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XI. On the Assaying of Iron Ores and Iron Stones by Fusion.
By Mr. DAVID MUSHET of the Clyde Iron Works. Communicated by the Author.

AMONGST the numerous and varied attainments of human genius, the results obtained in the practice of the art of fusion are not the least to stamp the industry of man with that full approbation to which the most ardent perseverance has entitled him. Destitute of the knowledge of principle, and labouring under the most violent prejudices, the artist has in all ages marked, at lengthened intervals, the coincidence of cause with effect: upon precedent alone he has ventured to enlarge his operations, and stake his fame and fortune. To this chiefly may be attributed his partial success; and by this alone can we account for the existence of manufactures, at an early period of civilisation, in this and in other countries. Although we cannot withhold our applause from such unremitting industry, yet the deep-rooted prejudices which this implicit reverence for custom has fostered are much to be regretted. In periods remote from our time, allowance will be readily granted for persevering in a mode of practice in which others had been comparatively successful; now, however, when investigation is abroad, the foundation of these principles ought to be tried by experiment, as the only standard whereby we are enabled to ascertain truth or detect error. At this impartial tribunal, errors may be detected which corrode the vitals of our manufactories; and truths which have hitherto slept, mingled in the rubbish of unenlightened tradition, be brought to full view.

In our manufactories, the just combination of art with science is what we can seldom boast; in authors the same happy union of theory and practice is also markedly deficient; and we have constantly to regret, that the want of liberality in the individuals of the one class, and opportunity in that of the other, prevent us from feeling the happy effects of this so much desired union.

The process of depriving ores of their metal by fusion in the assay-furnace, and that part particularly relating to iron, which I mean to make the principal subject of this paper, lead me more immediately to make these observations. With the manufacturer, in general, the uses and propriety of the assay-furnace are seldom admitted, or, at best, are restricted to such narrow limits as to be only capable of ascertaining the quantity of iron contained in ore or iron-stone. The chemist, on the other hand, intent only upon effecting his operation, and of giving accuracy to the result, confines his observations to a certain chain of science, and seldom or never considers manufactures as the ultimate and happy end towards which his labours should be directed.

With whatever deference and respect we look up to the names of men celebrated for their indefatigable zeal and industry in the cause of science, and with whatever satisfaction we rest upon the result of their labours as to truth; yet, in general, the practical man feels dissatisfied with the manner in which those subjects are treated which come more immediately under his own observation.

It is I fear with some truth that this charge is brought against that part of the arts relative to the assaying of iron ores. We never find, in the works of those whose attention has been directed to this subject, that the least connected idea ever exists betwixt the assay and the blast-furnace, or that the agents used for reduction in the laboratory can in general be applied to works in the large way. A total silence prevails amongst authors of this class, as to the various qualities of crude iron which certain ores and certain combinations of fluxes produce: all ores, however various, are reduced to the same complex treatment, and the operation itself measured by minutes; as if the fusibility of all the widely differently-combined ores was the same.

The celebrated Bergman even, has a degree of complexity in his receipts for the assaying of iron ores, that seems un-

worthy of the simple elements of science. The following one in particular seems to possess an air of incongruity even in the proportions, only equalled by the oddity of the assemblage of mixtures brought forward :

“ 100 Grains of the roasted ore, two parts of the black flux, (equal parts of borax and nitre,) one part of tartar, one of sal-ammoniac, one of sandever, half of (again) borax, half of glass, one-fourth of *clean foot*, one-fourth of charcoal; the whole to be covered with common salt.”

This motley association of earths, alkalies, and salts, is recommended as the best flux for ALL iron ores. The author however shews, that the advantages which it possesses are not complete, from the great caution prescribed in the mode of conveying the necessary degree of heat; and the perfection of the operation is rendered altogether doubtful by the consequences which the oversight of a *few minutes* may occasion.

It cannot be well reconciled to our ideas of advancement in any art, that we have not yet discovered a method of operation more perfect than that wherein a few minutes lost or gained (which error will more likely take place from the inequality of heat, than the reckoning of time,) make a variation from truth equal to 1-5th or 1-6th of the whole. The manufacturer would be in a lamentable predicament were he thus circumstanced, and obliged, by some means or other, to take the crude iron from the blast-furnace immediately upon being separated from the ores, lest a considerable portion of it should totally disappear. If the degree of heat produced from a smith's forge was at all times the same, though supplied with fuel of various natures, and under different changes of temperature, then it is most probable that, by reckoning Bergman's time to a minute, a button of iron, accurate in its results, might be obtained from *some* ores by the flux he has directed to be used. But I cannot conceive that this should be an universal consequence: far less can I comprehend, after a just separation has been effected, that

five minutes will destroy 1-10th of the produce of metal, while the incumbent fluid protects the surface of the metallic button from the action of the atmosphere.

