The metallurgical work of Henry Clifton Sorby and an annotated catalogue of his extant metallurgical specimens

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Abstract

This paper describes the development of Henry Clifton Sorby's metallurgical researches, 1863-5, his innovative specimen preparation and reflected light microscopical techniques and use of photomicrography. The chronology of the events leading to the eventual publication of these researches in 1886-7 and the further discoveries made by Sorby at this later period are discussed.
The Catalogue lists, and includes descriptions of, the present condition of Sorby's extant glass-mounted metallurgical specimens now held in the Collections of The University of Sheffield and the South Yorkshire Industrial History Society. The specimens in the former collection were bequeathed to the University by Sorby; the latter (except one) were discovered in 1987 in the effects of Dr Thomas Andrews. It is shown that nearly half of Sorby's specimens came from one source and that each collection contains one specimen which may be identified as the first metallurgical mount ever made.

The publication of Sorby's metallurgical researches

Sorby's pioneering researches into the structures of iron and steel represent a small, and in many ways unsatisfactory, element in his life's scientific work. There are a total of 115 metallurgical specimens extant, by comparison with 1400 geological ones, and although in both areas specimens have undoubtedly been lost, it is unlikely that the ratio of 1:12 is unrepresentative.

Moreover, whereas Sorby's interests in geology and in the preparation and observation in the light microscope of geological thin sections were maintained throughout his life, his metallurgical work appears to have been carried out in the brief period between the summer of 1863 and early 1865. Not only was it given up, it was not even properly published – there were merely a number of fragmentary verbal presentations at British Association meetings, conversaziones and soirées of the Sheffield Literary and Philosophical Society and the like, together with presentations of 'nature prints' and photomicrographs, which seem to have been calculated more to demonstrate technique than to elucidate the structures of iron and steel (Higham 1963, Hammond 1989).

1864, the year in which Sorby carried out the bulk of his metallurgical work, was marked by the Great Sheffield Flood which occurred on the night of March 11th. Sorby, as a Proprietor of the Water Works Company, was financially affected and he received letters of condolence from Henry Woodward of the British Museum and Ferdinand Zirkel, his great disciple in the fields of geology and petrology. He also received several letters enquiring after the progress of his researches, with requests to send specimens or reports. Thus, W P Beale, writing on 29th June, says 'The engineers meet in Glasgow in a month, I wish you would send a drawing or two to show them what magnified iron and steel look like' (Beale 1864). Again, Henry Woodward, writing on 28th September, says 'please send a brief abstract (of Sorby's paper presented at the 1864 meeting of the British Association) for insertion into the Geological Magazine' (Woodward 1864). On 17th January, 1865, George Gore of Birmingham asks Sorby for the loan of a photograph showing the structure of Bessemer steel and at the same time thanks him for demonstrating the structural differences arising from phosphorus – an important topic about which Sorby has left no record (Gore 1865). None of these letters of encouragement appear to have elicited a positive response and it was not until 1882, whilst he was President of Firth College in Sheffield, that Sorby gave the first lengthy and serious account of his metallurgical researches entitled 'On the Microscopical Structure of Iron and Steel'. This lecture was substantially repeated at a meeting of the Iron and Steel Institute in 1885 and was eventually published in a paper in the Journal of the Iron and Steel Institute in 1887 (Sorby 1887).

The problem of illumination of opaque specimens

Why did Sorby delay for so long? Partly it may have been due to the problem of developing a satisfactory epi-illumination technique for the observation of opaque specimens at high powers. In 1863-5 Sorby used either a concave parabolic reflector made for him by Richard Beck (from whose firm, Smith, Beck and Beck, Sorby had purchased a microscope in 1861) and which gave, in effect, oblique dark ground illumination; alternatively, he used a small mirror, of his own devising, which was inserted at an angle of 45° between the objective lens and the specimen, obstructing half the field of view. The parabolic reflector should not to be confused with a lieberkuhn which collects, not light from an illuminator at the side of the specimen, but light coming up around the specimen from a substage mirror and condenser lens.

These expedients and their application by Sorby to the study of iron and steel were described by Richard Beck in a paper given to the Microscopical Society of London in October 1865 (Fig 1) (Beck 1865).

They were recognised as not being satisfactory and of course were wholly unsatisfactory for high power objectives in which the space between the specimen surface and objective is limited. However, at about the same time that Sorby was giving up his metallurgical work in 1865, further rapid developments were being made with the problem of the 'vertical' illumination of opaque objects. At the meeting of the Microscopical Section of the Manchester Literary and Philosophical Society on October 16th 1865, Mr J B Dancer read a paper 'On the Illumination of Opaque Objects under High Powers of the Microscope' and reported an invention of Mr (Professor) H L Smith of Kenyon College, Gambier, Ohio, USA, in which a small mirror was fixed in a rectangular box which fitted between the objective and the body-tube of the microscope and in which light admitted from the side was reflected down through the back of the objective to the specimen (Dancer 1866). This is essentially the present-day arrangement, the objective also functioning as a condenser lens. This apparatus was sent over to England by Professor Smith and was exhibited by Mr E G Lobb at the 19th January 1866 meeting of the Microscopical Society of London, by which time the invention had been both taken up, and improved upon, by the two firms, Powell and Lealand, and Smith, Beck and Beck. Both these firms substituted, for the small silvered mirror of Professor Kenyon (which covered approximately half the aperture of the objective), unsilvered glass surfaces at an angle of 45°. Powell and Lealand used a thick fixed plate of optically worked glass whereas Smith, Beck and Beck used an ordinary thin cover glass with adjustable inclination. To the writers' knowledge no record of the Powell and Lealand device survives, but that of Beck was described and illustrated by Richard Beck in a paper read to the Microscopical Society of London at the 10th January 1866 meeting (Fig 2) (Beck 1866).

These developments aroused a good deal of interest and comment at the meeting. Mr Wenham (inventor of the Wenham binocular, which Sorby used with his Smith, Beck and Beck microscope) pointed out that 'upwards of five years ago Mr Hewitt had suggested the principle of making the object-glass its own illuminator', but that he (Mr Wenham) had abandoned the trials because of excessive internal glare. The use of a thin disc of glass was also 'an old idea' having been used by Troughton and Simms for illuminating the cross-wires in a telescope. These somewhat disparaging remarks were stopped by the President, James Glaisher, and the rest of the discussion was concerned with members' experiences in using either

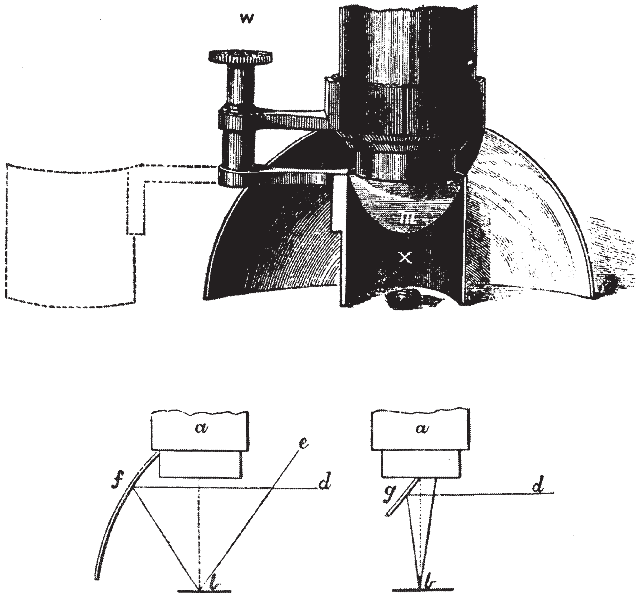


Figure 1: Beck's parabolic reflector with Sorby's flat mirror (m) inside a semi-cylindrical tube (x) to shut off light reflected by the parabola. Oblique illumination is achieved when the mirror and tube are rotated to the position shown by dotted lines. The light paths below are those for normal and oblique illumination.

the Powell and Lealand or the Beck vertical illuminator. What is striking about this discussion is that there is no reference whatever to the examination of metals, meteorites, rocks or other bulk materials – only diatoms, beetle-scales, insect hairs and so on. Similarly, in his Presidential Address of 1866, James Glaisher discusses Professor Smith's invention and its development, and also Richard Beck's 'Sorby Illuminator' (Glaisher 1866), but the application of the former to the examination of metals and minerals at high powers does not seem to have occurred either to him or to Sorby himself. Perhaps it was simply a change in interest – in 1865/1866 Sorby was absorbed in the development and application of the microspectroscope and Richard Beck, who might have pursued the wider applications of his vertical illuminator, died in 1866. Thus metallography, ceramography and ore microscopy were still-born!

In all cases an oil-lamp would have been used as the source of illumination (excepting the restricted use of sunlight), with a condensing lens (sometimes called a bulls-eye) to concentrate the light on to the reflector and the possible use of a colour filter. The lamp flame was normally arranged by microscopists to be "edge-on" to the microscope.

There are frequent references to both forms of vertical illuminator in the years between 1866 and 1885, for example in the book on 'Microscopical Manipulation' (Suffolk 1870) in which engravings of both forms (Figs 1 and 2) are reproduced, and the paper by G W Moorehouse (1877) 'Opaque Objects with High Powers' which was published in the *Monthly Microscopical Journal* in 1877

– (the same volume in which Sorby published his paper on the use of the quartz wedge and during his Presidency of the Royal Microscopical Society). Hence, Sorby cannot have been unaware of the potential of Beck's vertical illuminator, but again there is no suggestion as to its use for anything other than insect scales and the like.

Sorby's discoveries using Beck's vertical illuminator

It was not until the Autumn of 1885, whilst he was preparing his 1885 Iron and Steel Institute lecture for publication, that Sorby made use of Beck's vertical illuminator to re-examine the specimens which he had prepared in 1863-5. The high powers available (up to 650 x) allowed for the first time the structure of pearlite to be resolved: the structure which had lain unobserved, as it were, for twenty years.

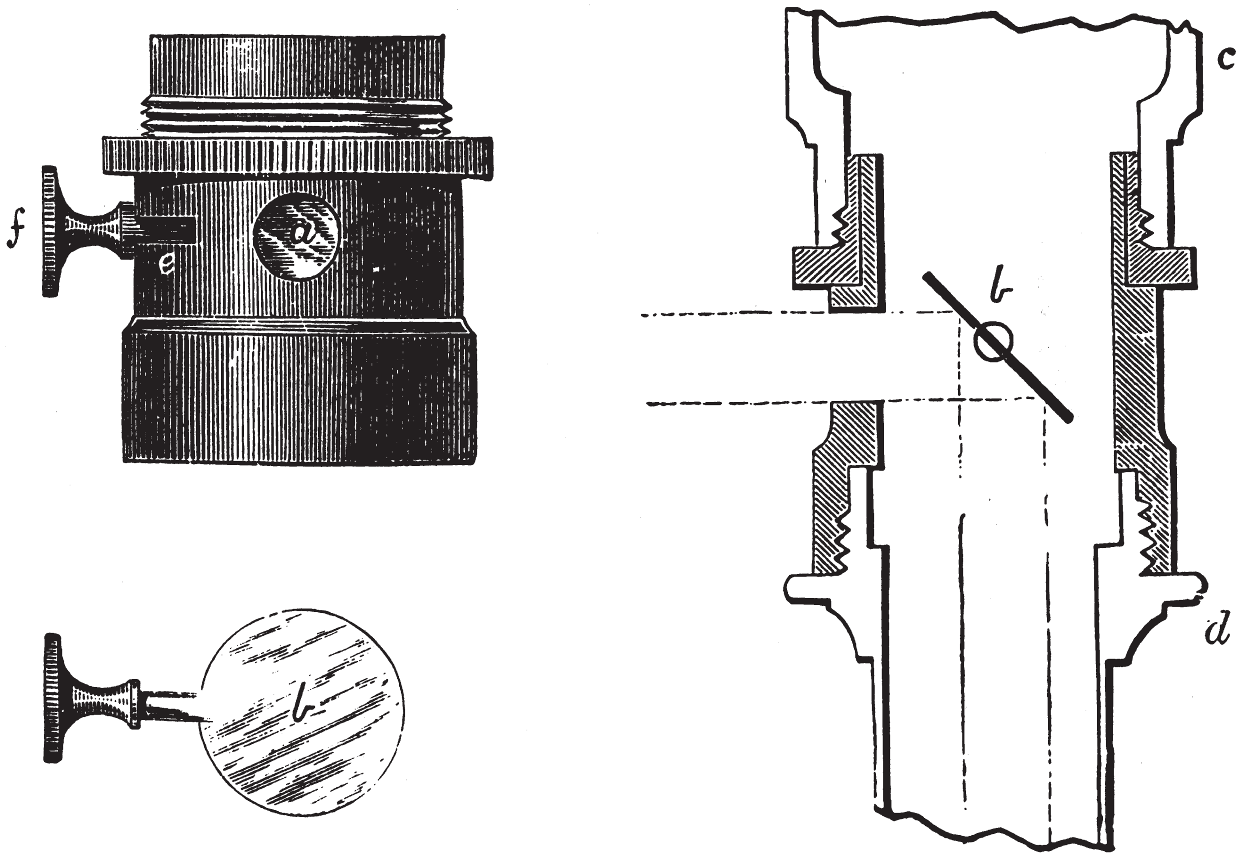


Figure 2: Beck's vertical illuminator for high powers, showing the coverslip (b) in the adjustable mount (e) the light entrance (a) and the arrangement of the illuminator between the objective and microscope nosepiece.

Sorby immediately published his discovery in a paper 'On the Application of Very High Powers to the Structure of Steel' which was presented at the Spring Meeting of the Iron and Steel Institute and published in the Journal in 1886, (Sorby 1886). Here Sorby describes the pearly constituent of steel (i.e. pearlite) as consisting of a mixture of lamellae, the thinner 1/40,000 inches thick and the thicker 1/80,000 inches thick giving striae 1/60,000 inches apart. He surmises, with remarkable insight, 'that this mixture arises as a result of the breakdown of a high temperature compound into lamellae of free iron and iron containing the whole of the combined carbon'. (The present day names are austenite for the high temperature compound, ferrite for the free iron and cementite for the iron containing the whole of the combined carbon. The names pearlite, ferrite and cementite were first used by the American metallurgist, Prof H M Howe, who suggested them to Sorby some ten years after the publication of the JISI papers). Sorby goes on to suggest the structure of martensite and the effects of alloying elements on hardenability. 'It is very possible that in the hardening process the unstable compound may not break down into soft iron and the hard brittle substance, but may suddenly be fixed, so as to give great hardness combined with great strength. According to this view, Mushet's self-hardening steel may be due to the presence of tungsten preventing this unusual separation.' There can be little doubt that, had Sorby made these observations on the basic phase transformations in steels, and published this work twenty years earlier, metallography, and indeed the whole of physical metallurgy, would have advanced and would have enjoyed the scientific prestige then accorded to mineralogy and petrology.

In his 1886 and 1887 papers, Sorby makes scant reference to the use of Beck's vertical illuminator, simply saying that the parabolic reflector and small silvered mirror (Fig 1) were superseded by a device 'contrived some years ago by Richard Beck' (Sorby, 1887) – which is clearly something of an understatement for a period of twenty years!

