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BRASS AND ZINC METALLURGY IN THE ANCIENT & MEDIEVAL WORLD: INDIA'S PRIMACY AND THE TECHNOLOGY TRANSFER TO THE WEST

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The primacy of India in the field of ancient brass and zinc metallurgy has been established and re-asserted. The doubts expressed by Ray, Needham and Habib, and their suggestions that primacy belonged to China, have been refuted.

The European scenario related to the subject, particularly since the 16th century and till the 18th century technology transfer from India, has been reviewed. There is the scope for further investigation in this broad subject.

Key words: Brass, China, India, Issue of Primacy, Metallurgy, Technology transfer from India, Zinc

INTRODUCTION

The Indian sub-continent enjoys the unique distinction of being the first to introduce brass and zinc metal to the world. Summarising the research and literature till 1992 on the subject [1-26], the present author was the first to claim [27] that the earliest brass in the world was in the Harappan site of Lothal and then in the early PGW-site of Atranjikhera. The primacy of zinc metallurgy in India was established by three kinds of evidences:

(a) second millennium BC radiocarbon dating of zinc ore mine in Southern Rajasthan [20,21],

(b) fourth century BC brass vase in Taxila assaying 34 p.c. zinc which could not be made by the cementation route and required the use of zinc[28,29] metal and

(c) second century AD scenario of Nāgārjuna describing reduction - distillation of zinc.

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The present author also documented the uninterrupted tradition in India on brassware, the details of the spectacular and large scale manufacture of zinc metal in medieval Zawar, and the unique phenomenon of a technology transfer from India to the Western world. The narrative of Indian's primacy in the ancient zinc metallurgy was updated in the subsequent monographs written by the present author [30,31].

China's Primacy?

In the meantime, Professor Irfan Habib has expressed his doubt whether India produced any zinc metal before 14th century AD, and suggested that 'zinc separation in India came distinctly later than in China, given the evidence presented by Joseph Needham'[32]. Very strangely, Habib ignored the evidences assiduously collected by us and ignored other references too, which discount China's claim to primacy. We would mention this topic later.

This paper starts with an account of the early references to the zinc minerals, metal and alloys in the Western world. In Strabo' s Geography (Book VIII Section 56) there was a reference to the now lost *Philippica* by Theopompus who had written in the 4th century BC that 'a stone near Andeira (Balya Maden in the modern Turkish province of Balkesir) yields drops of false silver which added to copper, forms oreichalkos(brass)'. Excavation at Athenian Agora (dated 4th -3rd century BC) yielded a zinc plate 6.6 x 4 cm.(0.05 cm. thick), 98 p.c. + pure zinc, 1.3 p.c lead globules of which were randomly elongated on account of hammering [33]. Forbes and Needham ignored this evidence of zinc sample in classical Greece (there was also a zinc statuette of Hellenistic type) but Craddock considered the possibility that this zinc came from Goslar mine in Germany or from China or India [24]. Solely on the basis of lead content, he surmised that Goslar was the source. We however suggested[27] that the Greeks had carried the material as souvenir from India. The zinc distillation technology had existed in Taxila as early as 4th century BC and possibly much earlier in the Zawar Mines, but nowhere in China or Europe in that deep antiquity.

Habib strangely ignored [32] the series of C-14 dates in the Rajasthan mines, bearing zinc ore, starting from 1260 BC and then specifically in the Zawar Mines during the Mauryan era. It is true as Habib pointed out, that Craddock identified some ancient slag residues as connected with recoveries of lead and silver only, but then Habib forgot[32] to quote Craddock fully: "But then we have to explain the huge ancient stopes at Zawar Mālā where the zinc ore contains only minimal amounts of lead; surely no one would have mined through all that sphalerite just for a little lead. There is also no evidence of discarded sphalerite on the beneficiation heaps. . . .Possibly the zinc ore was mined (during the Mauryan era) and sent away to be used elsewhere"[19]. The 'use' was evidently to make brass, not only by the cementation route (which cannot produce a material containing more than 28 p.c. zinc), but also by mixing distilled zinc metal with copper in the molten state.

As regards the recovery of zinc from the ore, the crucible reduction / distillation method was put to large scale commercial practice in the 13th century AD. Indirect and circumstantial evidences suggest that distillation method was in vogue much earlier, probably from the 4th century BC onwards, although not on a large scale, as we find in the 13th century AD context.

