid, ammonia, and iron, still greater than in the preceding experiment. The mixture of sulphate of magnesia, chloride of ammonium, and free ammonia, was then added, and the whole left for some days, at the end of which time no precipitate had appeared. More free ammonia and magnesian mixture were then added, and the whole left 24 hours more. Still no precipitate separated. A few drops more of the solution containing phosphoric acid were added, and left 24 hours longer, but still no precipitate formed. This could not be explained by the bulk of the liquid, which was not greater than in some previous experiments, in which the mixture of tartaric acid, iron, and ammonia was not present, but must have to be due to a power possessed by this mixture to retain a small quantity of ammonio-phosphate of magnesia in solution.

To prove the accuracy of the process described at page 49.—95·14 grs. of solution were added to a liquid containing about 60 grs. of iron, free from phosphoric acid. The iron was in the state of protoxide; a little of it was then peroxidized, and the solution nearly neutralized with carbonate of soda; excess of acetate of soda was added, and the liquid was boiled and filtered. The red coloured precipitate was collected on a filter, and dissolved in hydrochloric acid; tartaric acid and excess of ammonia were added to the solution, and the phosphoric acid was precipitated as ammonio-phosphate of magnesia, 24 hours being allowed for its separation. It was collected on a filter, dissolved in hydrochloric acid, and re-precipitated by ammonia from a solution containing some tartaric acid. Weight of pyrophosphate of magnesia 1·10 grs. equivalent to 0·735 per cent. phosphoric acid.

20·68 grs. of solution were treated in exactly the same manner as the above. Weight of pyrophosphate of magnesia 0·24 gr., equivalent to 0·80 per cent. of phosphoric acid. It must be remembered that this determination being made on about 20 grs. of solution, the error, in calculating to 100, becomes magnified 5 times.

In a mineral consisting in great part of phosphoric acid, the considerable quantity of iron required to precipitate this as perphosphate, might ultimately be sufficient to retain a little of the ammonio-phosphate of magnesia in solution; but as the iron ores contain only a comparatively small amount of phosphoric acid, there is no fear of any appreciable error on this account.

Separation of phosphoric acid from alumina.—To test the accuracy of Fuchs' method of separating phosphoric acid from alumina by silicate of potash, the following experiment was made:—5·31 grs. of phosphate of baryta, from the same sample as that alluded to at page 52, was dissolved in hydrochloric acid; sulphuric acid was added to the solution, which was then filtered. Some alumina, free from phosphoric acid, was dissolved in hydrochloric acid, and the solution added to the filtrate, which was then supersaturated with caustic potash. Excess of a solution of silica in caustic potash was added, and a bulky precipitate which separated collected on a filter and washed. The filtrate was acidified with hydrochloric acid, and supersaturated with ammonia to precipitate excess of silica as far as possible. The liquid was filtered off, concentrated, and the mixture of sulphate of magnesia, chloride of ammonium, and free ammonia added. This occasioned the formation of a bulky precipitate, in part flocculent, in part crystalline. The whole was acidified with hydrochloric acid, which dissolved the crystalline and left the flocculent part of the precipitate. The liquid was filtered off, supersaturated with ammonia, and left 24 hours. The ammonio-phosphate of magnesia which separated was highly crystalline. It was ignited, and found to weigh 2·69 grs., equivalent to 1·71 of phosphoric acid, the calculated quantity being 1·70. None of the precipitates were analyzed. It would seem, therefore, that the process is an accurate one.

The method proposed by Rose for the determination of phosphoric acid was tried by J. Spiller, and found to give accurate results, but was not adopted in the subsequent analyses of the ores on account of its being more tedious than the process already described. Rose's process depends upon the conversion of the phosphoric acid into a basic phosphate of suboxide of mercury (by treating the nitric acid solution of the phosphate with mercury, in quantity more than sufficient to dissolve completely), and the decomposition of this by fusion with an alkaline carbonate. The phosphoric acid in the phosphate so formed is then precipitated by a mixed solution of sulphate of magnesia, chloride of ammonium, and ammonia, and weighed in the form of pyrophosphate of magnesia as usual. In the actual experiment a phosphate of baryta, containing 27·37 per cent. of phosphoric acid gave by this process 26·85 per cent. showing a loss, therefore, of 0·52 of phosphoric acid.

I.—WEARDALE ORE (WEST LEVEL). (By J. SPILLER.)

Towlaw Iron Works, Durham.

Description.—An altered spathose ore, in which the greater part of the carbonate of iron has been converted into hydrated peroxide, which in many places still shows the structure of the original ore. The portions which are undecomposed occur in irregular nodule-like forms of a pale brownish gray colour; these are surrounded by a mass varying from crystalline to earthy, of which the colour is from a snuff brown to a dark purplish brown. The streak varies with the colour from yellowish to reddish brown.

A small quantity of fluorspar was attached to one side of the specimen, but was not included in the portion selected for analysis.

Analysis by Method No. III.

Water, hygroscopic, and total amount.	grs.
I. 27·02 grains of ore lost of water at 100° C. - - -	0·49
II. 62·72 „ „ - - -	1·155
I. 55·215 grs. of ore gave of water at a red heat - -	4·635
II. 26·93 „ „ - - -	2·275

By the action of hydrochloric acid :

	grs.
13·77 grs. of ore gave of—	
Insoluble residue	0·95
Manganoso-manganic oxide ($Mn_3 O_4$)	0·43
Peroxide of iron (containing 0·04 gr. of silica)	8·58
Alumina	0·06
Sulphate of lime	1·89
Pyrophosphate of magnesia	0·55
69·80 grs. of ore gave of—	
Sulphate of baryta (resulting from sulphates in the hydrochloric acid solution)	trace.
Insoluble residue	4·815
which being fused, gave of—	
Silica	4·435
Alumina	0·285
Peroxide of iron	0·05
Sulphate of lime	0·015
Pyrophosphate of magnesia	0·03
The insoluble residue from 48·69 grs. of ore gave of—	
Organic matter	trace.
Sulphate of potash	0·045
Phosphoric acid and sulphur as pyrites :	
100·77 grs. of ore gave of—	
Pyrophosphate of magnesia	0·015
Sulphate of baryta	0·12
I. 48·235 grs. of ore gave of carbonic acid	6·99
II. 32·91 „ „	4·84
Determinations repeated :	
16·845 grs. of ore gave of—	
Manganoso-manganic oxide ($Mn_3 O_4$)	0·555
Sulphate of lime	2·325
Pyrophosphate of magnesia	0·565
Alumina and peroxide of iron (containing 0·05 gr. of silica)	10·40

Iron, by standard solutions of bichromate and permanganate of potash :—

Standard : 1 grain of iron = 9·03 cub. cent. of bichromate of potash solution.
1 grain of iron = 9·15 cub. cent. of permanganate of potash solution

Iron, total amount.

By bichromate of potash :

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I. 9·665	37·5	42·97
II. 9·255	36·0	43·07

By permanganate of potash :

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
III. 5·31	20·9	43·01
IV. 10·04	39·2	42·67

Iron, existing in the state of protoxide.

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
By bichromate of potash:		
I. 18·85	14·2	8·34
II. 33·55	25·5	8·41
By permanganate of potash:		
III. 26·46	20·8	8·59
IV. 28·37	22·4	8·63

Results tabulated.