The problems of reproducing microstructures — (a) by nature printing

The other practical problem was that concerning a printing technique for the satisfactory reproduction of the microstructures of iron and steel. First, a specimen etched with dilute nitric acid could be used as a printing block; cementite, the lightly etched phase, standing in relief to the more deeply etched ferrite. This process, which Sorby called 'Nature Printing' (since it was similar to botanical 'nature printing') gave, of course, a magnification of unity and was the first used by Sorby in the description of his work carried out in the summer and autumn of 1863 in collaboration with Graham Stuart.

Sorby exhibited his etched specimens at the 1863 meeting of the British Association in Newcastle. There are two recorded reports of his presentation. First, among the Sorby papers held by the University of Sheffield, there is what appears to be a cutting from a Sheffield newspaper of 1863 which reads 'The line of research opened out by Sorby and Stuart seems likely to throw some light on the cause of change from fibrous to granular fracture in axles and other masses subject to vibration' (Anon 1863).

Second, there is the first of an interesting series of notes in *The Reader*, a local Sheffield weekly newspaper. On 5th March 1864, under the title 'Scientific Notes' appears the following (Anon 1864):

> 'MR H.C. SORBY, whose arrangements for viewing microscopically the internal structure of steel excited considerable interest at the meeting of the British Association at Newcastle last autumn, has hit upon a very ingenious method of rendering the structure visible by a novel species of nature-printing, by means of which a section of the pieces of steel becomes its own block to print on paper its own peculiar characteristics. When iron is converted into steel by cementation, three distinct crystallized compounds are formed, two of which are readily dissolved by diluted nitric acid, whereas one is scarcely affected by it at all. If, therefore, a piece of steel be ground flat and polished, and then placed in the acid, after a suitable amount of action this constituent retains its original surface and polish, while the other two are so much dissolved that it stands up in sufficient relief to admit of the block being used for surface printing, instead of a woodcut, to exhibit the structure of different kinds of steel. Such is Mr Sorby's ingenious process. Printed illustrations thus obtained were exhibited by Mr Sorby at the conversazione lately given by the Sheffield Literary and Philosophical Society. These consisted of a "square bar of iron once converted, transverse section, showing iron remaining in the centre"; a "flat bar of iron slightly converted, the crystals being small"; a "square bar of iron twice converted, transverse section, showing the centre incompletely converted"; a "flat bar of iron highly converted, the crystals being rather large"; a "round bar of homogeneous metal converted, transverse section"; and a "flat bar of hammered cast steel reconverted, the crystals very large.'

In the following week (12 March) the Scientific Notes continue (Anon 1864a):

> 'We are enabled, by the kindness of Mr Sorby, to lay specimens of the latest nature-printing process before our readers. Referring to our last week's remarks, we need only to mention that the steel cuts which we have chosen represent a square bar of iron twice converted, the centre being steel of low temper; and a round bar of Shortridge and Howell's "homogeneous metal" converted, transverse section, showing a much coarser crystalline structure than the other specimen. When the prints are mounted as stereoscopic objects the impressions show admirably, for they bear a low magnifying power to great advantage, which brings out their perfection. In justice to Mr Sorby, we should remark that our paper is scarcely adapted to his process.'

There was some controversy, however, in the following weeks. On 26th March appears the following (Anon 1864b):

> 'A CORRESPONDENT, who has no wish to deprive Mr Sorby of any of the credit which may be due to him for his ingenious application for nature-printing's with which we were enabled to make our readers acquainted a week or two ago, reminds us that a precisely similar process was used in 1853 by the Imperial printing office of Vienna for showing the structure of meteoric iron, a fact mentioned in a work by A. Bauer, called "Der Polygraphische apparat", published at Vienna in 1853.'

A further insight is then given by Sorby himself, on 9th April (Anon 1864c):

> 'MR SORBY begs us to say that he was well aware that prints had been taken from meteoric iron in Vienna as early as 1843 and published in Partsch's work on meteorites. He only claims novelty only as far as iron and steel are concerned.'

Sorby prepared lithographs of the six nature prints which he had exhibited at Newcastle and circulated them at a meeting of the Sheffield Literary and Philosophical Society on 23rd February 1864. One lithograph survives and was reported by Entwisle (1964) to be in the possession of Col T A McWilliam. It was reproduced in Entwisle's paper and the six prints are precisely as described in *The Reader* of 5th March 1864.

The problems of reproducing microstructures — (b) photomicrography

As a second means of reproduction, there was the use of photomicrography, in which Sorby was an undoubted pioneer. He made his first photomicrographs, at a low power of x9, in the period 1863-5 with the help of a Sheffield photographer, Charles Hoole. Presumably they used the Wet Collodion Process, but no record of this has been discovered. Sorby exhibited four photomicrographs showing the structures of cast iron, armour plate, cast steel and meteoric iron at the September meeting of the British Association at Bath in 1864, but the official record of his presentation is sparse and uninformative. However, he again exhibited them in 1872 at a conversazione of the Sheffield Literary and Philosophical Society, using as a small-scale reproduction process the newly invented (1869) Heliotype process, and then again in London in 1876 at a soirée of the Royal Microscopical Society during his Presidency. A copy of the 1872 Heliotype was stated by Entwisle (1964) to be in the possession of a Col T A McWilliam. Sorby donated a copy of the 1876 Heliotypes to the Science Museum, where it still remains.

However, the Heliotype Process did not lend itself satisfactorily to the large scale reproduction required for publication in books or journals. Eventually Sorby's and Hoole's four low-power photomicrographs were reproduced in the 1887 *Journal of Iron and Steel Institute* paper using the Woodburytype process, which had been proposed by Sir Henry Bessemer and the preparation of which caused the delay between Sorby's verbal presentation of his paper in 1885 and its publication two years later.

The Woodburytypes, mounted as circles on the pages of the *Journal* are, to this day, remarkably clear and show beautifully smooth variations in tone. They stand in marked contrast to the other attempts to convey metallographic information in the published papers of the period. For example, the paper by J C Bayles (1883) in the *Transactions of the American Institute of Mining Engineers*, includes very poorly reproduced copies of Sorby's original Heliotypes of meteoric iron, cast steel, armour plate and cast iron, in which the structures are hardly visible. Similarly, F L Garrison's paper published in the *Transactions* two years later (Garrison 1865) includes poorly reproduced photomicrographs of grossly overetched specimens. H Wedding's paper, published in the *Journal of the Iron and Steel Institute* (Wedding 1885), (the year of Sorby's presentation) includes only four engravings which are not only rather crude in themselves but also two of which appear to bear no relation to the descriptions in the text. These engravings are, in fact, incorrectly numbered, as pointed out by A L Colby, editor of *The Metallographist* in his bibliography of metallographic references published in *The Analysis of Steelworks Materials* by Brearley and Ibbotson, (1902); Figures 1, 2, 3, 4 should read, 4, 3, 2, 1.

The discussion of Wedding's paper provides an illustration of the personalities and social relationships of the time. Sir Henry Bessemer, the chairman, com-plimented the paper in passing and then went on to describe at length his own experiments on the crystallization of iron. He relates this to the crystallization of sugar, and compares the 'bold crystals' obtained on slow cooling without stirring 'which Englishmen were used to', to the 'morphous mass of saccharine' obtained during stirring which (by implication) was the form preferred by foreigners!

Sorby politely suggests that the reason that Wedding's results differed from his own was because his (Wedding's) sections had not been ground down with a soft stone which would thereby have revealed the difference between soft iron (ferrite) and hard iron (cementite) in blister steel and white iron. He also points out that direct (*ie* vertical) illumination is essential, and he was sure Dr Wedding did not use it. Wedding formally invited members of the Iron and Steel Institute to visit the Royal Prussian Mechanical Testing Institute in Berlin to inspect Dr A Martens' collection of 120 metallographic specimens which had provided the basis of his talk. There appears to be no record that the invitation was ever taken up.

The last phase: Sorby's involvement in metallography from 1887 to 1908

Despite the widespread interest aroused by his *Journal of the Iron and Steel Institute* papers and the fact that metallography was an established technique, Sorby made no further experimental contributions. This was not for want of encouragement. For example C H Desch (Professor of Metallurgy in the University of Sheffield, 1920 to 1931) wrote in 1921 (Desch, 1921):

> 'When Professor Arnold was appointed to the Chair in the Firth College in 1889, he asked Dr Sorby to resume his investigations, so as to correlate the microscopic structure with the thermal, mechanical and chemical investigations that were then in progress. Dr Sorby's eyesight was failing, and he was deeply engaged in other work, so he declined, but he showed Dr Arnold his methods and lent him his specimens, which were ultimately bequeathed to this Department.'

The comment by Desch that, in 1889, Sorby's eyesight was failing is clearly important. It was presumably conveyed to Desch by Arnold directly and therefore must have some credence. One can imagine Sorby, having developed other interests such as his marine biological lantern slides (Edyvean 1988), which did not require so much microscopical work, would not wish to risk his eyesight further. In addition the preparation techniques were tedious and expensive and in 1889 he would have begun to see other people taking up metallography in the College

which he had helped to found.
A residual interest persisted, however, as evidenced by a letter from Sorby to R A Hadfield dated as late as June 24th, 1906 (Sorby 1906):

> 'My Dear Hadfield,
>
> I must thank you for sending me a copy of your lecture which otherwise I might not have seen. I have read it with great interest since it gives me information respecting a number of the new alloys about which I knew so little. Looking back nearly 50 years to the time when I was working on iron and steel I cannot but see what enormous advances have been made. The questions which then were open to doubt are in many cases so well known that it seems almost impossible that any one ever thought different to what is now known.
>
> As you may be sure it is a source of great satisfaction to me to think that what I did has proved so fruitful and one can scarcely believe that for so long a time no one seemed to think it of any practical value.
>
> Congratulating you on what you have done for this subject.
>
> I remain yours very truly. H.C. Sorby.'

Sorby died on 9th March, 1908. In view of his pioneering work it is regrettable that his name is not adequately perpetuated. The name 'Sorbite' was first given (by H M Howe in 1890) to artificially produced titanium cyano-nitride, found as copper-red crystals in blast furnace slags. It was then given (by F Osmond in 1895) to describe the microstructure of a fully tempered steel and as a consequence the first name was withdrawn and replaced by the name 'Cochranite', from the iron-works of Messrs. Cochrane & Co near Middlesbrough where it was first identified. However, with the later rationalisation of metallurgical nomenclature for steels the name 'Sorbite' is now disused and Sorby's name is only perpetuated as 'Sorbyite', to describe a mineral from Madoc, Ontario (Embrey and Fuller 1980).

The development of Sorby's metallurgical researches, 1863-5

The influences on Sorby

A number of influences can be traced which led Sorby to a microscopical study of the structure of iron and steel – although curiously, his family firm was not one of them: there is no record that he ever examined the edge-tools manufactured by the family firm of John Sorby and Sons. First, a number of correspondents urged Sorby, who had already established his reputation in geology, to investigate the structures of metals and alloys. In 1855, David Forbes, who was later to become Foreign Secretary of the Iron and Steel Institute, sent Sorby a box of a 'few crystalline metallurgical products which might interest you' (Forbes 1855) . In 1857, William Crowder of the Newcastle Mercantile, Mining and Agricultural Laboratory reported to Sorby his investigations on the changes which take place on 'refining and puddling Cleveland pig' (Crowder 1857). In 1858, William Vivian, a mine agent in Llandudno, reported in a letter to Sorby that 'he had applied the microscope a little to the crystalline character of metals' and that he had 'received a medal from the Polytechnic Society of Cornwall for his microscopical observations on native copper' (Vivian 1858). Vivian presumably has the distinction of being the first man to observe non-ferrous metals. Indeed, it is very curious that Sorby never himself prepared specimens of non-ferrous metals or alloys – brasses, bronzes and the like which frequently exhibit beautiful large-grained microstructures, visible to the naked eye. Finally, in 1861, B C Salmon, editor of the Mining and Smelting Magazine, urged Sorby to investigate metals so as to 'give the interests a respectable and sound representative which they have not at present' (Salmon 1861). Clearly, the problem of establishing the status of the metallurgist in society is not a new one!

Second, as a prominent member of the Sheffield Literary and Philosophical Society, Sorby would almost certainly have been present at an 1860 meeting in which John Holland gave a paper on 'Ornamental Etching in Sheffield' in which he showed that the ancient craft of Damascening was based on the selective etching by acids on steels of different combined carbon contents.

Third, there was his interest in the structure of meteorites, which developed naturally from his interest in the structures of rocks. Earlier in the century, Aloys von Widmanstätten in Austria and William Thomson in England had demonstrated the beautiful interlocking platelet structures in polished and etched sections of meteorites. Sorby's attention to these was apparently brought about by Robert Hyde Greg, a Secretary at the British Association, in a correspondence beginning in 1861 (Greg 1861). Greg had prepared an Atlas of Meteorites which was published in that year by the Association and Sorby records in his diaries (Sorby 1862) in June 1862 his intention to 'look over meteoric rocks', and again in November to 'Read abt. meteors etc.' However, there is no firm evidence that Greg sent Sorby any meteoric materials and an earlier January entry in his diary 'send ac/s of meteor to Greg' may have referred to the Atlas. The first firm indication of Sorby's interest in the structures of meteoric irons comes in 1863 when in a letter dated 30th July, James R Gregory (of Golden Square, London) offered, presumably at Sorby's request, to sent him samples of the Tazewell and Tolucca meteoric irons (Gregory 1863). However, these were not immediately available and in subsequent letters (dated 6th August, 20th August and 18th September 1863) Gregory refers to the delay and mentions that he is sending samples of Tazewell, Tolucca and Arwa meteoric irons (Gregory 1863a). Hence, as discussed below, Sorby was not in possession of any meteoric irons, and presumably had only seen the

Widmanstätten structures for himself at meetings (such as the British Association Meeting of 1861) and in either the Atlas or other publications, when he made his famous diary entry on 28th July 1863: 'discover the Widmannstättischen figure in L iron' (Sorby 1863).

The identification of the first metallurgical specimen

There are 32 specimens dated 1863 in the Catalogue (see Table 1) and of these there are two possible contenders for the first metallurgical specimen prepared by Sorby: Cat No A7 (from the group of 22 specimens discovered by RGJE in 1987 as described below, and Cat No C1 (from the Department of Engineering Materials, University of Sheffield).

Cat No A7 is engraved 'Stuart's broken axle trans. The first polished obj, H.C.S. 1863' and on the reverse side is glued a slip of paper (not in Sorby's handwriting) 'first micro ever made by Sorby'. Cat No C1 is engraved ' L Wilkinson 1/2 in bar/as 1/dressed on hard water of Ayr. This is the first good object I made H.C.S. 1863.'