It is not, however, my province to enter into a minute examination of the products obtained from the use of such vitreous fluxes, which are always productive of the most oxygenated state of crude iron; and the accuracy of whose results, under a state of such high oxygenation, are always to be suspected. I have frequently proved that, in using them, the affinity of the metal was so great to oxygen, that a slight derangement of the crucible, which had thrown the vitrid fluid from any point of the surface, was immediately attended by a rapid deflagration, and a considerable portion of the iron oxydated.

I shall chiefly confine myself to a communication of those facts, which I have repeatedly confirmed, with a view of extending my results and observations to a more extensive scale. I have constantly considered the assay-furnace as capable of affording conclusions applicable to the operations of the smelting-furnace, and that change or innovation should always have the concurring testimony of truth to back them, though, on a small scale, before they be risked on one more momentous or extensive. Influenced by such motives, I early rejected, as totally inapplicable to the scale of manufacture, the numerous tribe of salts, alkalies, and earths: these, in the application, are subject to no rule, nor guided by any immediate object of general utility, but are as arbitrary as their authors are numerous. On the contrary, I have directed my endeavours to the use of such agents as effect separation upon the large scale, and have been fortunate to find that the same solvents, when properly applied, are productive of the most perfect and finished results. By the simple application of lime or chalk, in various proportions, as a calcareous earth, and common bottle glass, in the place of flint, to constitute fusibility, I have been able to produce in the assay-furnace all the various qualities of crude

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iron,

iron, as to strength and fusibility. In no case has the result of any assay been considered perfect, unless the vitrid mass found upon the surface of the metallic button exhibited a degree of transparency and purity of colour little inferior to flint glass, or slightly darkened by a faint shade of azure. In such vitrifications, purity of colour is the surest proof of the non-existence of iron in the state of a fused oxyd: the same degree of pellucidity renders it easy to detect the smallest globe of metal which by chance may have been suspended during fusion. In all experiments where a just association of mixtures has been present to produce this peculiar scoria, the quality of the iron will be found richly carbonated, and the button possessing a smooth, silvery, greasy-feel surface. On the other hand, experience has repeatedly shewn, that when the scoria obtained in assaying approached not to the colour and purity of fine glass, there remained a portion of the iron still unrevived, in the state of a fused oxyde, conveying colour and opacity to the mass; that at certain degrees of colour, certain degrees of opacity existed, and proportionate quantities of the metal remained diffused in the scoria. When the colour of this was green, the quantity of metal united was small; but as the green deepened, and became associated with light browns, the quantity of unrevived iron was greater, and became much increased as the scoria assumed darker browns, or became totally black: in such instances I have found it contain, upon being re-assayed, 12 *per cent.* The assaying of iron ores is susceptible of another extreme, by which experiment is equally clogged, and wherein it is very difficult to obtain an accurate result. In this case no perfect button of metal is found, but the portion of iron which the ore contained is in a vast variety of various sized globules of the richest crude iron, interspersed in, or covering the surface of a semi-vitrified opaque mass of scoria, of a greyish-blue, mottled, or whitish colour. The causes of which, and their strict analogy to similar results in the blast-furnace, shall be my chief object to explain.

In

In a former paper I mentioned, that if iron-stones were smelted without the addition of any other substance, the product in iron would be proportioned to the quantity of lime contained in the respective classes. We shall see from the following experiments how far this is confirmed by means of the assay-furnace, and furnish to ourselves one important lesson, How far the various mixtures of ores affect the operation of smelting?

1st, Into a crucible, with a well-fitted cover, I introduced 875 grains of a pulverised siliceous iron-stone in its raw state, and applied such degree of heat as is usually given in such operations. In twelve minutes I found that the iron-stone was in perfect fusion, much agitated, and emitting large bubbles of ignited gas of a fiery colour. In forty minutes the crucible was withdrawn; the surface of the vitrid fluid still continued to boil, and emit bubbles, though in less quantity. In this state I introduced a small rod through the scoria, and discovered the surface of a button of metal. The moment it came into contact with atmospheric air, a beautiful combustion took place; the metal rose in a spiral form to supply the rapid inflammation, and continued till the scoria (still in fusion) closed over the surface of the button. When cold, I found a perfect formed button of extremely oxygenated crude iron, which weighed 219 grains; a produce equal to 25.1 *per cent.* from the raw iron-stone. The scoria obtained was of a shining black colour, firm and ponderous, and weighed 402 grains; so that the loss in volatile matter was 254 grains, equal to 29 *per cent.*

Although this iron-stone was siliceous, yet I am convinced the loss of volatile matter would have been greater, had not nearly one-half of the whole contents of iron remained in the scoria, united with oxygen, at the rate of 35 *per cent.* I found the produce of the metallic button thus obtained white as silver, and presenting imperfect radii; the surface was considerably oxydated, especially where the combustion had taken effect.