	I.	II.
Peroxide of iron	49·50	
Protoxide of iron	10·77	
Protoxide of manganese	3·06	2·90
Alumina	0·43	
Lime	5·68	5·66
Magnesia	1·20	1·42
Silica	0·29	0·29
Carbonic acid	14·49	14·70
Phosphoric acid	0·01	
Sulphuric acid	trace.	
Bisulphide of iron	0·03	
Water, hygroscopic	1·81	8·40
,, in combination	6·63	
Organic matter	trace.	
Insoluble residue	6·90	6·90
	100·80	

Insoluble Residue.

Silica	6·35
Alumina	0·41
Peroxide of iron	0·07
Lime	0·01
Magnesia	0·01
Potash	0·05
	6·90

Iron, total amount - 43·02

A trace of lead was found in 400 grains of the ore,

II.—WEARDALE ORE, RISPEY. (BY A. DICK.)

Description.—Spathose ore; easily scratched by the file; lustre, semi-vitreous; colour, yellowish gray; streak, white; fracture, crystalline: some portions are much darker than others. When a mass of the ore is digested in hydrochloric acid till all carbonates are dissolved, there remains a skeleton of quartz, having the shape and size of the original mass, containing casts of the crystals which have been dissolved. The dark coloured parts of the ore leave a dark skeleton, which, when exposed to the vapour of hydrofluoric acid till all silica is removed, leaves a small amount of matter, having a dark gray colour. When this is washed with hydrochloric acid and water there remains a very small amount of black matter, which burns when heated in the air, and leaves no residue. It is therefore carbonaceous matter.

Analysis by Method No. III.

Water, total amount.

33·07 grs. of ore lost at 100° C. 0·02. Above 100° C. 0·08.

By the action of hydrochloric acid:	
13·10 grs. of ore gave of insoluble residue	0·50
Manganoso-manganic oxide	0·34
Alumina	trace.
Carbonate of lime	0·82
(Above converted into sulphate of lime	1·10)
Pyrophosphate of magnesia	1 13
3·35 grs. of insoluble matter gave of silica	3·32
Alumina containing a trace of iron	006
Phosphoric and sulphuric acids, and bisulphide of iron.	
64·95 grs. of ore gave of—	
Pyrophosphate of magnesia	trace.
70·30 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·20
I. 39·59 grs. of ore gave of carbonic acid	14·92
II. 24·25 grs. of ore gave of carbonic acid	9·10

Iron by standard solution of bichromate of potash.

Standard: 1 grain of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent. of iron.
8·37	27·3	38·56

Several other determinations of iron were made with a solution of bichromate of potash of different standard. They all agree closely with the above; none being more than 0·20 per cent. different.

All the iron occurs in the state of protoxide.

41·61 grs. of ore gave no alkalies, and only a trace of organic matter.

The silica obtained from the iron in the hydrochloric acid solution was, by one determination, as much as 1·20 per cent.; by another, only 0·62 per cent. This separation, as has been said, never being complete, can never be constant, but is seldom so great as this.

Results tabulated.—Ore dried above 100° C.

Protoxide of iron (mean of 5 determinations)	49·47
Protoxide of manganese	2·42
Alumina	trace.
Lime	3·47
Magnesia	3·15
Carbonic acid (mean of 2 determinations)	37·71
Phosphoric acid	trace.
Silica, by one determination 0·62, by another	1·20
Sulphuric acid	trace.
Bisulphide of iron	0·08
Organic matter	trace.
Insoluble matter, by one determination 3·89	3·77
	101·27

Insoluble Residue.

Silica	3·73
Alumina containing trace of iron	0·06
	3·79

Iron, total amount	38·56

No metal, precipitable by sulphuretted hydrogen from the hydrochloric acid solution of 1000 grs. of ore, was detected.

III.—Cleator Moor Hæmatite. (By A. Dick.)

(Nos. 424 and 426 of the Illustrated Catalogue.)

Description, No. 424.—Compact red hæmatite; easily scratched by a file; lustre, earthy; colour, purplish gray; streak, bright red; fracture, uneven, showing cavities lined with crystals of specular iron, and containing, in some cases, quartz.

No. 426 resembles 424. It is harder, being scarcely scratched by a file, more lustrous, and darker in colour; the cavities contain more quartz, but the substance of the ore seems purer.

The sample analyzed was composed of a mixture of the two.

Analysis by Method No. III.

	grs.
Water, total amount.	
21·61 grs. of ore lost on ignition	0·10
By the action of hydrochloric acid:	
23·16 grs. of ore gave of—	
Insoluble residue	1·315
Manganoso-manganic oxide	0·06
Alumina	trace.
Sulphate of lime	0·04
7·905 of insoluble residue gave of—	
Silica	7·87
Alumina containing a trace of iron	0·08
Phosphoric and sulphuric acids, and bisulphide of iron.	
108·90 grs. of ore gave of—	
Pyrophosphate of magnesia	trace.
31·00 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
5·81 grs. of residue gave of—	
Sulphate of baryta (from bisulphide of iron)	trace.

Iron, by standard solution of bichromate of potash.

Standard: 1 grain of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent. of iron.
I. 8·765	49·2	66·73
II. 7·22	40·4	66·50

All the iron occurred in the state of peroxide of iron. Before adding the standard solution, the perchloride of iron was reduced by sulphite of soda. When this is used as the reducing agent the result is apt to be too high, owing to the difficulty of expelling the last traces of sulphurous acid. For this reason zinc was almost invariably used as the reducing agent.

Results tabulated.—Ore dried above 100° C.

Peroxide of iron - - -	95·16
Protoxide of manganese - - -	0·24
Lime - - - -	0·07
Phosphoric acid - - -	trace.
Sulphuric acid - - -	trace.
Bisulphide of iron - -	trace.
Insoluble residue - - -	5·68
	101·15

Insoluble Residue.

Silica - - - -	5·66
Alumina, containing a trace of iron -	0·06
	5·72
Iron, total amount - - -	66·60

A most minute trace of lead was detected in 400 grs. of ore.

IV.—CLEATOR MOOR IRON ORE. (BY A. DICK.)

(Nos. 427 and 429, Illustrated Catalogue.)

Description, No. 427.—Compact red hæmatite; easily scratched by a file; lustre, earthy; colour, deep red-gray; streak, bright red; fracture, uneven, showing numerous cavities lined with microscopic crystals. This ore does not contain quartz visibly diffused through it.

No. 429.—Composed of a mixture of small pieces of compact hard red ore and a powdery variety of hæmatite. This latter is unctuous, more lustrous, and redder in colour than the compact variety. The sample analyzed was composed of a mixture of the two.

Analysis by Method No. III.

	grs.
Water total amount.	
27·91 grs. of the ore lost on ignition	0·19
By the action of hydrochloric acid 13·42 grs. of ore gave of—	
Insoluble residue	1·145
Manganoso-manganic oxide	0·015
Alumina	0·05
Sulphate of lime	0·23
Pyrophosphate of magnesia	0·02
9·025 grs. of insoluble residue gave of	
Silica	7·44
Alumina	1·12
Peroxide of iron	0·25
Lime	trace.
Phosphoric and sulphuric acids, and bisulphide of iron.	
114·80 grs. of ore gave of—	
Pyrophosphate of magnesia	trace.
31·00 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
26·08 grs. of insoluble residue gave of—	
Sulphate of baryta (from bisulphide of iron)	0·64

Iron by standard solution of bichromate of potash.