Cat. No. C1 (or its immediate predecessor 'as 1') is almost certainly the specimen to which Sorby referred in his diary entry of 28th July (Sorby 1863). But was Sorby mistaken in his identification of a Widmanstätten structure? In general, L iron, (L signifying that it was the highly-prized Swedish Dannemora wrought iron from the Leufstra Forge), consists of equiaxed ferrite grains with a very small volume fraction of slag stringers and particles, which Sorby would surely not have mistaken for Widmanstätten plates. But such wrought irons are also very inhomogeneous and local regions of high carbon content can give rise to a microstructure consisting of ferrite (or cementite) plates in a pearlite matrix. Specimen Cat No C1 is mounted in a display case (see below) and the only region in which the microstructure is still visible (bottom left hand corner) shows what appears to be uniform ferrite and pearlite – there is no apparent graduation in pearlite content and no indication of any Widmanstätten structure. Of course it may be possible that the diary entry refers to a converted L iron (carburised by means of the cementation process to give blister steel). Again, such steels are very inhomogeneous and the only such specimen dating from 1863, (Cat No C32, L Wilkinson blister steel), shows a microstructure consisting of equiaxed ferrite grains. All the other 'once converted' L irons (Cat Nos B29, B30, B35, C33, C34, C35, and C36) date from 1864 and 1865 and the two other L irons (Cat No A4 L (180% red, longitudin) and Cat No A13 (Wilkinson Transverse) date from 1864. All these specimens show, where observable, a wide range of microstructures (see Appendix 2). Of most interest is specimen Cat No A13 which may be another specimen of the same L Wilkinson 1/2 in bar as specimen Cat No C1. This shows an inhomogeneous microstructure graduating from equiaxed ferrite grains at one edge to ferrite/pearlite and pearlite/cementite at the other; part of the cementite occurs as coarse Widmanstätten plates. So the question remains open: specimen Cat No C1 does show some pearlite but (at least in the visible area) in an insufficiently high carbon content to give a Widmanstätten structure.

However, Stuart's broken axle, Catalogue No A7 'the first polished object', may precede C1 'the first good object' and it is reasonable to suppose that Sorby was examining these specimens at about the same time. The slip of paper glued to the back is in all probability in Thomas Andrews' handwriting (see section 3A) which clearly implies that he considered it to be 'the first micro (metallurgical specimen) prepared by Sorby.' Graham Stuart was Honorary Curator of the Museum of the Sheffield Literary and Philosophical Society and it appears that Sorby was carrying out some investigative work with him on an axle failure, using as a basis for comparison the structure of the L iron. Indeed, the very same evening as his diary entry (July 28th) he showed his observations to Stuart and to William Baker, a joint Honorary Secretary with Sorby of the Society. Baker was then engaged in the preparation of a paper to be read to the Society entitled 'On the processes employed in refining iron and steel' and must have been an immediately formative influence on Sorby. One can imagine the excitement of these three on July 28th!

Further progress in Sorby's metallurgical work

Sorby pressed forward with his metallurgical work in the autumn of 1863 although the active involvement with Graham Stuart appears to cease. He records in his diary for September 10th 'Make out changes of structure in hardened steel'; and on September 18th 'Kirkaldy stays with me several hours looking at hardened irons' and finally on November 13th 'Baker comes in morn to look at irons' (Sorby 1863). He also records the progress with his microscopical techniques: on September 23rd is the entry 'expt. with mirror and write to R Beck' and on November 13th he refers to 'improvements.'

The work attracted the attention of Walter White, Secretary of the Royal Society, who wrote (White, 1864):

> 'I like the notion of showing your latest discoveries in the magic lantern.... the anatomy of steel and iron under the microscope would be a telling sight.'

Clearly, Sorby foresaw in 1863 the necessity of carrying out a systematic programme of research and the need to acquire a range of specimens from which comparisons could be made on the changes in structure as a result of heat treatment and deformation. Such a series of specimens were sent to him on November 10th 1863 by W P Beale of Park Gate Iron Works in Rotherham (the covering letter and list of specimens Beale provided are included in Appendix 1). The authors have compared this list of specimens with the inscriptions on the specimens in the catalogue which, together with the date and initials 'H.C.S.' are engraved on the glass mounts above, below, and sometimes to one side of the specimens. Those which can be identified as having been sent by Beale are labelled PG. The identification is followed by an asterisk (*) in those cases where Sorby's inscription is the same as in Beale's list and a query (?) in those cases where the identification is only tentative. Altogether these specimens comprise nearly half of the total number of specimens in the Catalogue.

On 25th March 1864, Beale sent a further six specimens: 2 pieces of ordinary No. 1 slab, 1 inch thick, 2 pieces of armour plate rolled down to the thickness of No. 1 slab and 2 pieces $^{9}/_{10}$ inch thick, cut out of a plate that was tried at Portsmouth and pronounced A1. However, it is difficult to distinguish these specimens from those of armour plate previously supplied on 10th November 1863 (see Appendix 1).

It is doubtful whether Sorby had prepared the section of the Tazewell meteorite (not in the Catalogue), which was photographed by Charles Hoole and exhibited at the September 1864 meeting of the British Association at Bath, much before the spring or summer of 1864 – almost a year after his initial observations with Graham Stuart. In his paper 'On the Microscopical Structure of Meteorites and Meteoric Iron' received on June 7th and published in the Proceedings of the Royal Society in 1864, Sorby merely states that 'I will also give a full account of the microscopical structure of meteoric iron as compared with that produced by artificial processes' (Sorby 1864). Nor does he mention any meteoric irons which he intends to examine by name. Perhaps on June 7th, 1864 he had yet to receive the specimens from Gregory. In summary, it appears to be most likely that Sorby received his first meteoric specimens from Gregory in the spring or summer of 1864 and that he began work on them then. This conclusion is corroborated by the evidence of J W Judd, who arrived in Sheffield to take up employment as a chemist at the Great Cyclops works and who records (Judd 1908):

> 'I went to Sheffield .... in the summer of 1864, and at once met Sorby, he not only taught me to make rock sections, but showed me what he was doing with artificial irons – led to it by his studies of iron-meteorites. Mr George Wilson, then Manager of Cammells, a very enlightened man, gave me permission to supply Sorby with any irons that I analysed for this work, so that I saw the beginning of his metallurgical work...'

The specimen preparation technique which Sorby adopted was to prepare first a thin polished section (rather like a geological section) mounted on a 40mm square glass slide; the upper surface was etched and then protected with a cover slip. This tedious and unnecessarily lengthy method was quickly abandoned by subsequent metallographers. As Professor Desch wrote in 1921: 'Whilst in our present practice we select by preference sections which can be comfortably held between finger and thumb ... Sorby used sections about $^{1}/_{16}$ inch thick and $1^{1}/_{4}$ inch square, cemented with Canada balsam to a plate of glass, as in the preparation of rock specimens.'

Sorby's early samples were filed smooth and then the sections were ground down, like those of rocks, on a glass plate, using powdered rotten stone with water as an abrasive. This was followed by polishing with the finest jeweller's rouge on wash-leather. The polished specimens were then etched with 1% nitric acid, well washed with distilled water, dried with alcohol, and mounted like rock sections with Canada Balsam under a cover glass. All grinding was performed by hand. Desch (1921) reports Arnold as saying that the specimen of spiegeleisen was ground by a labourer who was paid £1 a week and that his bill came to £5. Later on Sorby used emery papers placed on sheet glass, still grinding and polishing by hand. Presumably the specimen labelled 'Water of Ayr' in the collection was the first or nearly the first to be prepared using this modified method. Again, this provides another clue as to why Sorby did not pursue metallurgical studies. The specimens were costly, in both time or money to produce, depending on whether he did them himself or employed someone else, and while he received some encouragement locally, and even nationally, his findings did not receive the enthusiasm in the wider academic field that he might have expected.

Conclusions

Sorby briefly summarised the influences in the development of his metallurgical work in an autobiographical sketch of 1897 entitled '50 Years of Scientific Research', first given as an address to the Sheffield Literary and Philosophical Society (Sorby 1898):

> 'It was a natural thing I should be led from the study of the microscopical structure of rocks to that of meteorites, and in order to explain the structure of meteoric iron I commenced the study of artificial irons. I began this work in 1863 and in 1864 gave an account of it at the British Association. This attracted no attention for 22 years, but in 1885, the Iron and Steel Institute requested me to again take the matter up ... In those early days, if a railway accident occurred and I had suggested that the company should take up a rail and have it examined with a microscope, I should have been looked upon as a fit man to send to an asylum, but that is what is now being done; and very gratified am I to think that our member, Mr Thos. Andrews, is doing most admirable work in connection with this subject. What I really proved was that various kinds of iron and steel are varying mixtures of well defined substances, and that their structure is in many respects analogous to that of igneous rock. I also took specimens of iron and steel and acted upon them with acid so that

it was possible to print from them as from type, and show many interesting points connected with their structure.'

In conclusion, it was largely through his concern to explain the Widmanstätten structures in meteoric iron that Sorby prepared and examined specimens of iron and steel. Perhaps he was disappointed with what he saw, hoping for, but not finding, the clear and beautiful Widmanstätten structures of meteoric irons; failing also to make use of the high powers available with Beck's vertical illuminator; deterred, in spite of letters of encouragement, by prevailing attitudes of scepticism and the difficulties and cost of specimen preparation. In such a situation it is perhaps not surprising that his metallurgical interests were supplanted by microspectroscopy and the search for new elements.

A descriptive history of the Catalogue

Specimens in the collection of the South Yorkshire Industrial History Society (formerly the Sheffield Trades Historical Society)

This group (catalogued as Group A, a total of 22 specimens), was discovered fortuitously by one of the authors (RGJE) amongst a collection of metallographic specimens, brought to him by Dr K C Barraclough in 1987, which had been bequeathed to the Sheffield Trades Historical Society by Dr Mary Andrews. This collection had belonged to Thomas Andrews, Jr. (1847-1907), grandfather of Dr Mary Andrews (the Thos. Andrews referred to by Sorby in his autobiographical sketch quoted above). Andrews ran Wortley Forge and Colliery, but was dedicated more to scientific study, being interested in the properties of iron and the effects of temperature on its strength, corrosion resistance and structure. He became successively a Fellow of the Geological Society, a member of the Institution of Civil Engineers, a Fellow of the Royal Society of Edinburgh and, in 1888, a Fellow of the Royal Society. He received the Telford Gold Medal, three Telford Premiums and the Gold Medal of the Society of Engineers.

This collection was stored in shallow drawers in a small wooden box or cabinet (Fig 3) which contains many specimens other than Sorby's. Most are metallurgical specimens — cross-sections of bars or rods about $^1/_2$ inch (12.5mm) in diameter and $^1/_{16}$ inch (1.5mm) thickness mounted on standard 3 inch x 1 inch (75mm x 25mm) glass slides some with glass cover-slips and some with retaining rings. These are in a very poor state of preservation – mainly corroded and most have become detached from the slides. There are also prepared slides, all except two for transmission microscopy, of various specimens – volcanic dust and ash, pumice stone and biological specimens which were evidently prepared or collected by Andrews. However, amongst all this material and debris were metallurgical specimens mounted on square glass slides of side $1^5/_8$ inches (40mm), protected

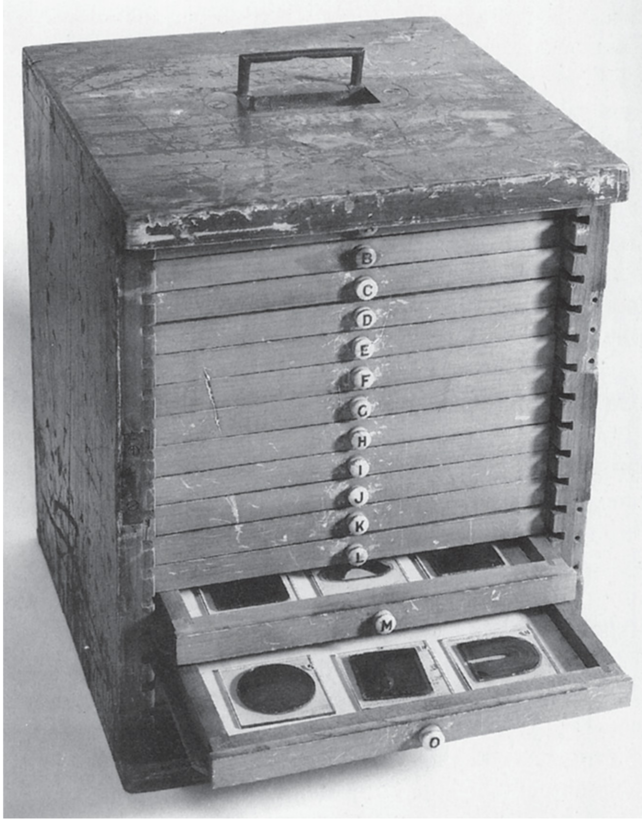


Figure 3: The cabinet formerly in the possession of Thos. Andrews Jr. and bequeathed by Dr Mary Andrews to the Sheffield Trades Historical Society in which are 22 of Sorby's specimens.

by coverslips and most in an excellent state of preservation. The slides were labelled by hand-engraving on the glass. RGJE immediately recognised them as characteristic of Sorby's slides and on cleaning the dust away his initials and date were (with few exceptions) clearly revealed (Fig 4). In addition one slide (Cat No A7) has a ragged slip of paper glued to the reverse side with the words 'first micro ever made by Sorby' in (presumably) Andrews' handwriting.

There is no written evidence of how these specimens came to be in Andrews' possession; presumably they were given or lent to him by Sorby some time before 1887. It is doubtful whether they came via, or were even known about by, Professor Arnold, since he would surely have wished to include them in the University's collection.

Specimens held by the Department of Engineering Materials (formerly the Department of Metallurgy), in the collections of the University of Sheffield

These specimens have a well known history. They were lent by Sorby to Professor J O Arnold, soon after his appointment (in 1889) to the Chair of Metallurgy and Mechanical Engineering at Firth College, and were bequeathed to the Metallurgy Department of the newly-founded University of Sheffield on Sorby's death in 1908. The University's specimens are in two groups, one set is

Figure 4: Examples of the specimens from the cabinet (Fig 3) showing the style of mounting and engraving and the slip of paper on the reverse of specimen Cat No A7

a: Cat No A1 (no inscription) Converted blister steel bar with large internal voids

b: Cat No A7 'Stuart's broken axle trans. The first polished obj. H.C.S. 1863'

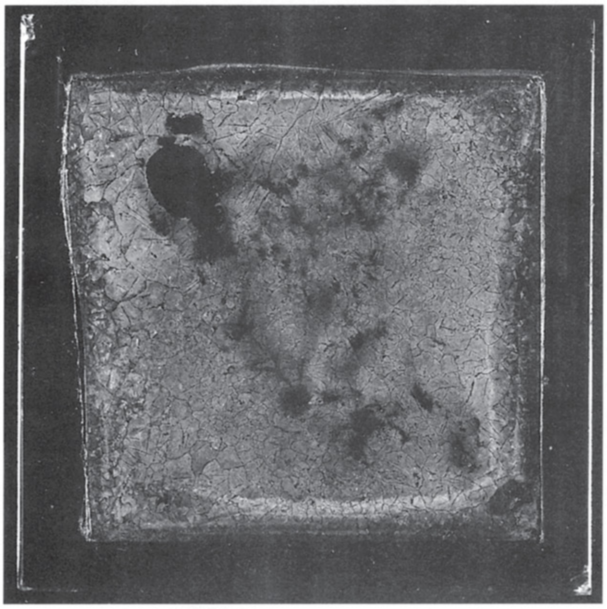
c: Cat No A7 Reverse side of the specimen showing slip of paper with Thos. Andrews (?) handwriting

d: Cat No A16 'Decarbonized cast iron bent cold H.C.S. 1863'

e: Cat No A20 'Bessemer steel as 1 forged transverse H.C.S. 1863'

c

a



d

b

e

mounted in a display case (catalogued as Group C) and the other is kept in a black-painted 'tin' box (catalogued as Group B). This box is similar to those in which Sorby kept his rock specimens and is therefore likely to be the original container (Fig 5).