In this connection, we recall the evidence from Rampura Agucha.[17,34] The zinc-lead-silver ore at the site was selectively mined at least as early as 370 and 250 BC. An appreciable amount of zinc must have been separated from the zinc-rich ore (present-day ore in the site contains 13.5% zinc), as revealed from the low-zinc content slag. One sample of slag assayed as low as 0.01% zinc [34]. Near the slag dump area several retort-like pieces were reported. When assembled, their appearance suggested a cylinder approximately 20 cm long with walls 4-5 cm thick and an innermost pipelike feature with a coating of dirty white material, mainly zinc sulphate. They could be mistaken for tuyeres but for their closed pointed ends. This is highly suggestive of a used retort. Along with this some thin-walled tube-like object containing a thin coating of blister type material was also found [17].

It is conceivable that the retorts were being used in the said context for roasting zinc ore to obtain the light, white, smoky zinc oxide, which the ancient Greeks called pompholyx or philosopher's wool. In the modern zinc plant at Udaipur, roasting of zinc sulphide concentrate produces not only zinc oxide (and sulphur dioxide gas) but also some zinc sulphate, which was detected in the 4th -3rd century BC retort in Rampura-Agucha.

The said retorts, already found sealed at one end, must have been closed or sealed at the other, and also to prevent the escape of smoky zinc oxide into the atmosphere. The retorts were possibly modified to serve as reduction -distillation chambers (to produce metallic zinc), the final version of which was evolved in the 13th century AD. Very significantly, Tiwari et al [34] that the slag sample from Agucha containing only 0.01 % zinc but as high as 9.30% lead, was 'attached to baked earthen materials which could be part of the earthen appliance used for smelting'. We suggested the possibility that the earthen appliance was a zinc distillation retort. Remains of zinc furnaces have been found at Sojat in Jodhpur also. We recommend that intensive mining archaeological investigations may be undertaken in the Zawar, Rajpura-Dariba and Rampura-Agucha areas in Rajasthan to yield more evidences of zinc smelting in deep antiquity in the Indian sub-continent.

The earliest use of zinc ore in the ancient world, both in India as well as outside, was to make cementation brass by reducing the ore *in situ* in presence of copper powder which absorbed a part of the generated zinc vapour (b.p.913°C) to produce brass (zinc content not exceeding 28 p.c.). The ores used were the sulphide, sphalerite and the carbonate, calamine. Zinc vapour was quickly oxidized to zinc oxide, known as *pompholyx* and *spodos* in Europe and *tūtiyā* in Persia, and this was also used as a source material for producing cementation brass. Only Indians succeeded in recovering zinc as a metal by condensing the vapour in reducing atmosphere before it could be oxidized.

Dioscorides, a Greek physician, and Pliny, the Roman mentioned calamine (from the brass-exporting port of Kalyan in India), *pompholyx* and *spodos* (zinc oxide). Dioscorides distinguished between the impure, black, heavy *spodos* and the white, light, flying in air, purer *pompholyx* which was known as *tūtiyā* by the Persians. Zinc oxide was obtained as coating in the brass-making furnace walls and ceilings and used as a medicine. The 9th and 10th century AD Persian writers described varieties of *tūtiyā*. Abu Dulaf stated that 'the Indian variety is to be preferred as it is made from the vapour of tin'[35]. Quoting this, Craddock remarked: "Almost certainly metallic zinc is to be understood here".

Abu Dulaf's statement is another proof that India was producing zinc metal during 9th-10th century AD. Craddock has published a 10th century AD

Kashmir plaque of goddess Tārā which is 'made of zinc amalgam pressed into a mould'.

Joseph Needham traced the history of zinc metallurgy in China back from Sung Ying Hsing's classic account of its distillation from calamine (1637 AD). He concluded: "We can be sure of the existence and use of isolated zinc metal from 900 AD onwards"[36]. As Habib has himself pointed out, Tangkun 'did not show as much confidence in so early a date for zinc-smelting in China'[37]. He dated the deliberate addition of zinc oxides to copper in order to produce cementation brass, to the period of Western Han (206 BC-24 AD), and assigned to the Ming dynasty (1368-1644 AD) the first production of 'metallic zinc' in China. This demolishes Needam's and Habib's claim regarding primacy of China over India in the area of zinc smelting.