Standard: 1 grain of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent of iron.
I. 6·14 grs.	32·7	63·44
II. 7·93 grs.	42·0	63·06

All the iron occurred in the state of peroxide.

Tabulated Results.—Ore dried above 100° C.

Peroxide of iron	90·36
Protoxide of manganese	0·10
Alumina	0·37
Lime	0·71
Magnesia	0·06
Phosphoric acid	trace.
Sulphuric acid	trace.
Bisulphide of iron	0·06
Insoluble residue	8·54
	100·20

Insoluble Residue.

Silica	7·05
Alumina	1·06
Peroxide of iron	0·19
Lime	trace.
	8·30
Iron, total amount	63·25

A trace of lead was detected in 500 grs. of ore.

V.—GILLBROW ORE, ULVERSTONE. (By A. DICK.)

Description.—Red hæmatite; unctuous; easily scratched by the file; lustre, sub-metallic; colour, purplish red; streak, bright red; fracture, uneven and minutely crystalline; pieces of carbonate of lime and other minerals occur in it, which, getting coloured by the powder, cannot be seen until the specimen is washed.

Analysis by Method No. III.

Water, total amount.

20·85 grs. of ore lost at 100° C. 0·70.

And gave 0·12 grs. more water by heating to redness.

By the action of hydrochloric acid—

	grs.
9·09 grs. of ore gave of—	
Insoluble residue	0·57
Manganoso-manganic oxide	0·02
Sulphate of lime	0·585
Pyrophosphate of magnesia	0·35
2·21 grs. of insoluble residue gave of—	
Silica	2·085
Alumina	0·11

Phosphoric and sulphuric acids, and bisulphide of iron.

114·90 grs. of ore gave only a trace of pyrophosphate of magnesia.

	grs.
36·19 grs. of ore gave of sulphate of baryta - -	0·11
Bisulphide of iron was not sought for, as the residue did not contain a weighable quantity of iron.	
34·03 grs. of ore gave of carbonic acid - - -	0·97

Iron by standard solution of bichromate of potash.

Standard: 1 grain of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent. of iron.
I. 7·40	36·4	60·56
II. 9·295	45·7	60·55

All the iron exists in the state of peroxide.

Results tabulated.—Ore dried above 100° C.

Peroxide of iron - - -	86·50
Protoxide of manganese - -	0·21
Lime - - - -	2·77
Magnesia - - - -	1·46
Carbonic acid - - -	2.96
Phosphoric acid - - -	trace.
Sulphuric acid - - -	0·11
Insoluble residue - - -	6·55
	100·56

Insoluble Residue.

Silica - - - -	6·18
Alumina, containing a trace of iron -	0·30
	6·48

Iron, total amount - - -	60·55

A whitish metal, precipitable by sulphuretted hydrogen from the hydrochloric acid solution, was found. The quantity obtained from 500 grs. of ore was so small that it could not be identified.

VI.—Hæmatite, Lindale Moor, near Ulverstone, Lancashire. (By J. Spiller.)

The sample was selected from a large quantity of the ore, consisting of fragments of various degrees of hardness, the majority of which were of the hard compact variety, deep grayish purple in colour, and covered with a brownish red unctuous powder; there were also small quantities of fibrous hæmatite and specular iron, together with quartz and a little earthy matter.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
33·66 grs. of ore lost of water at 100° C.	0·13
Water, total amount.	
20·325 grs. of ore lost on ignition	0·115
By the action of hydrochloric acid :	
7·80 grs. of ore gave of—	
Insoluble residue	0·42
Manganoso-manganic oxide (Mn_3O_4)	0·02
Alumina	0·04
44·28 grs. of ore gave of—	
Sulphate of lime	0·055
Pyrophosphate of magnesia	0·01
17·165 grs. of ore gave of—	
Insoluble residue	0·89
Which being fused, yielded of—	
Silica	0·83
Alumina	0·02
Peroxide of iron Oxalate of lime	traces.
Phosphoric and sulphuric acids, and bisulphide of iron.	
54·865 grs. of ore gave of—	
Pyrophosphate of magnesia	a minute trace.
Sulphate of baryta (from sulphates)	0·145
Sulphate of baryta (from bisulphide of iron)	0·07

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I. 4·915	27·4	65·96
II. 5·075	28·3	65·99

All the iron exists in the state of peroxide.

Results tabulated.

Peroxide of iron	94·23—94·27
Protoxide of manganese	0·23
Alumina	0·51
Lime	0·05
Magnesia	trace.
Phosphoric acid	minute trace.
Sulphuric acid	0·09
Bisulphide of iron	0·03
Water, hygroscopic	0·39
,, combined	0·17
Insoluble residue	5·18
	100·88

Insoluble Residue.

Silica	4·90
Alumina	0·12
Peroxide of iron Lime	traces.
	5·02

Iron, total amount	65·98

A distinct trace of arsenic was detected in 1680 grs. of ore.

VII.—WHITE BED MINE, BIERLEY, YORKSHIRE.

(BY J. SPILLER.)

(Nos. 300 to 304 of the Illustrated Catalogue.)

Clay ironstones, of varying colour, from a light brown gray to black gray, the shades deepening in intensity with the order of the numbers. Nos. 302 and 303 show a conchoidal fracture, have a closer texture, and are harder than the others. No. 304 has a rough surface of fracture. A vein of iron pyrites occurs in No. 302; and is the cause of the somewhat large proportion of that substance described in the analysis.

The sample analyzed consisted of equal weights of the several ores.

Analysis by Method No. III.

	grs.
Water, hygroscopic, and total amount.	
34·38 grs. of ore lost of water at 100° C.	0·255
14·60 grs. of ore yielded of water at a red heat	0·27
By the action of hydrochloric acid:	
21·22 grs. of ore gave of—	
Insoluble residue	5·94
Manganoso-manganic oxide ($Mn_3 O_4$)	0·215
Alumina	0·17
Sulphate of lime	1·435
Pyrophosphate of magnesia	1·32
The insoluble residue gave by analysis—	
Silica	4·06
Alumina	1·45
Peroxide of iron	0·12
Sulphate of lime	0·055
Pyrophosphate of magnesia	0·04
34·38 grs. of ore gave of—	
Organic matter	0·08
Chloride of potassium	0·43
25·70 grs. of ore gave of carbonic acid	6·53
Phosphoric and sulphuric acids, and bisulphide of iron:	
55·36 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·40
Pyrophosphate of magnesia	0·415

Iron by standard solution of bichromate of potash.

(Standard: 1 gr. of iron = 8·45 cub. cent. of solution.)

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	10·55	25·2	28·26
II.	9·77	23·5	28·46

Iron, in the state of protoxide.

III.	8·43	19·6	27·52

Results tabulated.

Protoxide of iron	35·38
Peroxide of iron	1·20
Protoxide of manganese	0·94
Alumina	0·80
Lime	2·78
Magnesia	2·22
Carbonic acid	25·41
Phosphoric acid	0·48
Sulphuric acid	trace.
Bisulphide of iron	0·18
Water, hygroscopic	0·74
,, combined	1·11
Organic matter	0·23
Insoluble residue	28·00
	99·47

Insoluble Residue.

Silica	19·13
Alumina	6·83
Peroxide of iron	0·57
Lime	0·11
Magnesia	0·07
Potash	0·78
	27·49

Iron, total amount	28·76

A distinct trace of copper was detected in 500 grains of the ore.