The method of mounting (on 40mm square glass slides) and style of engraving of the specimens are identical to those in Group A (Fig 6). The display specimens (Group C) have undergone some rearrangement over the years. The original arrangement of 55 specimens made by Professor Arnold is shown in Fig 7 and the key according to the catalogue is given in Fig 8. Note that this does not include specimen Cat No C1 which was, in view of its special interest, kept separately. The specimens were re-arranged, presumably by Professor Desch for his 1921 Sorby lecture, who also prepared a lantern-slide of specimen Cat. No. C1. This continued to be displayed separately, behind a magnifying glass in order that the inscription could be read, but had been mislaid at the time of the 1963 Sorby Centenary (Entwistle, 1964). However, in 1988 this key specimen was found and is displayed in the cabinet with the other 55 specimens. Fig 9 shows this present arrangement and the key according to the catalogue

Figure 5: Sorby's black-painted 'tin' box with wooden slide dividers containing 36 specimens bequeathed to the University of Sheffield on Sorby's death but not arranged for display by Professor Arnold

is given in Fig 10 (Cat No C1 in the top left hand corner).

In total, the University's collection numbers 92 specimens, 36 boxed and 56 in the display case (Table 1). Most of these must be in their original condition. For the second Sorby lecture, Desch wrote that a section of wrought iron had been successfully photographed without removing the cover glass, some 50 years after it was prepared and etched (Desch 1921). He also reports:

> 'Among the specimens of Dr. Sorby's preparations left in this Department were some of converted and doubly converted bars. The Canada Balsam with which they were covered had darkened and become partly opaque in the course of time. On cleaning it off by means of a solvent, the original etching was found to be as brilliant as when first developed, and through the kindness of Mr Monypenny I am enabled to show you slides made from these specimens, which were etched 40 or more years ago, and have remained perfect ever since ...'

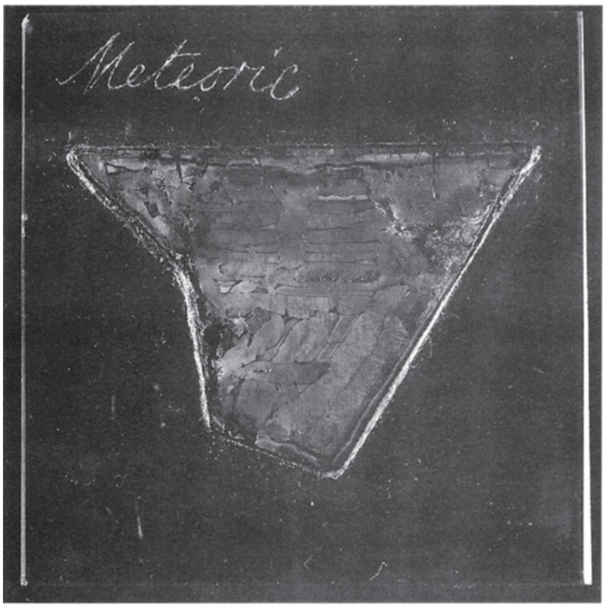
Desch reproduces these slides as figures 5 and 6 in his published lecture (Desch 1921). However quite why Desch writes '40 or more years ago' is unclear. This refers back to the early 1880s whereas as far as we know, Sorby made no sections outside the period 1863-65. Had Desch, who had a link with Sorby through Arnold (who had known Sorby well), heard that Sorby had re-prepared his specimens, perhaps for the higher magnifications with which he used to examine them in the mid 1880's? It is doubtful whether this is the case. Certainly Sorby would not have re-prepared all his specimens and there is no visual evidence that some selected ones have been re-prepared.

Specimen formerly held by Professor W H Williams of McGill University, Canada, and now in the collection of the South Yorkshire Industrial History Society

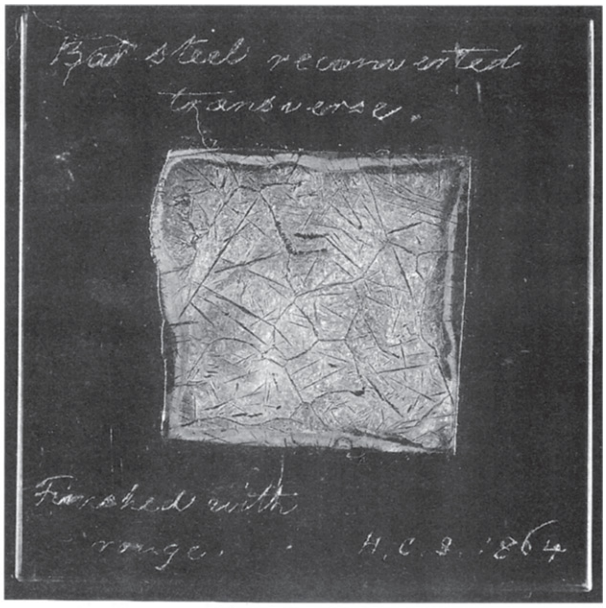
It has been the good fortune of one of the authors (RGJE) that, whilst writing this paper, Professor W H Williams of the Mining and Metallurgical Engineering Department of McGill University corresponded with Professor Greenwood at Sheffield about a Sorby specimen in their collection (catalogued as D). Details of its provenance have kindly been made available by Professor Williams. It appears that this specimen was given to a Mr Dalton (who presumably was an employee of Thomas Andrews & Co and who eventually moved to Canada) by C Reginald Andrews (son of Thomas Andrews). Together with the specimen is an original letter written to Mr Dalton from CR Andrews at Cheltenham dated March 16th 1921 which reads "in reply to your letter, I shall certainly be glad to let you have one of the Sorby slides, as I know of no one who will value it more, and after all they are "historic", but don't run away with the "pearlite" one, I want that for a special purpose.' There is also an unsigned, undated *aide memoire* which reads '...given to me by C.R. Andrews Esq. out of a collection of Dr. Sorby's slides

Figure 6: Examples of specimens from the box (Fig 5), showing the style of mounting and engraving identical to those from the wooden cabinet (Fig 4).

a: Cat No B1 'Meteoric' (no date)
b: Cat No B5 'Hard tool steel ingot trans. H.C.S. 1864.'
c: Cat No B14 'Bar steel reconverted transverse H.C.S. 1864.'
d: Cat No B25 'Armour plate Parkgate 1 plane of plate H.C.S. 1864.'



a



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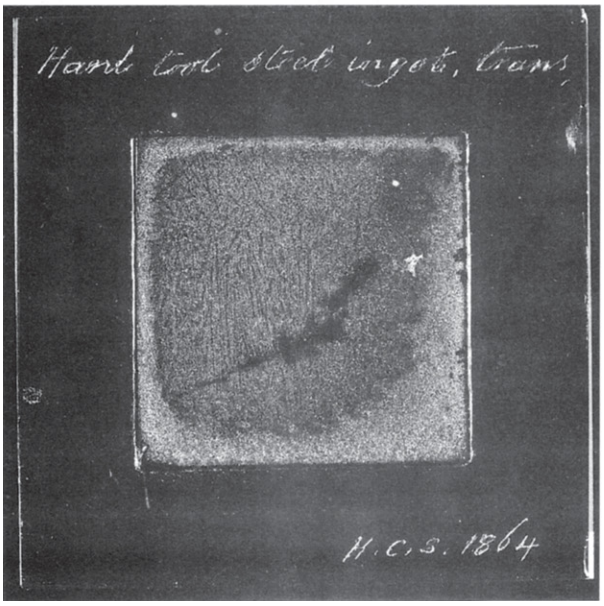


b

d

given by Dr. S. to Mr. Andrews father, Thos. Andrews FRS.' Specimen D is also mounted on a 40mm square slide which is inscribed 'white cast iron broken from a round bar and decarbon long. section H.C.S. 1863' (Fig 11). It has been fully described by Hardwick and Williams (1980).

Table 1 summarises the distribution of the specimens in the catalogue in each category, A, B, C and D and by year. This clearly indicates that, while Sorby did not commence the preparation of metallographic specimens until the summer of 1863, this and 1864 were the years of his most intense metallurgical activity.

Table 1: Catalogue categories

Date of Preparation	A	B	C	D	Total
1863	9	5	17	1	32
1864	11	21	25	—	57
1865	1	8	7	—	16
Not dated	1	2	7	—	10
Total	22	36	56	1	115

Figure 7: Photograph of the original display arrangement made by J O Arnold some time after 1908. The brass plate reads 'HENRY CLIFTON SORBY'S MICRO-SECTIONS OF IRON AND STEEL MADE IN 1863-5. LENT IN 1889, FOR SORBY'S LIFETIME, TO JOHN OLIVER ARNOLD AND BEQUEATHED ON SORBY'S DEATH IN 1908 TO THE METALLURGICAL DEPARTMENT OF THE UNIVERSITY OF SHEFFIELD.' The paper label above reads 'prepared by H.C.Sorby at "Broomfield" 1863-5. Framed by J.O.Arnold at...' (the rest of the label presumably was covered over by mounted specimens).

C34	C20	C11	C54	C52	C2	C48	C7	C15	C29
C17 over another?	C4	C27	C44	C9 remounted	C14	C39	C24	C42	C5
C18	C16	C12	C13	C31	C53	C35	C28	C45	C22
C51	C33	C46	C32	C25	C38	C47	C21	C41	C40
C49	C56	C23	C26	C3 remounted	C43	C30	C50	C19	C6
C37	C36						C10	C55	C8

Figure 8: Key to the original arrangement (Fig 7) according to the Catalogue numbering. Note Specimen Cat No C1 is missing. It was displayed separately and photographed by Professor CH Desch.

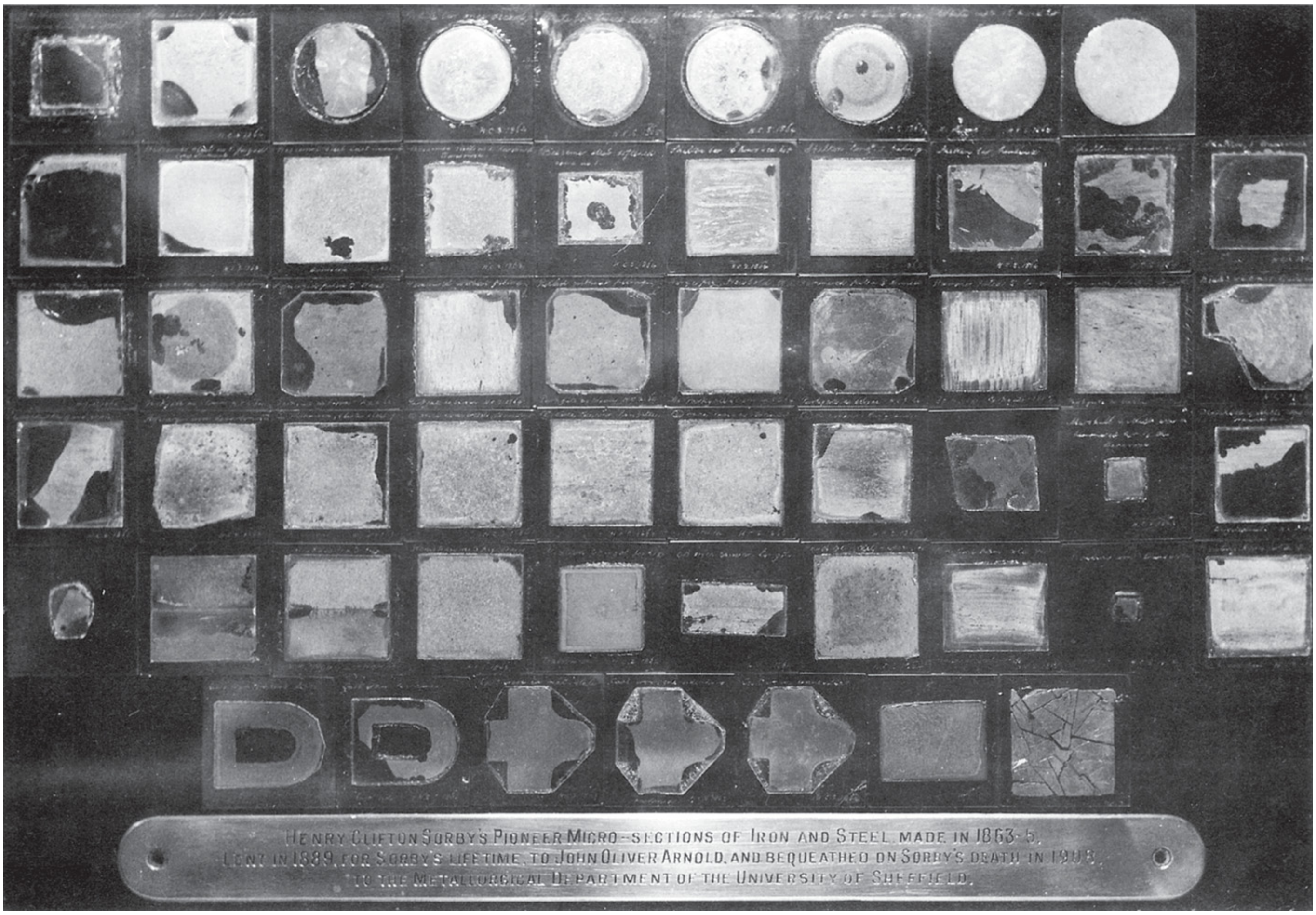


Figure 9: Photograph of the present arrangement presumably made by Professor Desch about 1921 for the preparation of the Second Sorby Lecture.

C1	C2	C3	C4	C5	C6	C7	C8	C9	
C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
C20	C21	C22	C23	C24	C25	C26	C27	C28	C29
C30	C31	C32	C33	C34	C35	C36	C37	C38	C39
C40	C41	C42	C43	C44	C45	C46	C47	C48	C49
	C50	C51	C52	C53	C54	C55	C56		

Figure 10: Key to the present arrangement (Fig 9). Note that Desch continued to display specimen Cat No C1 separately and it was mislaid at the time of the Sorby Centenary Conference. It was then found and placed (in 1988) in the top left hand corner. Specimens Cat Nos C30, C39 and C51 show some deterioration since Desch's rearrangement.