2d, I subjected to a similar treatment 875 grains of an argillaceous iron-stone, which contained a usual proportion of lime; the fusion of this powder was more difficult than that of the former, though the phenomena exhibited by both during reduction were alike. The crucible was withdrawn from the furnace in forty minutes after introduction, and the surface of the button exposed to combustion as before. The deflagration differed little in point of appearance from that effected with the siliceous iron-stone: the button of crude iron was found oxygenated, and weighed 249 grains; a produce in iron from the raw stone = 28.5 *per cent.*: the vitrid mass was found to weigh 354 grains; the loss of volatile mixtures was therefore 272 grains, or 31 *per cent.* The fracture of the regulus now obtained was still white, though not allied to any degree of crystallisation, and its surface smoother and less oxydated. The glass produced in this experiment was of a deep brown shining colour, in many places porous, and enriched with fine tints of colouring.

3d, The same experiment was repeated upon 875 grains of a fine calcareous iron-stone. The fusion of this required a violent heat of seventeen minutes, during which time the disengagement of a gaseous substance was most evident; in other respects it exhibited the same features, when in fusion, as the two former: the degree and length of heat conveyed was nearly the same; and the result obtained was a button of carbo-oxygenated crude iron * weighing 261 grains; a produce

* Although in this experiment a true carbonation is effected by means of the presence of lime alone, yet experience has never confirmed this in the large way; nor shewn, after a just proportion of materials was in the furnace, that additional lime alone conferred any additional degree of carbonation. The widely different manner in which the heat is excited, and the substances which are operated upon exposed to its action, may account for this want of coincidence of effect. It is the same principle that C. Clouet has lately ingeniously applied to the fabrication of cast steel from bar iron. To the decomposition of the carbonic acid alone, I attribute the advantages derived from the use of lime in the manufacturing of crude iron.

produce in iron equal to 30 *per cent.* from the raw iron-stone; fused earths, now reduced to an opaque brown glass streaked with white, 294 grains: loss in volatile mixtures 320 grains, or 36.5 *per cent.*

The metallic button produced in this operation had a smooth crystallised surface; and, when in fusion, combined less readily with oxygen offered by the contact of atmospheric air, than did the former two. The fracture was light grey, with a regular distinct grain; the mass of fused earths were disposed after the manner of a crystallisation, in radii, shooting from the circumference of a minute circle to the extremity of one larger.

From these experiments it is obvious that reguli of crude iron may be obtained from the different classes of iron-stones, of a respectable produce, without any addition whatever; and that the tendency which these have to part with their iron is in the exact ratio of the quantity of lime present. The following statement exhibits the difference betwixt the real and partial assay of the foregoing iron-stones.

The siliceous iron-stone, properly assayed, yielded 34.5 *per cent.*, but by fusion *per se* only 25; leaving in the latter method 9.5 mixed with the scoria. Argillaceous stone, properly assayed, gave 35.6, by fusion *per se* 28.5; leaving 7.1 mixed with the scoria. Calcareous iron-stone, properly assayed, yielded 33.7, by fusion *per se* 30; which left 3.7 mixed with the scoria.

One reason may be advanced why the iron produced from the calcareous stone was so much more in proportion than the other two classes: both the siliceous and argillaceous buttons, when deprived of their scoria, decomposed atmospheric air so rapidly as to suffer a little, in point of real metal, from the combination of oxygen. It was otherwise, however, when the surface of the calcareous button was exposed: the affinity of the oxygen to the metal being less

iron. I have for the last three years made use of this truth with the greatest advantage in the assaying of ores and other experiments.

that

than to the carbon united with it, carbonic acid was formed. A review of these experiments leads to another conclusion, that, without the presence of carbon, either in chemical union in the ore, or attracted from the ignited gas by the particles of metal, crude iron will not separate from the ore or stone; and that, in proportion as the metal is exposed to inhale this principle, its produce is increased and its quality improved.