VIII.—BLACK BED MINE, LOW MOOR, YORKSHIRE.

(By J. SPILLER.)

(Nos. 305 to 310 of the Illustrated Catalogue.)

All are dark blackish gray clay ironstones, particularly Nos. 309 and 310. The two latter are easily scratched by a steel point, the rest being much harder; fracture, Nos. 305, 306, 307, 308 compact, showing a tendency to the conchoidal in Nos. 305 and 308; that of 309 and 310, rough and irregular. No. 308 contains iron pyrites in the form of exceedingly fine films taking the outline of shells.

The ores were mixed in the proportion of equal weights to procure the sample for analysis.

Analysis by Method No. III.

Water, hygroscopic, and combined.	grs.
27·98 grs. of ore lost of water at 100° C.	0·17
And yielded of water at a red heat	0·325
By the action of hydrochloric acid:	
26·20 grs. of ore gave of—	
Insoluble residue	6·62
Manganoso-manganic oxide ($Mn_3 O_4$)	0·39
Alumina	0·135
Sulphate of lime	1·72
Pyrophosphate of magnesia	1·505
The insoluble residue gave of—	
Silica	4·55
Alumina	1·63
Peroxide of iron	0·22
Oxalate of lime	trace.
Pyrophosphate of magnesia	0·09
41·20 grs. of ore gave of—	
Organic matter	0·99
Chloride of potassium	0·43
Phosphoric and sulphuric acids, and bisulphide of iron.	
74·90 grs. of ore gave of—	
Pyrophosphate of magnesia	0·405
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·29
32·97 grs. of ore gave of carbonic acid	8·76

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	10·64	25·7	28·58
II.	10·85	26·1	28·50
Iron, as protoxide.			
III.	11·115	26·5	28·11

Results tabulated.

Protoxide of iron - - -	36·14
Peroxide of iron - - -	0·61
Protoxide of manganese - -	1·38
Alumina - - - -	0·52
Lime - - - -	2·70
Magnesia - - - -	2·05
Carbonic acid - - - -	26·57
Phosphoric acid - - -	0·34
Sulphuric acid - - - -	trace.
Bisulphide of iron - - -	0·10
Water, hygroscopic - - -	0·61
„ combined - - -	1·16
Organic matter - - -	2·40
Insoluble residue - - -	25·27
	99·85

Insoluble Residue.

Silica - - - - -	17·37
Alumina - - - -	6·22
Peroxide of iron - - -	0·84
Lime - - - - -	trace.
Magnesia - - - -	0·12
Potash - - - - -	0·65
	25·20

Iron, total amount - - -	29·12

None of the metals, precipitable by sulphuretted hydrogen from the hydrochloric acid solution, were found in 600 grains of ore.

IX.—THORNCLIFFE OR OLD BLACK MINE, PARKGATE, YORKSHIRE. (By J. SPILLER.)

(Nos. 320 and 321 of the Illustrated Catalogue.)

Clay Ironstones, No. 320.—Colour, dark brownish gray; easily scratched by a steel point; fracture, compact and slightly conchoidal. The ore is abundantly seamed by cracks of contraction filled with carbonate of lime, iron, &c. (brown spar). No. 321 has a brown gray colour; same hardness as 320; fracture, rough and irregular. It contains impressions of rootlets of stigmaria.

The sample analyzed consisted of equal weights of each ore.

Analysis by Method No. III.

	grs.
Water, hygroscopic, and total amount.	
26·515 grs. of ore lost of water at 100° C.	0·145
19·765 grs. of ore yielded of water at red heat	0·335
By the action of hydrochloric acid:	
25·63 grs. of ore gave of—	
Insoluble residue	3·63
Manganoso-manganic oxide ($Mn_3 O_4$)	0·31
Alumina	0·15
Sulphate of lime	1·59
Pyrophosphate of magnesia	2·665
The insoluble residue gave of—	
Silica	2·29
Alumina	1·08
Peroxide of iron	0·11
Oxalate of lime	trace.
Pyrophosphate of magnesia	0·105
37·48 grs. of ore gave of—	
Organic matter	0·325
Chloride of potassium	0·25
Phosphoric and sulphuric acids, and bisulphide of iron.	
40·74 grs. of ore gave of—	
Pyrophosphate of magnesia	0·48
Sulphate of baryta (from sulphates) Sulphate of baryta (from bisulphide of iron)	traces.
33·29 grs. of ore gave of carbonic acid	10·45

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	9·095	26.0	33·83
II.	9·20	26·35	33·89

Iron, as protoxide.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	13·925	38·1	32·38
II.	8·855	24·4	32·61

Results tabulated.

Protoxide of iron	41·77
Peroxide of iron	1·96
Protoxide of manganese	1·13
Alumina	0·58
Lime	2·55
Magnesia	3·71
Carbonic acid	31·39
Phosphoric acid	0·75
Sulphuric acid Bisulphide of iron	traces.
Water, hygroscopic	0·55
,, in combination	1·15
Organic matter	0·86
Insoluble residue	14·16
	100·56

Insoluble Residue.

Silica	8·93
Alumina	4·21
Peroxide of iron	0·43
Lime	trace.
Magnesia	0·14
Potash	0·43
	14·14

Iron, total amount	34·16

None of the metals, precipitable by sulphuretted hydrogen from the hydrochloric acid solution, were found in 500 grs. of ore.

X.—Thorncliffe White Mine, Parkgate, Yorkshire.

(By J. Spiller.)

(Nos. 322, 323 *a* and *b*, of the Illustrated Catalogue.)

Clay Ironstones, No. 322.—Light brownish gray in colour; easily scratched by a steel point; fracture, rough, with a slight tendency to the conchoidal. Nos. 323 *a* and *b* are very similar in appearance; their colour is a darker brownish gray than 322, and much harder. Texture, very compact, and fracture, conchoidal. No. 323 *a* has small veins of sulphate of baryta and carbonate of lime, with a trace of pyrites.

The sample analyzed consisted of equal weights of the three ores.

Analysis by Method No. III.

	grs.
Water, hygroscopic and combined.	
21·93 grs. of ore lost of water at 100° C.	0·15
Same portion of ore yielded of water at a red heat	0·31
By the action of hydrochloric acid:	
30·92 grs. of ore gave of—	
Insoluble residue	5·985
Manganoso-manganic oxide ($Mn_3 O_4$)	0·315
Alumina	0·255
Sulphate of lime	1·70
Pyrophosphate of magnesia	3·225
The insoluble residue gave of—	
Silica	3·76
Alumina	1·73
Peroxide of iron	0·14
Oxalate of lime	trace.
Pyrophosphate of magnesia	0·15
Sulphate of baryta	trace.
41·52 grs. of ore gave of—	
Organic matter	0·225
Chloride of potassium	0·245
Phosphoric and sulphuric acids, and bisulphide of iron.	
56·96 grs. of ore gave of—	
Pyrophosphate of magnesia	0·42
Sulphate of baryta (as such in the ore) Sulphate of baryta (from bisulphide of iron	traces.
35·86 grs. of ore gave of carbonic acid	10·535

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	13·31	35·5	31·56
II.	13·435	35·7	31·45
Iron, as protoxide.			
III.	10·47	27·1	30·63

Results tabulated.