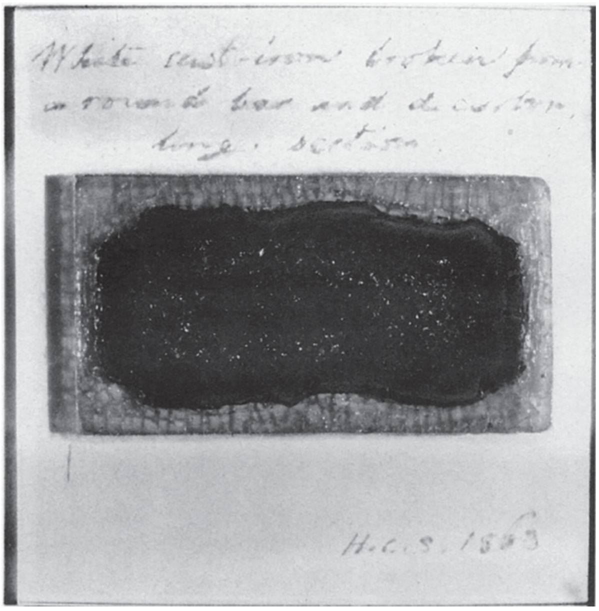


Figure 11: (Cat Group D). 'White cast iron broken from a round bar and decarbon. long. section H.C.S. 1863'

Appendix 1: Transcript of WP Beale's letter to Sorby of November 10th 1863 (Beale 1863) with corresponding identifications made by the authors to specimens in the Catalogue

LETTER (TYPOGRAPHICALLY SET OUT AS IN THE MANUSCRIPT)	CORRESPONDING CATALOGUE NUMBERS * = CERTAIN identification ? = TENTATIVE identification
Offices, 10 Park Street, Westminster Park Gate Iron Works Rotherham. Nov 10th 1863	
Dear Sorby, I have got the series of samples made in a satisfactory manner, that is, so that there can be no doubt that whatever difference we find in the structure is due to mechanical processes. I shall be in Sheffield tomorrow and will leave them for you at Messrs. Chadburn's before 2 pm - I send you a list of the marks and their meanings, of course it will be necessary to be very careful that they do not get missed -	
A bit of hammered bloom - D	A10
A – F Bloom rolled down to $1\frac{1}{4}$"	
B – I bloom rolled down to $1\frac{1}{4}$"	B 24?, C24*
C – E Bar $1\frac{1}{4}$", from hammered puddled iron piled 5 high	B 27*, B26?, C26*, C27*
D — L Similar bar from squeezed iron	C28*, C22*
All the specimens are from one heat	
(A -) means cut in the direction of the fibre	
(A X) cut at right angles to the fibre -	
Similarly B- & BX etc etc	
α - A $^{=5}$ Armour plate - horizontal section	A10, B23
β - C $^{=6}$ " - vertical at right angle to fibre	A12
γ - K $^{=2}$ " - vertical in direction of fibre -	A11, B25
I think you will easily distinguish them. Yrs very truly W.P. Beale	

LIST OF SPECIMENS (TYPOGRAPHICALLY SET OUT AS IN THE MANUSCRIPT)		CORRESPONDING CATALOGUE SPECIMEN NUMBERS
Bowling trans. hard side nicked		B22
Shelton - - - -		
Tazewell, Tolucca & (???) met iron		B3
layer square irreg		
Marshall & Mills hammered		A18*, C38,
transverse $^{1}/_{2}$ sq bent		C39
α Shelton 16 hours at bright		
red (B marked) on long brass not square		
OO Ingot Tool steel small square		C15
Puddle Ball OO blister		
Grey Baird pig more uneven top	J	B34, C20*
No. 3 Renishaw pig	G	B36, C42*, C43*
Bowling ham. cold welded	I	A8*
L square trans	G	B30
OO forged steel long	A	
OO - trans	N	
L once conver. blister	L	B29, B35, C33, C34, C35, C36
Shelton iron trans, white)		
hot for 2 min)	M	A3*, B6*
Decarbon 3 times round bar	D	
- 2 - - -	H	
L flat bar trans	C	
OO blister trans	J	A2?
Bowling 80 hours bright red	F	B18*, B20*
as forged cold		C47*, C49*
OO hard steel converted	O	
Scotch pig	J	
Renishaw	G	B9* C46* B36?
Rail B = 7 & H = 8		
Rolled Homogeneous iron	M = 3	
Cast Tool Steel	N	
Hard Cast steel from	O	
end of ingot hot hammered		
Shelton with cut	A	
" 1 to piling	D	A5*
Bowling broken on tilt	H	A17
" forged cold	B	
Forge pig, Beale	K	
L blister 1st conver.	M lop in blister	B29, B30
Hammered bloom	C	
D as above	E	
C as above =	P	
List of irons etc.		
Simple casting 2 one nick		C50*, C52*
Same annealed 2 2 nicks		C54*
Same hardened 2 3 nicks		C51*, C53*
Decarb. bar thicker bit 1 nick		
on iron		
" (?) fine bar 2 nicks		
cast bar		
Refinery iron 1.15 square		
" decarb $1^{1}/_{4}$ 2 sides not filed etc.		C31*
Bessemer forged and hardened long 1 $^{1}/_{8}$ sqr.		B32, C13
Decarb long no side filed		
Bent round small decarb		
Bessemer steel cast & softened		C14*
Nail iron		
Decarb bent cold		A16*
Small in. parallel & bent		

The specimens clearly not supplied by Beale are as follows:

A4 (L iron 80% reduction, 1864)
A6, A7, B33 (Stuarts broken axle, trans. and longitudinal, 1863)
A13, C1, C32 (Wilkinson iron, 1863 and 1864)

A19, B16, B17, ($\frac{T}{M}$ iron, 1864 and 1865)

B1 (Meteoric, undated)
B3 (As Tolucca, undated)
B4 (Styrian cast iron, 1865)
B31 (Bessemer steel rail, 1863)
C4, C5, C6, C7, C8 (White (cast iron) bar 1864 and 1865)
C25 (Forged pig iron, Newbold 1864)
C30 (Cammell's iron, 1865)

Appendix 2: Photomicrography of some specimens in the catalogue

All of the specimens in groups A and B of the catalogue have been examined using standard reflected light microscope techniques and low power objectives. In most specimens the microstructures are partially or wholly obscured by corrosion and oxidation or opacity of the Canada balsam. However, in some they are sufficiently clear to be photographed, which is indicative of the care which Sorby took in the preparation of the specimens and the effectiveness of Canada balsam and glass coverslips in excluding air and water from the etched surfaces. The following Figures (12-21) are a selection of photomicrographs in which the microstructures are of most historical interest and/or informative about the manufacture and heat-treatment of the specimens.

Specimen Cat No A2 (00 once converted transv H.C.S. 1864):
This specimen and specimen Cat No A1 (Fig 4 a) have a similar microstructure, consisting of a network of cementite outlining prior austenite grains and a matrix of coarse and partially spheroidised pearlite (Fig 12). This microstructure (and the presence of inhomogeneities and voids) is consistent with a wrought iron converted to 'blister' steel by carburization in the cementation furnace.

Specimens Cat Nos A6, A7 and B33:
These specimens are all from Stuart's broken axle. The microstructure of specimen Cat No A7, which is possibly the first metallurgical specimen prepared by Sorby (Figs 4b and 4c) is unfortunately obscured by oxidation and the opacity of the Canada balsam. The microstructure consists of equiaxed ferrite grains which are revealed in strong contrast using dark-ground illumination (Fig 13).
The other transverse section, specimen Cat No A6, shows an inhomogeneous microstructure consisting of regions of fine and coarse ferrite grains with spots and patches of oxide (Fig 14). The inhomogeneity of the microstructure

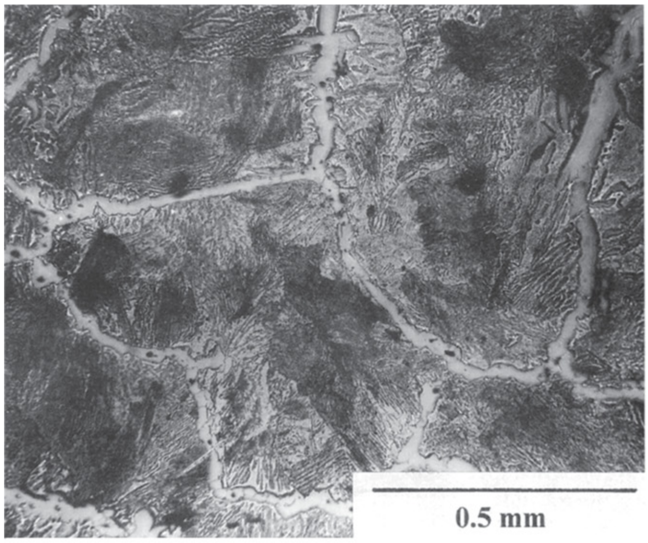


Figure 12: Cat No A2 'OO once converted transv H.C.S. 1864'

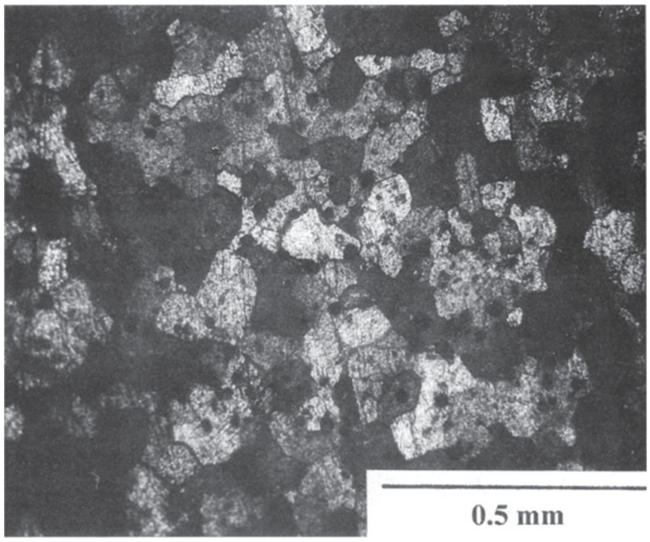


Figure 13: Cat No A7 'Stuart's broken axle trans. The first polished obj H.C.S. 1863'

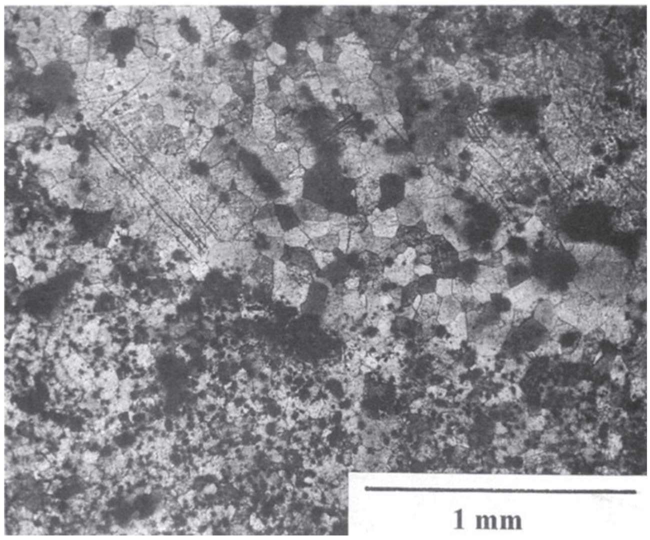
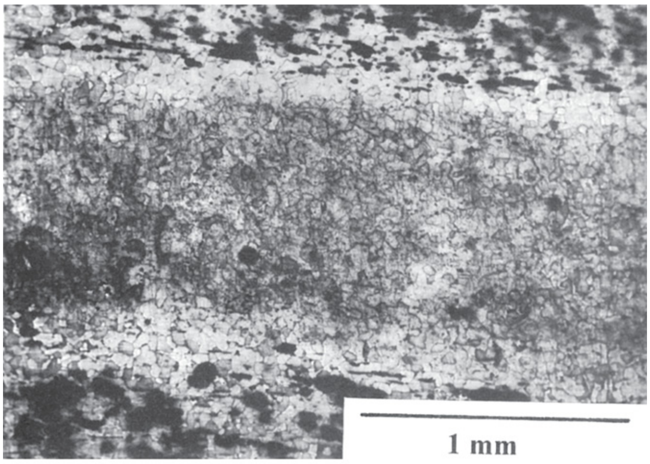
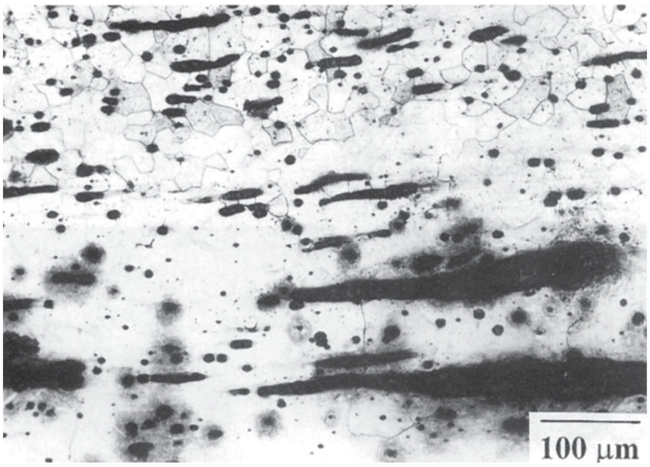


Figure 14: Cat No A6 'Stuart's broken axle trans. H.C.S. 1863'

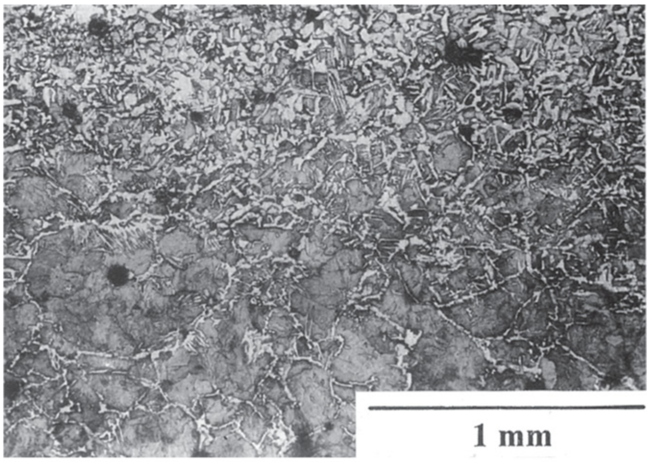


a



b

Figure 15 a and b: Cat No B33 'Stuart's broken axle long. H.C.S. 1863'



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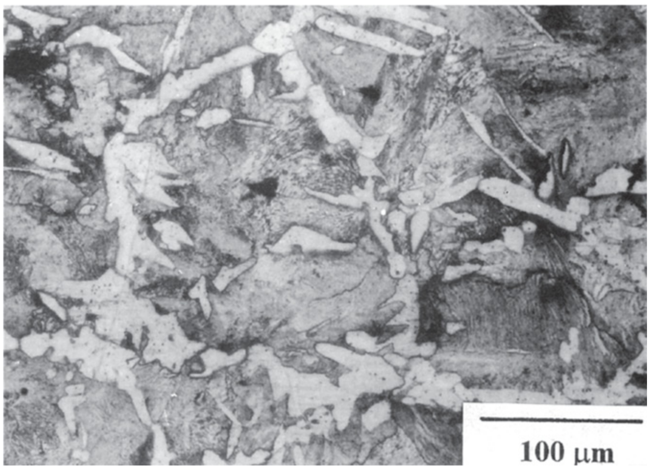


b

Figure 16 a and b: Cat No B33 'Stuart's broken axle long. H.C.S. 1863'

is further revealed in the longitudinal sections, specimen Cat No 33 (Fig 15a) shows a band of fine-grained ferrite sandwiched between bands of coarser-grained ferrite. The transition between the two microstructures (Fig 15b) also indicates that the oxide spots appear to develop at the slag stringers which are elongated along the direction of the bar. These microstructures indicate that the axle was fabricated by hammer-welding strips or bars of wrought iron. However, in addition it is clear that bars of blister steel were also used in its construction. Figure 16a shows a transition from a fine-grained ferrite microstructure (top) to one which is characteristic of blister steel (bottom), as shown in Figure 12. This is shown in more detail in Figure 16b and suggests that the axle failure may have arisen as a result of the presence of the coarse needle-like cementite platelets.