It is quite plausible that the tradition of brass and zinc in ancient India was marked by several spurts or phases: (a) post-Harappan Lothal and Atranjikhera traditions in cementation brass, (b) C-14 dates in zinc ore mining archaeology starting from 1260 BC, (c) intensive zinc ore mining and smelting of the metal during the Maurya era, souvenir samples reaching Athens, the earliest variety of smelting crucible noted in Rampura-Agucha, (d) widespread brass icons and coins during the Kuṣāna and Sātavāhana eras, Nāgārjuna's description, the tradition reaching China during the period of Western Han, (e) the 7th century AD resurgence in the Zawar area as proven by inscriptions found at Sanoli and other old temples around Zawar, this tradition reaching Persia as well as China after Hien-en-tsang, and lastly, (f) the smelting activity at Zawar of the C-14 date of 1150 AD onwards, the main expansion of the industrial phase of zinc production executed by Rana Laksh Singh who conquered Mewar from his base at Chittor in the 1380's, the large-scale production going on till the 18th century. The technical details were fully described in the 13th -14th century text *Rasaratnasamuccaya*[3].

Tangkun has significantly dated the introduction of zinc metal technology in China to the Ming dynasty (1368-1644 AD), that is after Rana Laksh Singh in Zawar, and after Timur Lang invading India. At that time Bidri alloy (over 80 p.c. zinc) was being produced in India and a special Bidriware was made for Timur. *Tūtiyā* vessels of pure Indian zinc (1 p.c. lead, trace of silver), heavily encrusted with jewels and inlays were made in the 16th century, some of the samples being kept in the Top Kapi Museum, Istanbul. Bidriwares dated 15th century AD onwards, are found in many museums of the world whereas the late 15th century Chinese encyclopaedias contain no mention of zinc or of the distillation process. Citing this fact, Craddock has argued that: "It is surely not chance that shortly after zinc from Zawar entered international trade (through the Portuguese, early 16th century) that the necessary technology was discovered in both Europe and China'[39]. Bowman et al have been more categorical[40]. Around 1505 AD there was a sudden spurt in production of brass coin in China with very high zinc content, and a Chinese record claiming that a new metal 'superior tin' was used. Craddock suggested that this 'superior tin' was Indian zinc being brought by the Portuguese vessels.

Needham himself promised to investigate the beginning of zinc smelting in India in Section 36 of his work [V(2), p.254] , but death prevented him to accomplish his objective. Yet, Irfan Habib concluded that 'zinc separation in India came distinctly later than in China, given the evidence presented by Needham[32]. In our opinion the postulate of India's primacy in ancient zinc metallurgy remains uncontested."

The Euroean Scenario

Joan Day has presented a lucid account of brass and zinc in Europe during the middle ages.[41] Since Charlemagne's rule over the Holy Roman Empire, Europe produced many decorative items for its Christian churches such as the great bronze doors of the Palatine Chapel at Aachen. The copper-based alloys often contained appreciable proportions of zinc. Brasswares were produced 10th century onwards, around Meuse river bordering Belgium and Germany. The brass works at Dinant ('dinanderie' product), Namur, Huy, Liege etc exploited local calamine ore.

The technical details of brass-making were first reported by Theophilus, a German monk around 1100 AD. In the following century, Albertus Magnus, a Greek monk mentioned about *tuchia*, or *tutty* or *pompholyx*, zinc oxide from which brass could be made. In Germany, Aachen and Cologne on the Rhine were developed as new areas for the brass industry and the 'Cullen' brassware. German *latte* or sheet brass used to be exported to England for making commemorative tombs as in St.Mary's Church, Warwick in 1453 AD.

In the Dinant area, water-power had been forbidden by overlords who wished to restrict its use to the more lucrative production of arms. The brass industry gradually shifted during the entire 15th century to the Aachen area where water-powered tief hammers were freely used for shaping hollow-ware brass vessels.

By the advent of the 16th century, Europe had invented printing press and published books on mining and assaying, was familiar with brass but not the metal zinc, and was unaware that calamine (carbonate) and *pompholyx* or *tūtiā* (oxide) contained the common metallic element. That metal was being imported from India in Portuguese vessels bearing the name *tutenage* or Malabar lead.