Protoxide of iron	39·38
Peroxide of iron	1·24
Protoxide of manganese	0·95
Alumina	0·82
Lime	2·26
Magnesia	3·72
Carbonic acid	29·38
Phosphoric acid	0·47
Sulphate of baryta Bisulphide of iron	traces.
Water, hygroscopic	0·68
,, in combination	1·41
Organic matter	0·54
Insoluble residue	19·35
	100·20

Insoluble Residue.

Silica	12·16
Alumina	5·60
Peroxide of iron	0·45
Lime	trace.
Magnesia	0·17
Potash	0·37
	18·75

Iron, total amount - - - 31·82

A minute trace of copper was detected in 450 grains of the ore.

XI.—BLACK OR CLAY WOOD MINE, PARKGATE, YORKSHIRE.

(By J. SPILLER.)

(No. 326 of the Illustrated Catalogue.)

A dark grayish black clay ironstone, having some very small particles of pyrites sparingly diffused through it. Tolerably hard; the surface of fracture minutely granular.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
51·03 grs. of ore lost of water at 100° C.	0·30
Water, total amount.	
29·175 grs. of ore yielded of water at a red heat	0·525
By the action of hydrochloric acid:	
18·18 grs. of ore gave of—	
Insoluble residue	3·69
Manganoso-manganic oxide (Mn_3O_4)	0·27
Alumina	0·135
Sulphate of lime	0·935
Pyrophosphate of magnesia	1·345
The analysis of the insoluble residue gave of—	
Silica	2·455
Alumina	0·98
Peroxide of iron	0·14
Oxalate of lime	trace.
Pyrophosphate of magnesia	0·07
39·15 grs. of ore gave of—	
Organic matter	0·325
Chloride of potassium	0·11
Phosphoric and sulphuric acids, and bisulphide of iron.	
51·03 grs. of ore gave of—	
Pyrophosphate of magnesia	0·545
Sulphate of baryta (from sulphates)	0·02
Sulphate of baryta (from bisulphide of iron)	0·10
22·13 grs. of ore gave of carbonic acid	6·30

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
Iron, total amount.			
I.	9·47	25·1	31·36
II.	10·82	28·7	31·39
Iron, existing as protoxide.			
III.	11·755	30·8	31·01

Results tabulated.

Protoxide of iron - - -	39·87
Peroxide of iron - - - -	0·53
Protoxide of manganese - -	1·38
Alumina - - - - -	0·74
Lime - - - - -	2·12
Magnesia - - - -	2·64
Carbonic acid - - -	28·47
Phosphoric acid - - -	0·69
Sulphuric acid - - - -	trace.
Bisulphide of iron - - -	0·05
Water, hygroscopic - - -	0·59
„ combined - - -	1·21
Organic matter - - -	0·83
Insoluble residue - - -	20·30
	99·42

Insoluble Residue.

Silica - - - - -	13·50
Alumina - - - -	5·39
Peroxide of iron - - -	0·77
Lime - - - -	trace.
Magnesia - - - -	0·13
Potash - - -	0·18
	19·97

Iron, total amount - - -	31·92

Traces of lead and copper were detected in 680 grains of the ore.

XII.—SWALLOW-WOOD RAKE, STANTON, DERBYSHIRE.*

(BY J. SPILLER.)

(Nos. 335, 336, and 337 of the Illustrated Catalogue.)

Clay Ironstones.—Easily scratched; Nos 336 and 337, light drab in colour; No. 335, a shade darker. All have a rough, non-crystalline fracture, and are readily reduced to powder, especially 337.

The sample analyzed consisted of equal weights of each ore.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
50·255 grs. of ore lost of water at 100° C.	0·29
Water, total amount.	
22·50 grs. of ore gave of water at a red heat	0·325
By the action of hydrochloric acid:	
21·51 grs. of ore gave of—	
Insoluble residue	5·065
Manganoso-manganic oxide ($Mn_3 O_4$)	0·235
Alumina.	0·145
Sulphate of lime	2·085
Pyrophosphate of magnesia	3·27
The analysis of the insoluble residue yielded of—	
Silica	3·445
Alumina	1·235
Peroxide of iron	0·17
Oxalate of lime	trace.
Pyrophosphate of magnesia	0·035
53·78 grs. of ore gave of—	
Organic matter	0·19
Chloride of potassium	0·40
Phosphoric and sulphuric acids, and bisulphide of iron.	
50·255 grs. of ore gave of—	
Pyrophosphate of magnesia	0·335
Sulphate of baryta (derived from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·26
16·50 grs. of ore gave of carbonic acid	4·725

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I. 12·11	26·7	26·09
II. 10·33	22·9	26·23

Hydrochloric acid does not extract any appreciable amount of peroxide of iron from the ore; all this iron exists, therefore, in the state of protoxide.

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* For the position of this ore, see Yorkshire Section, p. 35.

Results tabulated.

Protoxide of iron	33·72
Protoxide of manganese	1·01
Alumina	0·67
Lime	3·99
Magnesia	5·43
Carbonic acid	28·64
Phosphoric acid	0·41
Sulphuric acid	trace.
Bisulphide of iron	0·13
Water, hygroscopic	0·57
,, in combination	0·87
Organic matter	0·36
Insoluble residue	23·55
	99·35

Insoluble Residue.

Silica	16·02
Alumina	5·74
Peroxide of iron	0·79
Lime	trace.
Magnesia	0·06
Potash	0·47
	23·08
Iron, total amount	26·79

None of the metals, precipitable by sulphuretted hydrogen from the hydrochloric acid solution, were detected in 560 grains of ore.

XIII.—Brown Rake, Butterley, Derbyshire.

(By J. Spiller.)

(Nos. 344 and 345 of the Illustrated Catalogue.)

Clay Ironstones, No. 344.—Colour, pale brownish gray, inclining to red in some parts from peroxidation; very thin seams of a blueish shale are irregularly interstratified with the ore; fracture, unusually rough. No. 345; colour, blackish gray, of various degrees of intensity in irregular bands parallel to the plane of stratification. The ore contains an abundance of fossil shells incrusted with ochrey peroxide of iron.

A mixture of equal weights of the two ores was taken for analysis.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
31·49 grs. of ore lost of water at 100° C.	0·235
Water, total amount.	
15·82 grs. of ore yielded of water at a red heat	0·35
By the action of hydrochloric acid:	
18·775 grs. of ore gave of—	
Insoluble residue	3·07
Manganoso-manganic oxide (Mn_3O_4)	0·305
Alumina	0·08
Sulphate of lime	2·065
Pyrophosphate of magnesia	1·735
The insoluble residue gave by analysis—	
Silica	1·885
Alumina	0·97
Peroxide of iron	0·085
Sulphate of lime	0·03
Pyrophosphate of magnesia	0·04
40·76 grs. of ore gave of—	
Organic matter	0·58
Chloride of potassium	0·36
Phosphoric and sulphuric acids, and bisulphide of iron.	
47·27 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·105
Pyrophosphate of magnesia	0·585
19·10 grs. of ore yielded of carbonic acid	5·715

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	10·22	26·2	30·33
II.	9·315	23·8	30·24

Iron, in the state of protoxide.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	10·02	25·0	29·52
II.	10·80	27·0	29·58

Results tabulated.