Specimen Cat No A20 (Bessemer steel as 1 forged Transverse) HCS 1863

The contrast between the microstructure of this specimen and those of the wrought irons and blister steels is striking. The Bessemer steel microstructure consists of fine ferrite and pearlite grains approximately 10 μm in diameter (Fig 17). The pearlite volume fraction indicates 0.2% carbon content and the lamellar structure is clearly resolved. Apart from an internal (forging?) defect and decarburization at the surface of the bar (Fig 4e), the ferrite/pearlite microstructure is homogeneous throughout the specimen with no slag inclusions. There are, however, what appear to be small manganese sulphide inclusions which may indicate that Bessemer was using ferro-manganese as a deoxidizer prior to 1863. It is remarkable that Sorby never intimated to Bessemer at or following his 1885 Iron and Steel Institute lecture, that he had prepared a specimen of Bessemer's steel only nine years after the invention of the process was first announced.

Specimen Cat No A22 (Bowling 2 longitude bent cold H.C.S. 1863)

Figure 18 shows a fracture initiated at the outer surface and the process of delamination across the slag/ferrite matrix interfaces, giving rise to a fibrous fracture surface.

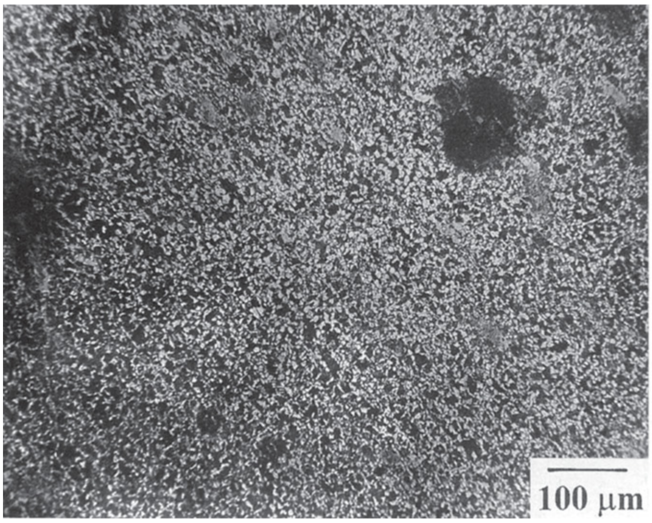


Figure 17: Cat No A20 'Bessemer steel as 1 forged transverse H.C.S. 1863'

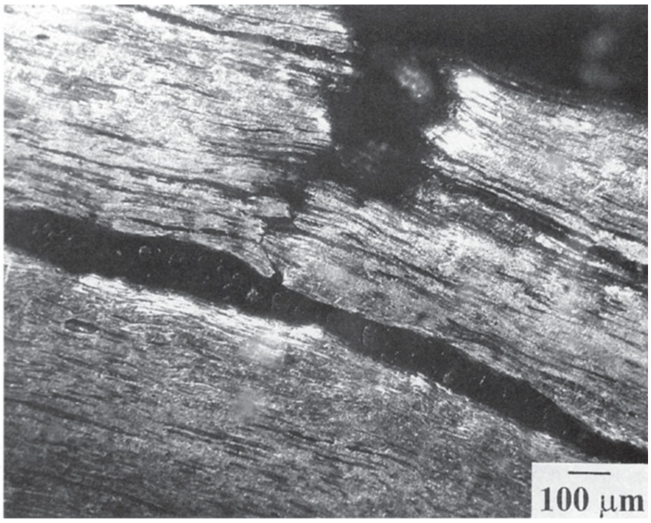


Figure 18: Cat No A22 'Bowling 2 longitude bent cold. H.C.S. 1863'

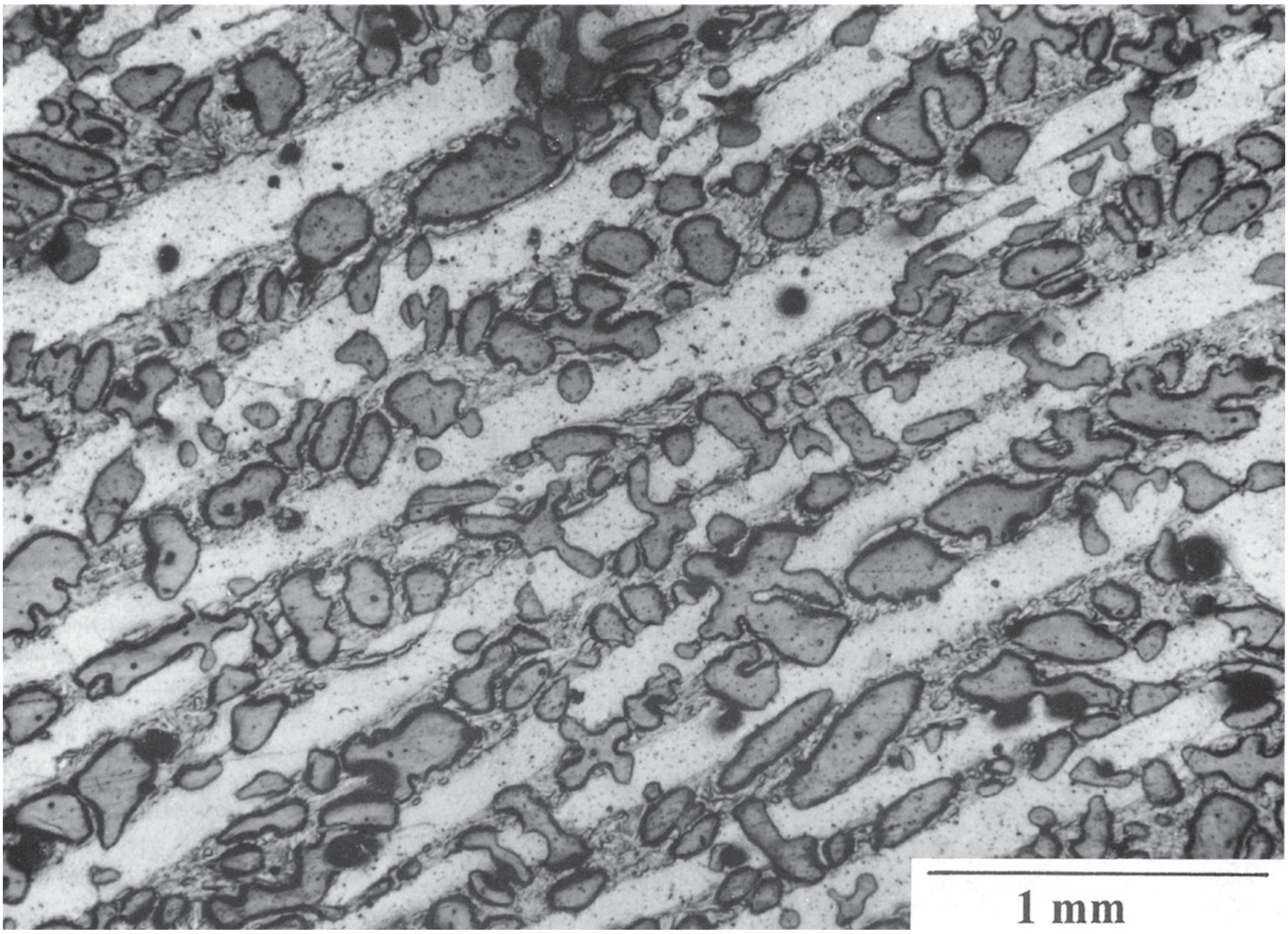


Figure 19: Cat No B4 'Styrian white cast iron H.C.S. 1865'

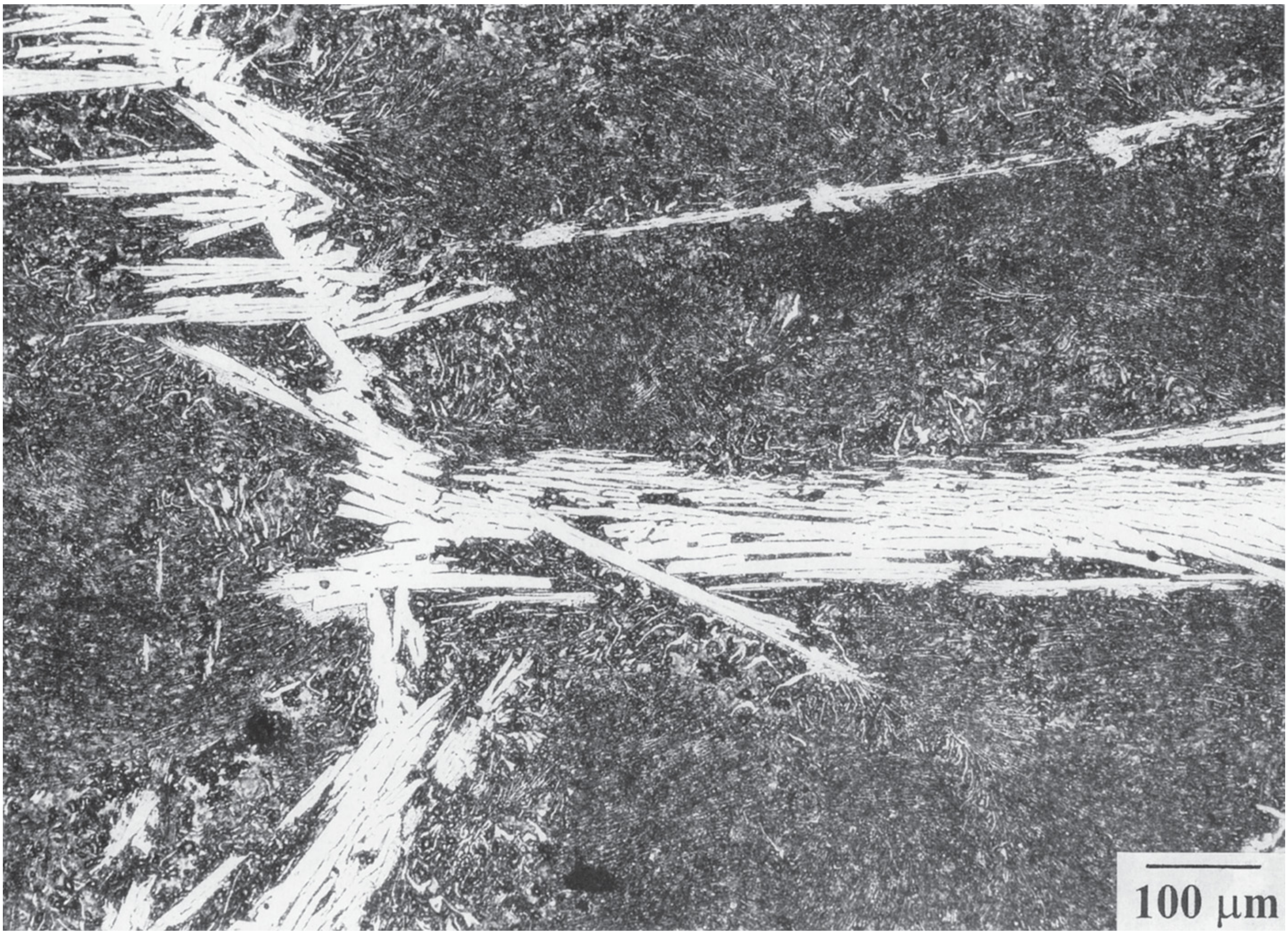


Figure 20: Cat No B14 'Bar steel reconverted transverse. Finished with rouge H.C.S. 1864'

The fracture process appears to have been arrested at the large slag stringer at the centre of the micrograph.

Specimen Cat No B4 (Styrian white cast iron H.C.S. 1865)
The microstructure (Fig 19) consists of a ledeburite (austenite-cementite eutectic) in which the austenite has decomposed into cementite and pearlite. The white-etching phase is cementite and the dark-grey etching phase is unresolved pearlite.

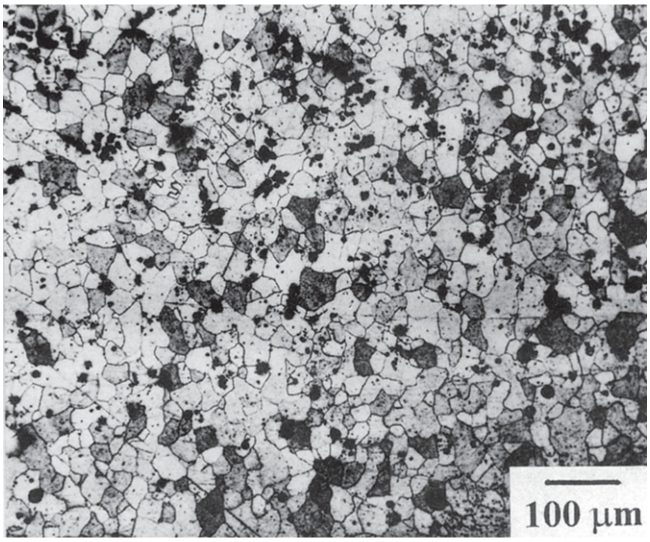
Specimen Cat No B14 (Bar Steel reconverted transverse. Finished with rouge H.C.S. 1864)
Reconversion indicates that the steel has been subjected to a further carburization treatment, resulting in a higher carbon content, as compared with 'once converted' bars. This is shown by a comparison between Figures 4a and 6c and Figures 12 and 20. Figure 6c shows, in addition to the grain boundary cementite, large plates of cementite distributed throughout the prior austenite grains. Figure 20 shows that these plates consist of irregular bundles of cementite plates or needles in a matrix of pearlite.

Specimen Cat No D (White cast-iron broken from a round bar and decarbon. long. section. H.C.S. 1863)

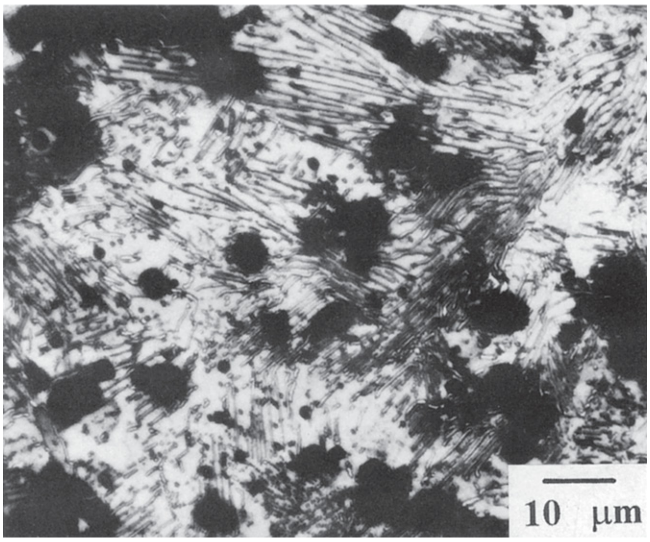
Despite the poor appearance of this specimen (Fig 11) the microstructures are remarkably clear. Figure 21a shows a fine-grained ferrite microstructure (and superficial oxide particles) in a region close to the decarburized surface of the bar and Figure 21b shows a microstructure consisting of graphite rosettes or nodules in a pearlite matrix in a region near the centre. These microstructures are entirely consistent with those obtained as a result of the 'whiteheart' malleablizing process.

Dedication and acknowledgements

This paper is dedicated to the memory of Dr K C Barraclough, 1917 - 1990, who did so much to stimulate the study of the history of Sheffield steelmaking through his books and publications, his personal enthusiasm and close involvement with the Historical Metallurgy Society, the Sheffield Metallurgical and Engineering Association



a



b

Figure 21 a and b: Cat Group D 'White cast-iron broken from a round bar and decarbon. long. section. H.C.S. 1863'

and Sheffield Trades Historical Society (now the South Yorkshire Industrial History Society), being President at different times of all three bodies.