In the 16th century there were three important publications on mining and metallurgy: Biringuccio's *Pirotechnia* [42] in1540, Agricola's *De Re Metallica*[43] in 1556 and Eracker's *Treatise on Ores and Assaying* [44] in1574. Biringuccio observed brass-making furnaces in several locations which were on a much larger scale than those described by Theophilus. He mentioned calamine as a 'semi-mineral which colours or dyes' (*tegnere*) copper into brass, and found it 'impossible to deny that conversion of red copper to yellow brass is one of the works of alchemy'. Biringuccio also referred to *tutty*, impure zinc oxide collected on the upper parts of the furnace, which could be used for making brass. As a matter of fact, Erasmus Ebener introduced the manufacture of brass from *ofenbruch* or furnace *tutty* in place of native calamine at Rammelsberg in about the year 1550 AD, and this resulted in great profit. Later in 1574, Ercker mentioned the use of furnace accretions from the Goslar lead ores for brass-making, and described a blast furnace with removable front to allow their ready removal.[45]

Metallic zinc was imported in considerable quantities from the East as early as the 16th century under such terms as *tutenage, calaem, spiauter,* Malabar lead, and even the real Sanskritic term *yaśadam.* The present author proposes the hypothesis that the term *yaśadam*, which means that metal which 'provides *yaśa* or fame to copper by converting it to gold' (actually yellow brass), reached the ears of Paracelsus and Agricola through the Portuguese merchants as *zincken* and *zincum* respectively . Hoover and Hoover have provided very useful footnotes on this topic[46] which we quote below.

The first certain mention of metallic zinc in Europe is generally accredited to Paracelsus (1493-1541), a contemporary of Agricola. Paracelsus stated in *Liber Mineralium II*, which was probably not printed in his lifetime:

> "Moreover there is another metal, generally unknown, called *zincken.* It is of peculiar nature and origin; many other metals adulterate it. It can be melted, for it is generated from three fluid principles, it is not malleable.. ...Its ultimate matter (*ultima materia*) is not to me yet fully known. It admits of no mixture and does not permit of the *fabricationes* of other metals. It stands alone entirely to itself"

Paracelsus wrote in his note *Chronica des Landts Kornten* (Carinthia), dated 24 August 1538, addressed to the Archduchy of Carinthia that:

> "There are many kinds of mines in this land, more than in others..... Iron, lead, alum, gold etc. Also the ore *Zincken* which is not elsewhere found in Europe, a very stange metal".

In his *Philosophia,* Paracelsus wrote:

> "*Zincken* is a metal and yet none. *Zincken* is for the most part a bastard of copper, and wismuth of tin".

We postulate that Agricola knew Paracelsus, his contemporary and a colleague in mines and medicine, and heard from him about this hitherto unknown and imported metal. Agricola referred to *zincum* in an obscure way, and his remarks appear, not in the first edition of his works, but only in the revised editions of 1559. In his revised *Bermannus* he referred to a variety of pyrites occurring in Reichenstein, which is in Silesia: "Much more is found in Raurici, which they call *zincum*". Again in his *De Natura Fossilium* , Agricola mentioned volatile cadmia or *cadmia sublimata.* "This possesses corrosive properties to the highest degree; cognate with this *cadmia* and pyrites is a compound which the Noricans and Rhetians call *zincum*".

In Book IX of *De Re Metallica,* Agricola mentioned the products of lead pyrite smelting at Goslar, 'a white molten substance, injurious and noxious to silver for it consumes it, a slag floating on the top' and another 'a furnace exudation product deposited on the walls'. In the glossary he called the first as '*kobelt*' and the second as '*conterfei,* quem parietes fornacis exudant.'

Unfortunately, Agricola failed to recognize his *conterfei* from the Goslar furnaces as the same substance as the *zincum* from Silesia. The first correlation of these substances came from Lohneiss in 1617 writing in his *Bericht Von Bergwercken:*

> "During smelting there-is made under the furnace and in the cracks in the walls among the badly plastered stones, a metal which is called *zinc* or *counterfeht,* and when the wall is scraped it falls into a vessel placed to receive it. This metal greatly resembles tin, but is harder and less malleable.The Alchemists have a great desire for this *zinc* or bismuth". We have noted earlier that in 1574 AD Ercker referred to the use of furnace accretions from the Goslar lead ores for brass-making.[45]

We are indebted to Agricola for initiating debate and research on zinc ores and minerals and the by-products related to the accidental production of the metal itself. We have mentioned calamine (carbonate), *tūtiyā* or *pompholyx* (oxide) and now the *conterfei,* the metal zinc itself. The 'white molten noxious early slag' in the lead furnace was *speiss,* a mixed iron arsenide/ antimonide, which readily absorbs silver.[47] There had been 'infinite confusion' regarding the use of the terms *spodos, cadmia* and *cobelt* or *kobelt etc,* which during Agricola's time corresponded to complex, volatile and toxic minerals containing zinc, arsenic, cobalt etc.