Protoxide of iron	37·99
Peroxide of iron	1·04
Protoxide of manganese	1·51
Alumina	0·41
Lime	4·53
Magnesia	3·30
Carbonic acid	29·92
Phosphoric acid	0·80
Sulphuric acid	trace.
Bisulphide of iron	0·06
Water, hygroscopic	0·74
,, in combination	1·47
Organic matter	1·42
Insoluble residue	16·35
	99·54

Insoluble Residue.

Silica	10·04
Alumina	5·16
Peroxide of iron	0·45
Lime	0·06
Magnesia	0·07
Potash	0·55
	16·33

Iron, total amount	30·60

A trace of reddish metal, too small to examine, was detected in 1200 grains of the ore.

XIV.—BROWN RAKE, BUTTERLEY, DERBYSHIRE.

(By J. SPILLER.)

(No. 346 of the Illustrated Catalogue.)

Clay Ironstone. — Slightly peroxidized throughout, brownish gray in colour; easily scratched by a steel point; fracture, rough and perfectly devoid of crystalline structure.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
30·60 grs. of ore lost of water at 100° C.	0·21
Water, total amount.	
16·80 grs. of ore yielded of water at a red heat	0·365
By the action of hydrochloric acid:	
22·715 grs. of ore gave of—	
Insoluble residue	5·64
Manganoso-manganic oxide ($Mn_3 O_4$)	0·30
Alumina	0·105
Sulphate of lime	1·62
Pyrophosphate of magnesia	1·72
The insoluble residue gave by analysis—	
Silica	3·65
Alumina	1·505
Peroxide of iron	0·21
Sulphate of lime	0·04
Pyrophosphate of magnesia	0·165
44·70 grs. of ore gave of—	
Organic matter	0·34
Chloride of potassium	0·47
Phosphoric and sulphuric acids, and bisulphide of iron.	
42·965 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	not weighable.
Sulphate of baryta (from bisulphide of iron)	0·08
Pyrophosphate of magnesia	0·44
24·025 grs. of ore gave of carbonic acid	6·425

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	11·615	28·1	28·63
II.	7·70	18·7	28·74
Iron, existing in the state of protoxide.			
I.	9·09	21·3	27·73
II.	10·145	23·9	27·87

Results tabulated.

Protoxide of iron	35·74
Peroxide of iron	1·26
Protoxide of manganese	1·23
Alumina	0·47
Lime	2·94
Magnesia	2·70
Carbonic acid	26·74
Phosphoric acid	0·66
Sulphuric acid	trace.
Bisulphide of iron	0·05
Water, hygroscopic	0·68
,, combined	1·49
Organic matter	0·76
Insoluble residue	24·83
	99·56

Insoluble Residue.

Silica	16·07
Alumina	6·62
Peroxide of iron	0·92
Lime	0·07
Magnesia	0·26
Potash	0·66
	24·60

Iron, total amount of	29·32

Distinct traces of lead and copper were found in 600 grains of ore.

XV.—Black Rake, Butterley, Derbyshire.

(By J. Spiller.)

(Nos. 347 and 348 of the Illustrated Catalogue.)

Clay Ironstones, No. 347.—Colour, dark gray; somewhat hard; fracture, irregular; structure, compact. The ore contains thin films of pyrites disposed in the form of shells. No. 348, a darker coloured carbonaceous ore, having a rough surface of fracture; easily pulverized.

The sample analyzed consisted of equal weights of the two ores.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
35·635 grs. of ore lost of water at 100° C.	0·265
Water, total amount.	
19·07 grs. of ore yielded of water at a red heat	0·43
By the action of hydrochloric acid:	
20·37 grs. of ore gave of—	
Insoluble residue	5·39
Manganoso-manganic oxide ($Mn_3 O_4$)	0·21
Alumina	0·15
Sulphate of lime	1·495
Pyrophosphate of magnesia	1·605
The insoluble residue by its analysis gave of—	
Silica	3·49
Alumina	1·58
Peroxide of iron	0·10
Sulphate of lime	0·07
Pyrophosphate of magnesia	0·145
39·79 grs. of ore gave of—	
Organic matter	0·625
Chloride of potassium	0·47
Phosphoric and sulphuric acids, and bisulphide of iron.	
32·84 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·33
Pyrophosphate of magnesia	0·405
30·275 grs. of ore gave of carbonic acid	7·76

Iron by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	8·65	19·9	27·23
II.	10·405	24·0	27·29
Iron, as protoxide.			
III.	9·885	21·8	26·10

Results tabulated.

Protoxide of iron	33·56
Peroxide of iron	1·66
Protoxide of manganese	0·96
Alumina	0·73
Lime	3·02
Magnesia	2·81
Carbonic acid	25·63
Phosphoric acid	0·79
Sulphuric acid	trace.
Bisulphide of iron	0·26
Water, hygroscopic	0·74
„ combined	1·51
Organic matter	1·57
Insoluble residue	26·46
	99·70

Insoluble Residue.

Silica	17·13
Alumina	7·76
Peroxide of iron	0·50
Lime	0·15
Magnesia	0·25
Potash	0·74
	26·53
Iron, total amount	27·61

Distinct traces of copper and lead were found in 700 grains of ore.

XVI.—Dog-tooth Rake, Staveley, Derbyshire.

(By J. Spiller.)

(Nos. 352, 353, and 355 of the Illustrated Catalogue.)

Clay Ironstones.—All of the same colour, light brownish gray; rough in fracture; easily scratched by a steel point. No. 353 contains a few shells irregularly diffused.

The sample analyzed consisted of equal weights of each ore.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
39·135 grs. of ore lost of water at 100° C.	0·25
Water, total amount.	
23·85 grs. of ore yielded of water at a red heat	0·395
By the action of hydrochloric acid:	
26·05 grs. of ore gave of—	
Insoluble residue	4·975
Manganoso-manganic oxide (Mn_3O_4)	0·305
Alumina	0·10
Sulphate of lime	1·00
Pyrophosphate of magnesia	3·37
The insoluble residue gave by its analysis—	
Silica	3·10
Alumina	1·445
Peroxide of iron	0·155
Sulphate of lime	0·025
Pyrophosphate of magnesia	0·145
47·51 grs. of ore gave of—	
Organic matter	0·145
Chloride of potassium	0·505
Phosphoric and sulphuric acids, and bisulphide of iron.	
39·84 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	not weighable.
Sulphate of baryta (from bisulphide of iron)	0·07
Pyrophosphate of magnesia	0·30
29·15 grs. of ore gave of carbonic acid	8·785

Iron, by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
Iron, total amount.		
I. 9·105	23·8	30·94
II. 10·645	27·8	30·91
Iron, in the state of protoxide.		
III. 12·30	31·5	30·31

Results tabulated.

Protoxide of iron	38·97
Peroxide of iron	0·88
Protoxide of manganese	1·09
Alumina	0·38
Lime	1·58
Magnesia	4·62
Carbonic acid	30·14
Phosphoric acid	0·48
Sulphuric acid	trace.
Bisulphide of iron	0·05
Water, hygroscopic	0·64
,, in combination	1·02
Organic matter	0·30
Insoluble residue	19·10
	99·25

Insoluble Residue.

Silica	11·90
Alumina	5·55
Peroxide of iron	0·59
Lime	0·04
Magnesia	0·20
Potash	0·67
	18·95

Iron, total amount	31·34

A minute trace of copper was found in 630 grains of ore.

XVII.—DOG-TOOTH RAKE, STAVELEY, DERBYSHIRE.

(By J. SPILLER.)