Thanks are due to the Council of the South Yorkshire Industrial History Society for the loan of specimens (Category Group A) and for permission to photograph them; to Professor C M Sellars of the Department of Engineering Materials, the University of Sheffield, for the loan of specimens (Category Group C) and for permission to photograph them and Professor W H Williams of McGill University for making available the results of work carried out on the single specimen in category Group D and for donating it to the South Yorkshire Industrial History Society.

Mr Tim Riley, formerly of the Sheffield City Museum, and Miss Ruth Harman of the Sheffield City Archives Department kindly provided information on Sorby's microscopical work and correspondence and Mrs O Mahoney, Miss S Toon, Miss K Jutlla and Mr D Horner of the University of Leeds provided secretarial and photographic assistance.

CATALOGUE OF METALLURGICAL SPECIMENS OF H C SORBY

A) In cabinet formerly belonging to Thomas Andrews (South Yorkshire Industrial History Society)

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
A1	(None)	32 mm square (bar), converted blister steel bar with large internal voids	Excellent (See Fig. 4(a))	Cementite network (around spheroidised pearlite) and case clearly visible
A2	OO once converted transv. H.C.S. 1864	30 mm x 15 mm section	Excellent, some discoloration at edges and across surface	Cementite network clearly visible as in (1), areas of clear pearlite and spheroidised pearlite (See Fig. 12)
A3	Shelton No. 2 bent hot H.C.S. 1863	5 mm bar bent in form of a horseshoe	Excellent	Slag stringers and recrystallised ferrite clearly visible, no cracking on outer surface
A4	Ⓛ 80% red. Longitudinal H.C.S. 1864	30 mm square bar deeply etched with small (1 mm) bright patches	Clear at edges, but oxidised in the whole central area, variation in surface condition probably due to deeper etching in centre	Pearlite and spheroidised pearlite, bright patches are ferrite/pearlite
A5	Shelton long, ⊥ piling cut cold with chisel 1864	32 mm x 30 mm section with deep (8 mm) triangular indent	Clear at edges, slightly oxidised in central area	Effect of V-shaped chisel cut on the flow pattern of the slag stringers clearly visible. Poorly defined recrystallised ferrite
A6	Stuart's broken axle trans. H.C.S. 1863	32 mm round bar section	Excellent, slight discoloration at some points round the edges	Specimen clearly made from hammer-forged and welded bars of varying carbon content and micro-structure, variable microstructure: ferrite, ferrite/pearlite, pearlite/cementite, slag inclusions (See Fig. 14)
A7	Stuart's broken axle trans. The first polished obj. H.C.S. 1863	32 mm round bar section, on reverse side paper slip inscribed 'first micro/ever made/by Sorby' Contender (with C1) as Sorby's first metallurgical specimen (see text, section 2)	Surface more oxidised than (A6) (See Figs. 4b and 4c)	Specimen is from an adjacent region of the bar compared with A6 as indicated by the macrostructure, microstructure very indistinct (See Fig. 13)
A8	Bowling ?? ham cold welded trs. H.C.S. 1864	32 mm x 27 mm section	Excellent, slight discoloration over surface	Coarse structure, apparently arising from bars of varying carbon contents and microstructures, slag stringers and recrystallised ferrite
A9	Armour plate Parkgate No. 1 longitudinal H.C.S. 1864	32 mm square section	Good-excellent, varying amount of discoloration over the surface	Coarse slag stringers and inclusions plus coarse re-crystallised ferrite with sub-grains. Also some areas of dendritic phosphide eutectic

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
A10	Hammered bloom as Parkgate iron H.C.S. 1864	30 mm square section very high inclusion/porosity content	Excellent, discoloration at corners	Ferrite plus slag stringers which show a clear eutectic substructure
A11	4 1/2 armour pl rolled down Parkgate H.C.S. 65 10 x 4 x 4 = 160 ft	32 mm square section slag stringers in plane of section	Excellent, discoloration at edges	Etching/pitting at the slag stringers; ferrite grain boundaries unetched
A12	Armour plate Parkgate 1 transverse H.C.S. 1864	32 mm square section, slag stringers/ inclusions in plane of section	Excellent, discoloration at corners	Recrystallised ferrite, slag shows eutectic substructure
A13	L Wilkinson, transverse H.C.S. 1864	30 mm x 12 mm section, more deeply etched and darker towards one end	Excellent	Clear equiaxed ferrite merging to ferrite/pearlite and pearlite/cementite
A14	Bowling, 1 transverse H.C.S. 1863	28 mm square section, irregular flow grain structure, very few slag particles	Excellent, discoloration at one corner	Recrystallised ferrite, high inclusion content (stringers perpendicular to section)
A15	Marshall and Mills charcoal hammered thin H.C.S. 1863	28 mm square section (as A14), but some areas more deeply etched than others	Excellent, small patch of discoloration on one side	As A14, the more deeply etched areas are also pitted
A16	Decarbonised cast iron. Bent cold. 1 H.C.S. 1863	5 mm bar section bent into U shape	Good, discoloration on one limb (see Fig. 4d)	Recrystallised ferrite of variable grain size. Shear lines (?) at the inner (compression) surface
A17	Bowling 15 hr on tilt when it broke. H.C.S. 1864	31 mm section, slag stringers in plane of section	Good, discoloration at one side, outside edges less oxidized (?), specimen detached from glass side	Ferrite grains very pitted. No evidence of distortion
A18	Marshall & Mills ? hammered & bent hot H.C.S. 1863	12 mm bar bent into U section, kinking at inner radius	Excellent, slight discoloration in one limb of bent bar	Elongated slag stringers, fairly coarse recrystallised ferrite, variable etching (some spheroidised pearlite)
A19	I once conv. BM transv. H.C.S. 1864	30 mm x 18 mm, gross porosity and high inclusion content. Cementite grain boundary network clear	Excellent	Grain boundary and intragranular cementite, pearlite spheroidised, matrix overetched
A20	Bessemer steel as forged transverse H.C.S. 1863	27 mm square section, 'rolled in' (?) defect near centre	Excellent, discoloration at corners (see Fig. 4(e))	Very fine grained (approx. 3 mm) ferrite/pearlite microstructure, very thin grain boundary films (of ferrite?) on a much larger scale (see Fig. 17)
A21	Round bar decarbonised longitudinal H.C.S. 1864	7 mm bar bent through 110° cracked on outside. Inner and outer surfaces etched less strongly	Excellent	Recrystallised ferrite/pearlite structure in centre, coarser ferrite on outside. Inner ferrite grains show signs of distortion
A22	Bowling 2 longitud bent cold H.C.S. 1863	6 mm bar bent in form of horseshoe	Excellent, discoloration only at one end	Coarse slag stringers kinked on inner surface. Fine weakly etched recrystallised ferrite (see Fig. 18)

B) In tin box in the Department of Engineering Materials (former Department of Metallurgy), University of Sheffield

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
B1	Meteoric	Roughly triangular/arrow-head shaped specimen with 30 mm sides	Excellent (see Fig. 6a)	Coarse Widmanstatten plates separated by white layers which also have a central darker etching layer. White layers cracked
B2	(None)	33 mm square section, one corner rounded	Coverslip cracked and discoloured	Very indistinct pearlite
B3	Iron ? as Tolucca meteor, not well melted H.C.S. 1864	25 mm x 20 mm section. Darkly etched, clear dendritic macrostructure	Darkly etched, discoloration at the corners	Cellular structure, rounded equiaxed grains with ill-defined Widmanstatten plates and grain boundary phase with eutectoid (?) substructure
B4	Styrian white cast H.C.S. 1865	Irregular shaped fragment 15 mm x 25 mm. Large void and cracks at one edge.	Excellent	Very clear cementite matrix/laths with inter-lath bands containing (transformed) ledeburite and globules of fine pearlite (see Fig. 19)
B5	Hard tool steel ingot, trans. H.C.S. 1864	24 mm square section, crack-like flaw 15 mm long in centre	Excellent, less oxidation around edges. (see Fig. 6b)	Elongated coarse (prior austenite?) grains, the boundaries decorated with cementite (?), fine pearlite matrix with cementite needles or plates
B6	Shelton bar white hot for 2 min trs. H.C.S. 1864	28 mm square section, irregular edges. Roughly banded structure, variable blue/purple tints	Without a cover slip	Slag stringers/inclusions seen 'end on' and showing eutectic microstructure. Equiaxed ferrite (grey) with Widmanstatten needles/plates (?) (brown/yellow)
B7	White cast iron once decarb cut from the bar H.C.S. 1864	29 mm round section, variable structure edge (light etching) to centre (with defect)	Excellent	Very coarse eutectic ledeburite, austenite transformed to pearlite with further cementite deposition on cementite/ledeburite plates. Rosettes of graphite and inclusions
B8	Decarb cast iron from bit $1^1/_4$ " thick broken from bar trans. No. 3 H.C.S. 1864	29 mm round section, more deeply etched towards centre	Without coverslip	Pearlite/ferrite matrix with slag particles and inclusions. Centre richer in pearlite. Possibly same structure as B7
B9	Hard OO steel reconverted plane of plate H.C.S. 1864	32 mm square section. Coarse grain boundary cementite network clearly visible	Overall slightly but uniformly discoloured	Very thin grain boundary layers of cementite with pearlite matrix
B10	OO iron longitudinal H.C.S. 1864	32 mm x 16 mm section	Good: variable etching with carbon content	Variable: fine and coarse ferrite grains merging to ferrite/pearlite
B11	OO medium ingot forged longitudinal H.C.S. 1864	32 mm x 26 mm section	Discoloration and separation of cover glass at corners	Very fine prior austenite grain size. Thin films of grain boundary cementite plus pearlite

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
B12	OO ingot medium hardness transverse H.C.S. 1864	33 mm x 32 mm section	Very discoloured, separation of cover glass at corners	Fine needles (of cementite or carbonitride) dividing up matrix into blocks of coarse/fine pearlite
B13	OO iron as conv. transver. not etched H.C.S. 1865	32 mm x 16 mm section	Discoloured	Structure oxidised and discoloured round slag particles
B14	Bar steel reconverted transverse Finished with rouge H.C.S. 1864	20 x 20 mm irregularly shaped roughly square section	Excellent. Coarse cementite network clearly visible. (see Fig. 6c)	Pearlite with coarse network of cementite laths (feathery) plus irregular cementite (formed on cooling with residual ferrite) (see Fig. 20)
B15	Beale's rail No. 1 longitu. H.C.S. 1864	35 x 32 mm section slag stringers of varying thickness/ elongated in section forged from 3-4 bars	Discoloured	Oxidized, not clear, re-crystallised ferrite and slag
B16	I iron BM transverse H.C.S. 1865	17 x 33 mm section	Yellow discoloration round edges, slightly oxidized flaw in centre	Speckled, oxidized surface
B17	I iron BM longitudinal H.C.S. 1864	17 x 32 mm section	Coverslip missing	Central band of coarse re-crystallised ferrite, finer ferrite/pearlite bands near edges. Clear dendritic sub-structure in slag stringers
B18	Bowling 18 bar 80h red 85 forged cold to 1.2 H.C.S. 64	32 mm square section	Badly discoloured Canada balsam over part of surface, oxidized over rest of surface	Elongated, wavy grain boundaries, rather speckled (oxide particles) surface
B19	Bowling $1^{3}/_{4}$" bar longitud as annealed ? H.C.S. 1865	32 mm square section	Uniformly darkened	Very dark and speckled
B20	Bowling as ham cold long 80h red heat H.C.S. 1864	32 mm square section	Non-uniformly darkened Canada balsam following pattern of ferrite laminae between the stringers	Recrystallised ferrite + slag stringers. Very speckled, especially near slag
B21	Bowling 1, longitudinal H.C.S. 1863	29 mm square section.	Discoloured at two opposite corners	Recrystallised ferrite plus slag stringers. Variable oxidation /discolouration round grain boundaries
B22	Bowling iron, hardened hardened side H.C.S. 1863	30 mm square section	Discoloured at non-hardened side	Recrystallited ferrite, slag, no apparent change at hardened side. Microstructure obscured by black spots of oxide
B23	No. 1 armour slab long. Parkgate H.C.S. 1865	29 x 33 mm section	Largely discoloured	Ferrite grain boundaries in-distinct, speckled/discoloured, especially around slag stringers

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
B24	Rolled without piling L Parkgate as bloom H.C.S. 64	32 mm square section	Partly discoloured Many internal oxidized cavities	Microstructure largely obscured
B25	Armour plate Parkgate 1 plane of plate H.C.S. 1864	32 mm square section	Discoloured only at one side (see Fig. 6d)	Very clear macrostructure, varying ferrite grain size plus porosity/inclusions Microstructure largely obscured
B26	Bloom, ? piled 5 hammered Parkgate H.C.S. 1864	Two 15 x 30 mm sections (one (a) transverse, one (b) longitudinal) mounted side-by-side	Some discolouration, rest very bright	(a) Slag stringers, unetched ferrite (bright) (b) Cross-section of slag stringers, much speckling (oxidation)
B27	Hammered, piled 5 long Parkgate as bloom H.C.S. 64	32 mm section	Slightly oxidized, very coarse thick crack-like stringers in plane of section	Fine ferrite grain size
B28	Shelton 1 long H.C.S. 1863	28 mm square section	Very slightly oxidized, coarse stringers of slag	Macrostructure of fine slag stringers and ferrite clear. Microstructure obscured by black oxide speckles
B29	L once conver transver fin with rouge H.C.S. 1865	32 mm square section	Slightly, uniformly oxidised	Macrostructure shows clear cementite network around edges. Microstructure obscured by oxide
B30	L as converted transver H.C.S. 1864	32 mm square section	Oxidized, yellow discolouration of balsam at edges	Wholly obscured, except at edges, fine ferrite/pearlite
B31	Bessemer steel rail trans H.C.S. 1863	30 x 30 mm section with concave surface	Apparent crack at concave surface	Fine ferrite/pearlite microstructure, apparently a higher carbon (more pearlite) content at region near crack
B32	Bessemer Steel as 1 hammered, hardened long 64	32 x 32 mm square section	Variable amount of oxidation, inhomogeneous microstructure	Inhomogeneous structure of equiaxed ferrite, acicular ferrite/pearlite (unresolved) and slag particles
B33	Stuart's broken axle, long H.C.S. 1863	28 x 28 mm section with continuous centreline crack	Much oxidation and discolouration along line of crack and one edge but otherwise very clear macrostructure	Fine equiaxed ferrite with variable amounts of slag stringers in bands (some slag-free bands) also pearlite-rich areas with grain boundary and Widmanstatten ferrite (see Figs. 15 and 16)
B34	annealed Baird's grey pig 7281 H.C.S. 1865 unannealed	Two specimens, 15 x 30 mm mounted side by side, annealed (left), unannealed (right).	Badly discoloured except for small central region	Coarse graphite in ferrite matrix (annealed) and ferrite/pearlite matrix (unannealed)
B35	L once conver, transver on W. of Ayr H.C.S. 1864	32 x 32 mm square section	No coverslip, but very little oxidized	Very pitted surface, large volume fraction of grain boundary and Widmanstatten cementite plus (unresolved) pearlite
B36	annealed Renishaw No. 3 pig H.C.S. 1865 unannealed	Two specimens, 16 x 32 mm mounted one above the other, the lower one has a hole in the corner. Labelling at sides is such as not to distinguish specimens clearly.	Dull, one side badly oxidized	'Lumpy' graphite plus phosphide eutectic (?) and ferrite