It will further appear obvious, from the various natures of scoriæ which the different iron-stones afford when fused *per se*, that there exists a want of mixture in most of them to form, when fused, a fluid so sufficiently divided that no portion of iron may be retained, either in a metallic state, or in that of an oxide. This deficiency of mixture is greatest in the siliceous iron-stones, less in the argillaceous, and least of all in the calcareous. The principle, therefore, I proceeded upon was, to ascertain what proportion of additional mixture, and of what nature, was necessary to give the proper equilibrium to form a transparent scoria. When flux predominated, it was found that a major proportion of calcareous earth, in the solvent or flux, supplied the natural deficiency; and that the whole contents in iron were justly revived, and fully saturated with carbon: when at any time it was wished to revive the metal, contained in such ores, possessing strength with carbonation, I found that this could be easily effected, in all proportions, by the addition of calcareous earth with a mixture of pure clay. In short, in every experiment I have made with ores, the various natures of lime-stones, or chalk, with certain proportions of bottle glass, have been found capable of reviving the iron contained in all the ores which have come under my knowledge, and of conferring upon their respective products every degree of strength and fusibility*. In order to form an accurate judgment of the tendency

* Although I have frequently had occasion to mention the combination of clay with iron-stone, as the mixture which in fusion conveyed strength

dency which individual ores have to afford their metal carbonated, possessing strength, or otherwise, a flux of a medium proportion of calcareous earth and glass is determined upon; such as, with an iron-stone of that genus, would afford super-carbonated crude iron. Let the button of iron so obtained be the standard whereby to judge of succeeding results; and let all the ores belonging to the same mine, or used at the same work, be compared with it: these will be found, according to their mixtures, possessing different degrees of carbonation; some of them white in the fracture, and others again as richly carbonated as the standard regulus; their degrees of strength also approaching or receding from the standard as they approximate or vary from the nature and proportion of its original mixture.

To complete such an undertaking with accuracy, requires a minute knowledge of the operations of the assay-furnace, and the degree of heat from time to time excited: the quantity of ore in such a chain of experiments should be at all times the same, and the requisite heat conveyed and completed at similar stages of fusion and of separation. Strict

strength to the metal, yet I have not ventured a conjecture how far and in what manner the mechanical structure of the metal is altered when additional strength is thus obtained. It will be a difficult matter to decide, whether it is derived from the natural infusibility of the clay, by preventing separation for a longer time, and new modifying the structure of the particles of metal; or whether the acquired strength is entirely owing to the molecules of the metal becoming more flattened and tenacious by a varied stage of crystallisation. Most probably it is owing to both causes, and that the former is productive of the latter; the one the cause, and the other the effect accounted for.

We find, that from siliceous iron-stone, which is fused with the greatest facility, iron is obtained uncommonly white and brittle; and again, from pure calcareous iron-stones, which are still more difficult to reduce than the other two classes, we find an opposite extreme of brittleness, arising from an extra combination of carbon, which destroys the continuity of the particles to each other. Clay still holds the medium; and its addition alone restores a just equilibrium, not of strength only, but of fusibility.

accuracy

accuracy of result, as to the quantity of metal, will not always be obtained; but a very comprehensive knowledge will be formed of the nature of the earthy mixtures, and the strength and fusibility of the metal. Once in the possession of these, it will be no difficult matter to superadd a portion of earths requisite for perfect reduction. In two simple experiments, therefore, not only the real quantity of metal contained in the ore is obtained, but its presumptive strength and fusibility developed in a great measure prior to its application to the purposes of the blast-furnace.

In order to facilitate this operation, and to compare the various degrees of heat in which different experiments are effected, I constructed a pyrometer upon the principle of the expansion of metal by heat; a representation of which, and a description of its use, will form an article for the next Number of the Philosophical Magazine.

XII. Agenda, or a Collection of Observations and Researches the Results of which may serve as the Foundation for a Theory of the Earth. By M. DE SAUSSURE.

[Continued from page 71.]

CHAP. XVII.

Observations to be made on the Remains and Vestiges of organized Bodies found in the Earth, in Mountains, and at their Surface.

THEIR nature, bulk, and quantity; the extent, depth, and other dimensions of the strata where they are found*.

2. Their preservation. Whether entire or broken, decomposed or not; shells with their pearly covering (*nacre*); their colour; remains or traces of their fish, or their skin if there be any. To deduce, if possible, from these data, some idea

* 1. A. If formed of trees, to mark down the direction of the strata; and whether they are placed horizontally, or inclined either towards the summit or the roots. C.