The other material of definite composition mentioned by Agricola as well as Biringuccio is white vitriol or the 'icicle, transparent like crystal' zinc sulphate ($ZnSO_4$) coming from the Goslar mine, *Goselariae,* christened by Dana as *goslarite.* Alchemists used vitriols including white goslarite to make their oils and strong corrosive acids. This was first processed around 1570 AD at Rammelsberg. During the smelting of copper and lead pyritic ore, sphalerite (ZnS) rich material yielded by-products like *pompholyx* (oxide), *conterfei* (metal itself) and goslarite ($ZnSO_4$) depending upon the partial pressure of oxygen in the furnace system. In the Indian context, zinc sulphate in archaeo-metallurgy was reported simultaneously by the present author[1] and Tiwari et al.[34]

Paracelsus's follower Andreas Libavius (1540-1616) described zinc metal, which was known as Malabar lead presumably imported from India, in his book *Alchymia* (1597). Johann Tholde wrote his *Triumphal Chariot of Antimony* (1604) in the name of the 15th century monk Basil Valentine, giving publicty to Paracelsus's first reference to zinc and his medical recipes based on mercury, zinc and antimony salts.

During the beginning of the 17th century, the Europeans were well aware of Indian zinc also known as Malabar lead. W.Hommel has provided a very satisfactory review of that era and the Eastern literature *(Engineering and Mining Journal,* 15 June, 1912) and concluded that the chief source of the metal was India, even though some quantity of the metal might have come from China. The Europeans did not have any idea how this metal was manufactured in India, nor could they connect the metal, not even Libavius the chemist, with the numerous minerals and sources of zinc which were being tapped to produce European brass by the cementation route.

Johann Rudolph Glauber (1604-1670), the German chemist, born in Bavaria, seems to be the first to describe alloys of copper with metallic zinc and to recognize zinc as the metallic base of calamine. In his *De Prosperitate Germanias* published from Amsterdam in 1656, he wrote:

> "Zinc is a volatile mineral or half-ripe metal when it is extracted from its ore. It is more brilliant than tin and not so fusible or malleable.....It turns copper into brass, as does *lapis calaminaris* , for indeed this stone is nothing but infusible zinc, and this zinc might be called a fusible *lapis calaminaris,* in as much as both of them partake of the same nature..... It sublimates into the cracks of the furnace, whereupon the smelters frequently break it out."[48]

It is very interesting to note that Glauber denoted calamine as 'infusible zinc' and Zinc as 'fusible calamine' since both can be used to produce brass. The link was established, but the *chemical nature* of the link, namely the fact that calamine is zinc carbonate, was unknown, since the subject of modern 'chemistry' and the concept of 'elements' and 'compounds' were not born yet! Homberg in 1695 AD was more definitive in asserting that zinc metal can be obtained from calamine.

Prince Rupert, with whom Glauber was associated for a time, made extensive use of an alloy of calamine brass with metallic zinc, thus obtaining a harder alloy than could be obtained with calamine alone, without the expense that would be involved by the use of all metallic zinc. The alloys made by him (presumably over 30 p.c. zinc) were studied in detail by Geoffroy in 1725 (*Mem.Acad.Royale des Sciences*, Paris 1725, pp. 57-66). By examining the fracture under a microscope, he distinguished yellow, reddish, and white constituents which are none other than alpha, beta and gamma phases of brass![49]

Rasaratnasamuccaya and other 13th/14th century texts of India had earlier described the physical properties of brasses with increasing proportions of zinc and even of leaded brass, *kākatuṇḍī* etc. The Europeans acquired the same knowledge several centuries later, but now armed with the emerging sciences of microscopy, metallography, painstaking experimentation and critical analysis of the data. The German writer Henckel stated in 1721 AD that he had succeeded in making zinc from calamine, but no technological development followed his discovery. In 1730, metallic zinc imported from India cost more than 40 times the price of local calamine in England.

In the meantime, England had made considerable progress in several fields. Since the Elizabethan period of mid-16th century, attempts were being made to evolve a brass industry in England but not much headway was made against the cheap import from Germany and Sweden. By the end of the 17th century, the British brass industry at Bristol was on its legs, thanks to the technical assistance from Germany and Holland, and its own indigenous production of copper and calamine ore very near Bristol.