(Nos. 354 and 356 of the Illustrated Catalogue.)

Clay Ironstones.—Both light brownish gray in colour’ and containing abundance of fossil shells, which in the case of No. 354 are large and confusedly packed together, though generally lying parallel to the plane of stratification; but in No. 356 occur as a more irregular deposit, made up in part, apparently, of fragments of shells. The hardness of the ores is such that they are not easily scratched by a steel point; fracture, compact and irregular, the surface of fracture being influenced by the position of the contained shells.

The sample analyzed consisted of a mixture of the two ores in equal weights.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
27·30 grs. of ore lost of water at 100° C.	0·05
Water, in combination.	
Same portion of ore yielded of water at a red heat	0·20
By the action of hydrochloric acid:	
18·14 grs. of ore gave of—	
Insoluble residue	1·16
Manganoso-manganic oxide ($Mn_3 O_4$)	0·20
Alumina	0·06
Sulphate of lime	6·145
Pyrophosphate of magnesia	4·665
The insoluble residue gave by analysis—	
Silica	0·645
Alumina	0·36
Peroxide of iron	0·075
Oxalate of lime	trace.
Pyrophosphate of magnesia	0·045
44·61 grs. of ore gave of—	
Organic matter	0·41
Chloride of potassium	0·115
Phosphoric and sulphuric acids, and bisulphide of iron.	
44·48 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·075
Pyrophosphate of magnesia	0·515
24·99 grs. of ore gave of carbonic acid	9·40

Iron, by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
Iron, total amount.		
I. 8·44	16·2	22·71
II. 10·22	19·6	22·69
Iron, existing as protoxide.		
I. 9·755	18·2	22·08
II. 13·19	24·4	21·90

Results tabulated.

Protoxide of iron	28·27
Peroxide of iron	1·01
Protoxide of manganese	1·02
Alumina	0·33
Lime	13·94
Magnesia	9·18
Carbonic acid	37·61
Phosphoric acid	0·74
Sulphuric acid	trace.
Bisulphide of iron	0·04
Water, hygroscopic	0·18
,, in combination	0·73
Organic matter	0·92
Insoluble residue	6·39
	100·36

Insoluble Residue.

Silica	3·55
Alumina	1·98
Peroxide of iron	0·41
Lime	trace.
Magnesia	0·09
Potash	0·16
	6·19

Iron, total amount	22·98

A minute trace of a white metal, too small to examine, was found in 460 grains of the ore.

XVIII.—HONEYCROFT RAKE, STANTON, DERBYSHIRE.

(By J. SPILLER.)

(Nos. 387 to 394 of the Illustrated Catalogue.)

Clay Ironstones.—Colour, Nos. 389 and 394, blackish gray; the others, brownish gray; hardness, the two just mentioned are easily scratched by a steel point; the others not so readily; surface of fracture, rough and irregular in Nos. 389 and 394; the rest are compact, and show a tendency to the conchoidal fracture, especially No. 392 No. 393 contains fossil shells, but not in great number; 391 very few; No. 388 has cracks of contraction filled with carbonate of iron, lime, &c. (brown spar); some shells and zinc blende.

The sample taken for analysis consisted of equal weights of the several ores.

Analysis by Method No. III.

	grs.
Water, hygroscopic and combined.	
24·06 grs. of ore lost of water at 100° C.	0·11
Same portion of ore yielded of water at a red heat	0·27
By the action of hydrochloric acid:	
25·505 grs. of ore gave of—	
Insoluble residue	4·55
Manganoso-manganic oxide ($Mn_3 O_4$)	0·345
Alumina	0·15
Sulphate of lime	1·725
Pyrophosphate of magnesia	2·055
The insoluble residue gave of—	
Silica	2·855
Alumina	1·36
Peroxide of iron	0·18
Oxalate of lime	trace.
Pyrophosphate of magnesia	0·12
40·95 grs. of ore gave of—	
Organic matter	0·565
Chloride of potassium	0·22
Phosphoric and sulphuric acids, and bisulphide of iron.	
42·86 grs. of ore gave of—	
Pyrophosphate of magnesia	0·225
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·155
31·995 grs. of ore gave of carbonic acid	9·51

Iron by standard solution of bichromate of potash.

Standard : 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	8·63	23·5	32·22
II.	9·795	26·7	32·26
Iron, as protoxide.			
III.	9·545	25·1	31·12

Results tabulated.

Protoxide of iron	40·01
Peroxide of iron	1·60
Protoxide of manganese	1·26
Alumina	0·58
Lime	2·78
Magnesia	2·88
Carbonic acid	29·72
Phosphoric acid	0·34
Sulphuric acid	trace.
Bisulphide of iron	0·09
Water, hygroscopic	0·45
„ combined	1·12
Organic matter	1·38
Insoluble residue	17·84
	100·05

Insoluble Residue.

Silica	11·19
Alumina	5·33
Peroxide of iron	0·70
Lime	trace.
Magnesia	0·17
Potash	0·34
	17·73

Iron, total amount	32·73

A minute trace of copper was detected in 480 grains of ore.

XIX.—CIVILLY RAKE, STANTON, DERBYSHIRE.

(By J. SPILLER.)

(Nos. 395 to 399 of the Illustrated Catalogue.)

Clay Ironstones.—Colour, No. 399, brown gray; all the others are dark blackish gray; hardness, Nos. 395, 397, 398, are easily scratched by a steel point, the other two are sensibly harder. The fractured surface is compact in Nos. 396 and 399; rough and irregular in the others. No. 396 exhibits internal cracks filled with pink sulphate of baryta, with a little carbonate of lime and zinc blende. The central part of the stone, where effected by these cracks, is altered in colour, apparently by peroxidation.

A mixture of equal weights of the several ores was taken for analysis.

Analysis by Method No. III.

	grs.
Water, hygroscopic.	
20·90 grs. of ore lost of water at 100° C.	0·145
Water, total amount.	
23·36 grs. of ore yielded of water at a red heat	0·60
By the action of hydrochloric acid:	
28·395 grs. of ore gave of—	
Insoluble residue	7·785
Manganoso-manganic oxide (Mn_3O_4)	0·665
Alumina	0·27
Sulphate of lime	1·60
Pyrophosphate of magnesia	1·945
The insoluble residue gave of—	
Silica	4·885
Alumina	2·245
Peroxide of iron	0·345
Pyrophosphate of magnesia	0·22
Sulphate of baryta	trace.
No lime was detected.	
35·95 grs. of ore gave of—	
Organic matter	0·665
Chloride of potassium	0·28
Phosphoric and sulphuric acids, and bisulphide of iron.	
43·67 grs. of ore gave of—	
Pyrophosphate of magnesia	0·425
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·22
26·10 grs. of ore gave of carbonic acid	6·48

Iron by standard solution of bichromate of potash.

Standard : 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I.	9·42	21·5	27·01
II.	10·485	23·8	26·87

Iron, in the state of protoxide.

III.	18·77	41·1	25·91

Results tabulated.

Protoxide of iron	33·31
Peroxide of iron	1·47
Protoxide of manganese	2·18
Alumina	0·95
Lime	2·32
Magnesia	2·44
Carbonic acid	24·83
Phosphoric acid	0·62
Sulphate of baryta	trace.
Bisulphide of iron	0·13
Water, hygroscopic	0·70
„ in combination	1·87
Organic matter	1·85
Insoluble residue	27·42
	100·09

Insoluble Residue.