C) Mounted in display case in the Department of Engineering Materials (former Department of Metallurgy), University of Sheffield

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
C1	L Wilkinson $^1/_2$" bar as 1 dressed on hard water of Ayr. This is the first good object I made H.C.S. 1863	20 mm square section. Contender (with A7) as Sorby's first metallurgical specimen (see text, section 2)	Poor, completely oxidized over. Crack in cover glass	Microstructure obscured by oxidation
C2	Saw steel pl of plate. H.C.S. 1864	32 mm square section	Oxidized at corners	Clear coarse grained (dendritic?) macrostructure
C3	(None)	28 mm diam. section	Oxidation at opposite sides	Cast dendritic structure clearly visible in central area
C4	White bar once decarb. H.C.S. 1864	28 mm diam. section	Excellent, some flecks of oxide near centre	
C5	White bar twice decarb. H.C.S. 1865	28 mm diam. section	Edges oxidized, clear variation in carbon content (reflectivity of microstructure)	Clear variation in carbon content from rim to centre
C6	White bar 3 times decar. H.C.S. 1864	28 mm diam. section	Edges oxidized, flecks of oxide near centre, 'rim' of highly reflecting microstructure	Structure similar to C5
C7	White bar 4 times decar. H.C.S. 1864	28 mm diam. section	Excellent	Clear variation in microstructure from rim to centre of bar
C8	White cast 16 hr red hot as decarb H.C.S. 1864	28 mm diam. section	Excellent	Coarse dendritic structure, some porosity, clear (white-iron) rim
C9	(None)	31 mm diam. section	Very slight oxidation from edge	Made from several bars of wrought iron - variable C content
C10	(None)	31 mm square section, one rounded corner with 3 holes	Poor, wholly oxidized except for top edge	
C11	Bessemer steel as 1 forged longitudinal H.C.S. 1863	28 mm square section	Bottom L.H. corner oxidized	Apparent rim of more highly reflecting microstructure
C12	Bessemer steel cast in sand transverse H.C.S. 1863	32 mm square section	Fair. This is probably Bessemer specimen '1'	Void near lower edge. Coarse acicular structure near centre, finer structure towards edge
C13	Bessemer steel as 1, hardened transverse H.C.S. 1863	27 x 27 mm section	Edges oxidized	Rough edges Coarse structure
C14	Bessemer steel softened same as 1 H.C.S. 1864	20 x 17 mm irregularly shaped section with void in centre	Fair	Rough irregular edges and void at centre, staining from centre void and edges

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
C15	Shelton bar 16 hours red hot H.C.S. 1864	28 mm square section	Excellent	Banded structure
C16	Shelton, longi 1 piling H.C.S. 1864	32 mm square section	Excellent	Fine slag stringers (banded structure) recrystallized ferrite matrix
C17	hardened side Shelton bar, hardened H.C.S. 1864	28 x 25 mm section	Lower half oxidized, particularly on hardened side	Hardened side on left
C18	Shelton transv. No.2 H.C.S. 1864	28 mm square section	Much oxidized in parts	Evidence of coarse grain structure, particularly near centre
C19	Shelton 1 transverse H.C.S. 1863	27 mm square section	All but centre heavily oxidized	Banded microstructure evident with dark markings, possibly slag stringers or oxides
C20	Baird's grey pig transv. top surface H.C.S. 1863	32 mm square section	Top RH corner oxidized	Beautiful microstructure showing coarse graphite flakes, partly oxidized
C21	Hammered without piling 1 Parkgate as bloom H.C.S. 64	32 mm square section	Some oxide patches	The coarse, irregular microstructure with voids and inclusions very evident
C22	Squeezed piled 5 trans Parkgate as bloom H.C.S. 64	32 mm square section	Edges oxidized, corners chamfered	Many small voids, clear ferrite grain structure
C23	Hammered without piling L Parkgate as bloom H.C.S. 64	32 mm square section	Good	Clear banded microstructure with fine slag stringers (appears to be made up from several bars)
C24	Rolled without piling. 1 Parkgate as Bloom H.C.S. 64	32 mm square section	Edges oxidized, corners rounded	Many voids (streaks perp to section ?) large ferrite grains
C25	Forge pig Newbold, tr. As Parkgate Bloom H.C.S. 64	32 mm square section	Excellent	Very fine grained homogeneous microstructure
C26	Hammered piled 5 transv. Parkgate as bloom H.C.S. 64	32 mm square section, clearly made from 5 flat bars	Slight staining, corners rounded	Angular pits and inclusions (probably streaks perpendicular to section)
C27	Hammer piled 5 long 80 hred Parkgate 1865	32 mm square section	Excellent	Clear fine banded ferrite network between slag streaks

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
C28	Squeezed piled 5 longitu. Parkgate as bloom H.C.S. 64 in pl of piling	32 mm square section	Excellent	Voids, probably slag stringers perpendicular to section
C29	Beale' s rail No. 1 transverse H.C.S. 1864	32 x 32 mm (irregular shape)	Edges oxidized, shaped edge concave	Very porous, clear evidence of forging pattern. (Very similar to C27)
C30	Cammell' s gurd iron H.C.S. 1865	32 mm square section	Oxidized at edges, centre clear	Coarse slag streaks with recrystallized ferrite
C31	Refinery iron decarbonized H.C.S. 1863	32 x 32 mm section (irregular shape)	Good	Many large pores/oxide inclusions. Surface irregularly oxidised, bluish in places
C32	L Wilkinson, blister steel 1 transverse H.C.S. 1863	32 mm square section	Edges oxidized	Coarse grain structure, low carbon (?) steel rim
C33	L once converted transv 1 H.C.S. 1864 Topside	32 mm square section	Good	Coarse grain structure, low carbon (?) steel rim
C34	L once conver. Longitu. H.C.S. 1864	32 mm square section	Fair	Coarse acicular grain structure with slag stringers
C35	L once conver. Transv. Much etched H.C.S. 1865	32 mm square section	Excellent	Very clear polygonal grain structure outlined by grain boundary cementite. Ferrite network near edge, possibly pearlite, darker etching in centre
C36	L as conver. longitudin. H.C.S. 1865	30 mm square section	Good but cracked across section from mid LHS to mid point	
C37	(None)	25 x 22 mm section (trapezium-shaped)	Oxidized at edges	Apparent dendritic structure
C38	Marshall and Mills iron m. hammered to this. transverse H.C.S. 1863	13 mm square section	Good	Inhomogeneous ferrite/pearlite structure
C39	Marshall and Mills, charcoal round bar 1 Longitudinal H.C.S. 1863	28 mm square section	Heavily oxidized except for area near top edge	Clear slag streaks in plane of section plus ferrite grains
C40	(None)	16 x 13 mm irregularly-shaped section with (drilled?) hole	Partly oxidized	Apparently unetched
C41	(None)	Two 32 x 16 mm sections mounted together	Highly oxidized	Upper section: clear flake graphite network. Lower section: finer microstructure with crack

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
C42	Renishaw no. 3 pig H.C.S 1865 Medium OO steel ingot both transverse	Two 32 x 13 mm sections mounted together	Upper section: good Lower section: darkened but not oxidized.	Upper section: fine ferrite network, probably around pearlite grains Lower section: coarse acicular grain structure
C43	Renishaw no. 3 pig trans. Top side H.C.S. 1863	32 mm square section	Excellent	Ferrite network around (probably) pearlite grains (same as upper section, C42)
C44	Medium OO ingot forged transverse H.C.S. 1864	25 mm square section	Excellent	Homogeneous fine grained structure. Clear rim around edges
C45	OO once conver. longitu. H.C.S. 1864	32 x 15 mm section	Edges stained	Very clear cementite network around pearlite grains
C46	Hard OO steel reconver. H.C.S. 1864	32 mm square section	Excellent	Very clear structure similar to C45, cementite network less prominent
C47	Bowling ham cold welded 80h red. H.C.S. 1865	32 x 26 mm section	Fair	Coarse grained banded structure, irregular slag stringers
C48	Bowling iron transverse H.C.S. 1863	6 mm square section	Oxidation in corners, otherwise very clear	Some voids visible
C49	Bowling ham cold longi. 80 h red heat H.C.S. 1864	32 mm square section.	Excellent	Slag stringers, elongated voids/cracks, variable carbon content
C50	Cast iron in nat. state	32 x 25 mm D-shaped bar, 8-10 mm thick, overall size 32 x 25 mm	Excellent, but structure very much darkened	Graphite flakes visible
C51	Cast iron hardened hard side H.C.S. 1863	As C50	Some oxidation, otherwise excellent	Graphite flakes clearly visible
C52	Cast iron in nat. state H.C.S. 1863	Shaped 32 x 32 mm section LHS has indented corners, RHS has concave corner chamfers	Excellent	Homogeneous fine grained structure
C53	Cast iron. One hardened side hard H.C.S. 1863	32 x 32 mm section, as C52	Edge stained, otherwise excellent	Homogeneous fine grained cementite network
C54	Cast iron, annealed H.C.S. 1863	32 x 32 mm section, as C52	Excellent Cracked mount	Homogeneous fine grained structure
C55	(None)	32 x 32 mm section	Good	Very clear coarse dendritic cast structure
C56	(None)	31 x 31 mm section	Specimen completely fragmented along planes of platelets	Coarse Widmanstä tten structure - probably a meteoric specimen

D) Single specimen returned from McGill University to the South Yorkshire Industrial History Society

CAT. No.	INSCRIPTION	DESCRIPTION OF MOUNTED SPECIMEN	CONDITION OF MOUNT	COMMENTS ON MACROSTRUCTURE & MICROSTRUCTURE
D	White cast iron broken from a round bar and decarbon, long H.C.S. 1863	26 x 14 mm section	Good (see Fig. 11)	Varying from ferrite near edge to pearlite and graphite near centre (See Fig. 21)

References

Anon, 1863. Sorby papers at Sheffield University (newspaper cuttings of 1863).

Anon 1864, *The Reader* 5 March 1864, 301.

Anon 1864a, *The Reader* 12 March 1864, 331.

Anon 1864b, *The Reader* 26 March 1864, 399.

Anon 1864c, *The Reader* 9 April 1864, 436.

Bayles J C 1883, 'Microscope analysis of the structures of Iron and Steel', *Trans Amer Inst Mining Engineers* 11 (1882-1883), 261-274.

Beale W P 1864, Letter: W P Beale to H C Sorby 29 June 1864, Sheffield City Libraries Archives SLPS 51-257.

Beck R 1865, 'Description of a New Form of Live Trap and Parabolic Illuminator', *Trans Micros Soc of London* 13, 113-118.

Beck R 1866, 'The Object Glass its own Condenser; or, a New Kind of Illumination for Opaque Objects under High Powers?', *Trans Micros Soc of London* 14, 36-39.

Brearley H and Ibbotson F 1902, *The Analysis of Steelworks Materials* (London).

Crowder W 1857, Letters to HC Sorby, 9th & 12th January 1857 Sheffield City Libraries Archives SLPS 51-82 and 51-83.

Dancer J B 1866, 'On the Illumination of opaque objects under high powers of the microscope' In: 'Proceedings of Societies', *Trans Micros Soc of London* 14, 130-132.

Desch C H 1921, *The Services of Henry Clifton Sorby to Metallurgy* Second Sorby Lecture, University of Sheffield (1921) (Sheffield).

Edyvean R G J 1988, 'Henry Clifton Sorby (1826-1908) Studies in Marine Biology – The Algal Lantern Slides', *Archives of Natural History* 15, 41-50.

Embrey P G and Fuller J P (eds) 1980, *A Manual of Mineral Names 1892-1978* (London).

Entwisle A R 1964, 'An Account of the Exhibits relating to Henry Clifton Sorby shown at the Sorby Centenary in Sheffield 1963', *Metallography 1963* (Spec Report No 80 of the Iron and Steel Inst), 313-326.

Forbes D 1855, Letters to HC Sorby 25 September and 24 November 1855 Sheffield City Libraries Archives SLPS 51-56 and 51-61.

Garrison F L 1865, 'The Microscopic structure of Iron and steel', *Trans Amer Inst Mining Engineers* 14 (1885-1886), 64-75.

Glaisher J 1866, 'President's Address to the Microscopical Society of London', *Trans Micros Soc of London* 14, 45-65.

Gore G 1865, Letter: G Gore to H C Sorby 17 January 1865, Sheffield City Libraries Archives SLPS 51-269.

Greg R H 1861, Letters: Robert Hyde Greg to H C Sorby 18 August and 29 October 1861, Sheffield City Libraries Archives SLPS 51-1972 and SLPS 51-204.

Gregory J R 1863, Letter to H C Sorby 30 July 1863, Sheffield City Libraries Archives SLPS 51-243.

Gregory J R 1863a, Letters to HC Sorby 6th and 20th August and 18 September 1863, Sheffield City Libraries Archives, SLPS 51-244, 51-245, 51-246.

Hammond C 1989, 'The Contribution of Henry Clifton Sorby to the study of Reflected Light Microscopy of Iron and Steel', *Hist Met* 23, 1-8.

Hardwick D A and Williams W M 1980 'The Birth of Metallography – The work of Henry Clifton Sorby (1826-1908)', *Bull Can Inst Mining and Metall* 73 No 813, 143-144.

Higham N 1963, *A Very Scientific Gentleman: The Achievements of Henry Clifton Sorby*, (London).

Judd J W 1908, "Henry Clifton Sorby and the Birth of Microscopical Petrology", *Geological Mag* decade 5 V, 193

Moorehouse G W 1877, 'Opaque Objects with High Powers', *The Monthly Microscopical Journal* 18, 29-32.

Salmon B C 1861, Letter to HC Sorby 22 November 1861, Sheffield City Libraries Archives SLPS 51-209.

Sorby H C 1862, Sorby's Diary for 1862. Sorby's diaries covering the period 1859-1908 (with two gaps) are in the library of the University of Sheffield (special collections).

Sorby, H C 1863, Sorby's Diary for 1863. Sorby's diaries covering the period 1859-1908 (with two gaps) are in the library of the University of Sheffield (special collections).

Sorby H C 1864 'On the Microscopical Structure of Meteorites and Meteoric Iron', *Proc Roy Soc* 13, 333-334.

Sorby H C 1886, 'On the Application of Very High Powers to the Structure of Steel', *J Iron Steel Inst* 1, 140-147.

Sorby H C 1887, 'On The Microscopical Structure of Iron and Steel', *J Iron Steel Inst* 1, 255-288.

Sorby H C 1898, 'Fifty Years of Scientific Research' in: *Ann Rept Sheffield Lit Phil Soc*.

Sorby H C 1906, Letter to RA Hadfield June 24th 1906, (Univ Sheffield Archive).

Suffolk W T 1870, *On Microscopical Manipulation, Lectures to The Quekett Microscopical Club 1869*, (London).

Vivian W 1858, Letter to H C Sorby 5 October 1858, Sheffield City Libraries Archives SLPS 51-124.

Wedding H 1885, 'The properties of malleable iron, deduced from its microscopic structure', *J Iron Steel Inst* 1, 187-204.

White W 1864, Letter to HC Sorby 23 January 1864, Sheffield City Libraries Archives SLPS 51-250.

Woodward H 1864, Letter: H Woodward to H C Sorby 28 September 1864, Sheffield City Libraries Archives SLPS 51-260.

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