During this period, England had made considerable progress in coal, cast iron and steel technology, armament and naval warfare techniques, then overpowered Spanish Armada, and gained a very strong foothold in India, the land of brass and zinc metal, overpowering the Portuguese, the Dutch and the French. The British merchants, missionaries, doctors, travellers and soldiers gradually displaced the Dutch from the saltpetre industry of Eastern India, gathering ammunition from the sub-continent to crush the people of the same holy land. Zawar mines were not very far from their trading post of Surat, and they had intelligent people to understand and smuggle the millennia-old zinc reduction -distillation technology from India.

Table I. Some Literature on Zinc (1374-1886 AD)

1374 AD	*Madanapāla-Nighaṇṭu* refers to *yaśadam vaṅgasadṛśam* (zinc: tin like): *yaśada* means that which gives *yaśa* or fame, converts copper into yellow gold-like brass.
1597 AD	Libavius receives a sample and calls it Indian or Malabar lead.
1540 AD	Paracelsus calls it 'zinc' from *yaśada*, in several Indian languages, *dastā*.
1695 AD	Homberg identifies Indian zinc as the same metal from European calamine.
Before 1730AD	An Englishman transmitted Zawar technology to the West, identity not known.

1730 AD	William Champion's experiment at Warmley near Bristol; patent in 1738. Cost of metal £ 260 a ton, whereas calmine cost only £ 6 a ton.
1743 AD	Champion starts manufacturing zinc by distillation per descensum-process 'notoriously close to the Zawar process' (Morgan and Craddock).
1751 AD	Postlewayt's *Dictionary of Trade and Commerce* admits ignorance about zinc technology. India contiues making high Zn brass statues.
1800-1820 AD	Zawar zinc industry devastated by famine and Marhatta invation.
1886 AD	V. Ball quotes Beckmann's *History of Inventions* (Bohn's Edition, ii, p.32): "An Englishman went to India in the 17th century to discover the process used there in the manufacture of zinc, and returned with an account of distillation per descensum. I have not yet been able to identity this Englishman".

Technology Transfer to the West

In 1730, William Champion of Warmley (near Bristol, England), started experiments on making zinc metal from calamine by the reduction-distillation route. In 1738, he applied for a patent and in 1743 he commenced production of zinc. Morgan, a modern expert of Imperial Smelting Process (ISP) Ltd., wonders 'how such a remarkable achievement was completed in so short a time'[9]. Morgan and Craddock et al [13] noted that: "Champion was notoriously close with details to Indian process at Zawar; possibly a third party described the general principle of the process to Champion".

The process at Warmley used the same arrangement of retorts and the same technique of 'distillation per descensum' as in Zawar and even included 1.5 weight % common salt in the zinc-smelting charge. The closeness was indeed 'notorious'! Craddock et al.[13] possibly overlooked the significant remark made earlier on the subject by Ball.[50] Mentioning Beckmann's *History of Inventions* (Bohn's Edition ii, p.32), and his comments about the earliest efforts for making zinc in Europe, V.Ball wrote:

> "Beckmann adds that an Englishman went to India in the 17th century to discover the process used there in the manufacture (of zinc), and returned with an account that it was obtained by distillation per descensum. I have not been able to identify this Englishman."[50].

Recently, Porter [51] has written: "A Dr.Lane seems to have smelted zinc ore at his copper works in Swansea as early as 1720". Had he visited Zawar?

It is thus established that there was a technology transfer from Zawar in India to Bristol in England sometime before 1730. The evidence contradicts the usual notion that the vector of science and technology transfer has always been from the West to the East. Indian traditions have frequently benefited the growths of the Greek, Arab and medieval European sciences. On brass and zinc metallurgy, the primacy of India in the ancient and medieval world is now beyond any dispute. We regret that we cannot accept the earlier views of Ray [52], Needham [36] and Irfan Habib[32] endorsing China's primacy in this matter. At the same time, we recommend that it may be worthwhile to conduct more archaeological investigations in India and China to settle this issue.

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Acharya Prafulla Chandra himself revised his earler view (1902,1908), in February 1918, when he stated, delivering his lecture 'Antiquity of Hindu Chemistry' to the Madras University students: "The Hindus are also entitled to unique credit of being the first to extract zinc from its ore calamine".