Silica	17·24
Alumina	7·90
Peroxide of iron	1·22
Magnesia	0·27
Potash	0·49
	27·12

Iron, total amount	27·79

A minute trace of copper was detected in 500 grains of the ore.

XX.—Dale Moor Rake, Stanton, Derbyshire.

(By J. Spiller.)

(Nos. 400 to 404 of the Illustrated Catalogue.)

Clay Ironstones.—Similar in the character of hardness and quality of the fractured surface, all being easily scratched by a steel point, and presenting rough surfaces of fracture. Colour, No. 400, pale gray brown ; No. 401, brown; Nos. 402, 403, 404, dark brownish gray. The colour of the streak is in all cases yellowish brown.

No. 400 contains impressions of vegetable remains, including many rootlets of stigmaria; also some fish scales.* The occurrence of these animal remains may probably account for the comparatively large amount of phosphoric acid obtained on analysis.

The sample selected for analysis was composed of equal weights of the several ores.

Analysis by Method No. III.

	grs.
Water, hygroscopic, and total amount.	
23·35 grs. of ore lost of water at 100° C.	0·12
20·26 grs. of ore yielded of water at a red heat	0·355
By the action of hydrochloric acid:	
26·365 grs. of ore gave of—	
Insoluble residue	4·165
Manganoso-manganic oxide (Mn_3O_4)	0·425
Alumina	0·30
Sulphate of lime	2·125
Pyrophosphate of magnesia	2·11
The insoluble residue gave by its analysis—	
Silica	2·695
Alumina	1·19

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* There are several very perfect specimens of fossil fishes, enclosed in this ironstone, exhibited in the cases of the Museum. They were presented by S. H. Blackwell, Esq.

	grs.
Peroxide of iron	0·205
Sulphate of lime	0·035
Pyrophosphate of magnesia	0·025
35·20 grs. of ore gave of—	
Organic matter	0·40
Chloride of potassium	0·265

Phosphoric and sulphuric acids, and bisulphide of iron.

38·79 grs. of ore gave of—	
Pyrophosphate of magnesia	0·675
Sulphate of baryta (from sulphates)	trace.
Sulphate of baryta (from bisulphide of iron)	0·07
37·55 grs. of ore gave of carbonic acid	10·75

Iron, by standard solution of bichromate of potash.

Standard: 1 gr. of iron = 8·45 cub. cent. of solution.

Iron, total amount.

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I. 7·43	20·5	32·65
II. 8·88	24·5	32·66

Iron, in the state of protoxide.

Weight of ore.	Cub. cent. of solution.	Per cent. iron.
I. 12·50	32·6	30·86
II. 9·84	25·5	30·67

Results tabulated.

Protoxide of iron	39·55
Peroxide of iron	2·71
Protoxide of manganese	1·50
Alumina	1·14
Lime	3·32
Magnesia	2·85
Carbonic acid	28·63
Phosphoric acid	1·12
Sulphuric acid	trace.
Bisulphide of iron	0·05
Water, hygroscopic	0·51
„ combined	1·24
Organic matter	1·14
Insoluble residue	15·80
	99·56

Insoluble Residue.

Silica	10·22
Alumina	4·51
Peroxide of iron	0·78
Lime	0·06
Magnesia	0·03
Potash	0·48
	16·08
Iron, total amount	33·20

Zinc blende, and a distinct trace of copper, were found in the ore.

XXI.—CLEVELAND ORE.

(By A. DICK.)

Description.—Chiefly a carbonate of protoxide of iron; lustre, earthy; colour, greenish gray; streak, similar; fracture, uneven, showing here and there small cavities, some of which are filled with carbonate of lime. Throughout the ore are diffused irregularly a multitude of small oolitic concretions, together with small pieces of an earthy substance resembling the ore but lighter in colour. When a mass of this ore is digested in hydrochloric acid till all carbonates and soluble silicates are dissolved, there remains a residue having the form of the original mass of ore. It is extremely light, and falls to powder unless very carefully handled. It contains the oolitic concretions, or else skeletons of them, which dissolve completely in dilute caustic potash, showing them to be silica in a soluble state. Under the microscope some of them are seen to have a central nucleus of dark colour and irregular shape, but none of them present any indication of organic structure or radiated crystallization. If the residue, after having been digested in caustic potash, be washed by decantation, there remains a small number of microscopic crystals; some of these, which are white, are quartz, and others, which are black and acutely pyramidal, consist chiefly of titanic acid. Professor Miller of Cambridge succeeded in measuring some of the angles of the crystals containing titanic acid, and found that they corresponded to similar angles in anatase. The green colour of the ore seems to be due to a silicate containing peroxide and protoxide of iron, but this could not be exactly determined because it was not found possible to dissolve out the carbonates without acting at the same time upon the silicate of iron.

Analysis by Method No. III.

Water, hygroscopic, and total amount.
82·64 grs. of ore lost 0·31 grs. at 100° C.
And gave 2·45 grs. more water by ignition.
By the action of highly dilute hydrochloric acid—

19·60 grs. of ore gave of—	grs.
Insoluble residue	0·34
Silica, which had dissolved in the acid	1·39
Peroxide of iron	9·35
Alumina, containing phosphoric acid	1·88
(Pyrophosphate of magnesia *from alumina*	0·54)
Manganoso-manganic oxide	0·20
Sulphate of lime	3·53
Pyrophosphate of magnesia	2·05
3·74 grs. of insoluble residue gave of—	
Silica, containing a little titanic acid	3·49
Alumina, containing a little peroxide of iron	0·24
Phosphoric and sulphuric acids, and bisulphide of iron.	
51·14 grs. of ore gave of—	
Pyrophosphate of magnesia	1·50
39·43 grs. of ore gave of—	
Sulphate of baryta (from sulphates)	trace.
The insoluble residue from 45·71 grs. of ore gave of—	
Sulphate of baryta (from bisulphide of iron)	0·21
32·35 grs. of ore gave of—	
Organic matter	trace.
Chloride of potassium	0·14
33·59 grs. of ore gave of—	
Carbonic acid	7·65

Iron, by standard solution of permanganate of potash.

Iron, total amount.

	Weight of ore.	Cub. cent. of solution.	Per cent. iron.
	12·28	36·8	33·62
Iron, as protoxide.			
I.	12·30	34·0	31·01
II.	10·25	28·7	31·41
III.	16·47	45·2	30·89

Results tabulated.—Ore dried at 100° C.

Protoxide of iron	39·92
Peroxide of iron	3·60
Protoxide of manganese	0·95
Alumina	7·86
Lime	7·44
Magnesia	3·82
Potash	0·27
Carbonic acid	22·85
Phosphoric acid	1·86
Silica, soluble in hydrochloric acid	7·12
Sulphuric acid	trace.
Bisulphide of iron	0·11
Water, in combination	2·97
Organic matter	trace.
Insoluble residue (of which 0·98 is soluble in dilute caustic potash), and consists chiefly of oolitic concretions	1·64
	100·41
Iron, total amount	33·62

Insoluble Residue.

Silica	1·50
Alumina, with a trace of peroxide of iron	0·10
Titanic acid, about	0·03
Lime	trace.
	1·63

No metal precipitable by sulphuretted hydrogen from the hydrochloric acid solution of about 1200 grs. of ore was detected.

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July 20, 1855.

RODERICK I. MURCHISON, Director-General.