May, is so remarkable that it is to be regretted that no microscopical examination of the metal was undertaken. It might even be found that the 1½-inch cube of metal described as cast iron was a furnace accretion composed of metal with unconsumed particles of charcoal, appearing in the analysis as graphitic carbon. Owing to roasting, the analysis of ancient irons presents great difficulties; and these are notably the case with cast iron. A cast-iron cannon ball, for example, recently discovered, in making the Paris underground railway, under the site of the old Bastille, whilst retaining its original shape, was found to consist chiefly of iron oxide. Its specific gravity was 4.854, instead of 7.6; and under the microscope it was found that the pearlite, which, in admixture with cementite, usually constitutes ordinary white pig-iron was oxidised throughout, whilst the cementite had preserved its metallic state. An analysis of the cannon ball by Mr. A. Portlier gave 5.9 per cent. of carbon, 0.25 per cent. of silicon, 0.75 per cent. of manganese, 2.9 per cent. of moisture, 72.0 per cent. of iron, and 17.45 per cent. of oxygen. The high percentage of carbon shows that some of the iron had been expelled; the original carbon percentage in the pig having probably been below 4. It is interesting to compare these results with the analysis given by Mr. May of supposed Roman cast iron, that had been subjected to oxidising influences for one thousand five hundred years. His figures are as follows:—Iron, 94.08; combined carbon, 0.23; graphite, 3.0; silicon, 1.05; sulphur, 0.48; phosphorus, 0.75; and manganese, 0.40 per cent.

In the early Middle Ages, although little progress was made in iron smelting, great advances were made in the manipulation of iron and steel. The sword was the triumph of the smith's art; but the manufacture of defensive armour called for skill of no mean order. The value of iron was, however, fully recognised. Writing in 1260, Bartholomew the English Franciscan, says: "Use of iron is more needful to men in many things than use of gold; though covetous men love more gold than iron. Without iron the commonalty be not sure against enemies, without dread of iron the common right is not governed; with iron innocent men are defended; and foolhardiness of wicked men is chastised with dread of iron. And well nigh no handiwork is wrought without iron; no field is eared without iron, neither tilling craft used, nor building builded without iron."

The invention of gunpowder, somewhere about 1310 to 1320, had a remarkable influence on iron manufacture; and it is interesting, in tracing the history of ordnance, to see the advances in the iron industry occasioned by the increasing demands of the artillerist. Although the first cannon of Berthold Schwarz were cast in bronze, it was not long before far more durable cannon were forged of iron bars hooped together: and the huge cannon such as Mons Meg (1455) at Edinburgh and La Dulle Griète at Ghent are remarkable examples of the skill in forging attained. The furnaces in which wrought iron was made at this epoch —the Catalan hearth, the Corsican furnace, the Osmund furnace, and the German Stückofen—are fully described in the historical treatises of Beck (5 vols., Brunswick, 1884-1903) and of Swank (Philadelphia, 1892), as well as in the standard metallurgical treatises of Percy, Bauerman, and others. From these furnaces, in which the metal was obtained in the malleable state in one operation, to the blast furnace, the transition was gradual. The basis of modern metallurgy was afforded by the discovery of cast iron, and by the employment of water-wheels, in the year 1323, for working the blast. The works were then removed from the forests to the river-valleys. Iron cannon balls were cast by Ulrich Beham in Memmingen in 1388, but cast-iron cannon are not mentioned before the fifteenth century. In 1412 two cannon, each 45 lbs. in weight, were cast for the town of Lille, and in 1422 cast-iron cannon were in use in the Hussite wars. The explanation of the late use of iron for castings is undoubtedly to be found in the unsuitability of the white pig-iron originally made. It was not until the height of the furnaces was increased that silicon could be reduced and grey pig obtained.

All the metallurgical operations of the ancients were entirely empirical. Nothing was known of the assaying ores. Colour and weight were the only indications of the quality of an iron ore. The idea of the transmutation of metals, which formed the aim of the chemical operations of the middle ages, did not go back to classic times. Geber, in the eighth century, was the first to recognise a metal as a fusible and malleable substance. He taught that all metals consist of sulphur and quicksilver in varying proportions. Alchemy did nothing to advance the iron industry; but there were besides the alchemists other philosophers who cared nothing for these things. Pre-eminent among these were Theophilus, the priest and monk, and Leonardo da Vinci, the artist. The former was a German who lived in the second half of the eleventh century. He was not only an author, but also a skilled worker in metals; and his book contains, besides the usual superstitions of the age, many practical observations, and gives a good idea of the workshop practice of a mediæval metallurgist. Leonardo da Vinci, who lived 300 years later, was not only a great painter and sculptor, but also an engineer and philosopher, with an astonishing knowledge of physics and mechanics. He developed the idea of the artesian well, and constructed deep boring plant, pumps, water-wheels, hydraulic presses, canals, and locks. He made a steam cannon, and had a dim idea of many other late inventions. His metallurgical knowledge was considerable. Among the many drawings left by him, one of a file-cutting machine is specially remarkable.

Georgius Agricola, who wrote the first systematic treatise on mining, living in Saxony, where no iron was worked, says but little about iron smelting. His illustrations show the increased height of the furnace; but he makes no reference to melting or casting iron. The subject of iron founding is, however, noticed by Lazarus Ercker in his work on assaying, published in 1574.

With the discovery of cast iron and the introduction of the blast furnace, the first stage in the history of iron closes with the end of the fifteenth century. Epoch-making inventions and discoveries soon followed. The introduction of coal as fuel for smelting by Dud Dudley in 1618, the replacement of coal by coke, the building by James Watt of the first blowing engine at the Carron ironworks in 1760, of puddling by Henry Cort in 1784, of the hot blast by Neilson in 1828, of the Bessemer process in 1856, of open-hearth steel making in 1861, and of basic steel making in 1879, are a few of the great improvements that have led to the marvellous development of the iron trade in this and other countries, and have rendered it possible for the world to produce, as it is now doing, 45 million tons of pig-iron annually.