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A Journal of Science Communication

Presenting Indian Science and Technology Heritage in Science Centres

Part II

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Continuing from where we left off in the first part of the article, in this second part a narration of how exhibits on the metallurgical heritage of India, have been showcased and the basis of choice of content and type and reasons for choice of display will be discussed. India has an outstanding heritage in metallurgy and its contributions in this field have now been universally accepted all across the world. Some of the master piece metallurgical heritage of India include the Delhi Iron Pillar[1] (4th-5th century AD), Dhar Iron Pillar, (10th-11th century AD) the long iron beams used in the Konark Sun temple (10th-11th century AD), Iron Cannons of Tanjore[2], internationally acclaimed Damascus swords that were made from the legendary Wootz Steel[3] from India etc and these are testimony to the mastery metallurgical skills of Indian metal craftsmen of yesteryears. Then there are these famous bronze statues from Tamilnadu, cast using the cire-perdue process, the tradition of which date back to several centuries[4]. The rich heritage of zinc smelting is unique to India since we were the first to smelt zinc in the world and also because zinc extraction was carried out in India on an industrial scale much before the Industrial Revolution.

National Science Centre was set up post the Exploratorium experience that took the world of science museums and centres by storm and therefore hands on approach to exhibits is one prime consideration for the Centre while designing exhibitions. Most of the science museums/centres set up across the world, our Centre included, that adopted the hands on approach espoused by the father of modern Science Centres, Frank Oppenheimer, unfortunately do not lay much emphasis on artifacts and also on historical subjects. This approach is also followed in most of the science centres in India and therefore artifacts, which form the heart of the history based exhibitions, is something which our centre unfortunately did not possess and therefore while covering a historical subject like the S&T Heritage of India, this major handicap had to be overcome with presentation styles that would partially make up for the absence of artifacts. With this handicap developing "Our Science and Technology Heritage" gallery at NSCD became more challenging and we had to rely more on creating content and letting our visitors understand what the achievement of India were through some innovative display and presentation techniques and presenting replicas in place of the original artifacts and creating period like setting with hands on multimedia presentations embedded inconspicuously in the exhibit. Notwithstanding the accolades that this gallery is continuing to receive from not just the lay visitors but also from scholars and museum experts we still feel that original objects/ artifacts would have greatly enhanced our presentation. In the absence of original objects or artifacts, we have tried to create as many replicas as possible and have used the replicas all across the gallery.

Metallurgical Heritage of India

The earliest records of use of metals in India date back to the Harappan times. The Harappan civilization gives ample evidence to a very high degree of metal culture[5] that is exemplified by the use of metallurgical objects made of gold, silver, lead, copper, bronze, and the famous statue of the dancing girl. The material evidence of use of metals in the Harappan civilization can be seen at the National Museum, New Delhi. A varied range of copper and bronze implements, weapons, household utensils and ornaments excavated and preserved in different museums in India and Pakistan points to a large scale exploitation of metals and to a flourishing industry of metal crafts during the Harappan times. Specialized technologies and the organization of crafts production and setting up of metal crafts centres in urban centres of the

Fig. 1. A section of Indus Valley period room diorama presentation in the gallery showing metal craftsmen at work.

Harappan towns and other Indus settlements have paved the way for the continuing metal crafts traditions in India and Pakistan[6].

The story of metallurgical heritage in the gallery begins with an exhibit on the mining activities in ancient India. Mining in India has a respectable antiquity and dates back to the 3rd million BC. The mining activities from the Hutti (Karnataka) Gold mines and other extant finds from the mines of Rajpur-Dariba, Agucha, etc provide tell tale signs of extraction of ores from the mines in antiquity. Mining activities at a depth of 100 metres have been found in Rajpur – Dariba mines and C-14 carbon dating of these sites suggest that a thriving mining activities dating back to 1260 BC, 1130 BC and 1050 BC[7] was going on at this site. There are several other places in Gujarat and Rajasthan where large dumps of ancient slag are noticed which provide archeological evidence to the ancient mining activities in India[8,9].

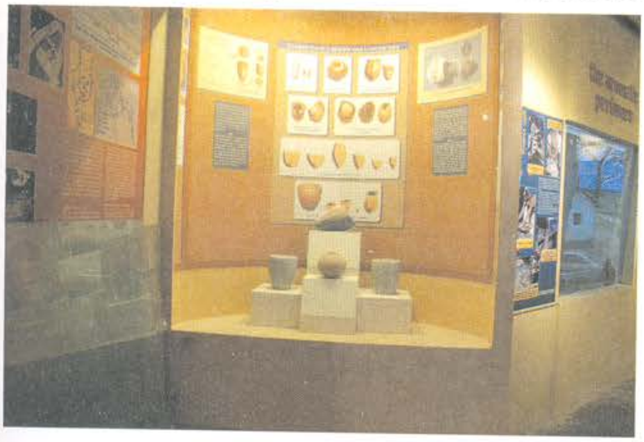

Fig. 2. Exhibit on the mining activities in ancient India with display of replicas of ancient crucibles.

Copper was one of the first metals to be extracted from nature and ancient mining activities for copper ore is seen all across India[10]. The earliest evidence of copper in India is seen from a cylindrical copper object from Mehrgarh which dates back to about 6000 BC. Several old copper mining sites with vertical shafts and open trenches have been found in Baleshwar, a site near to the Khetri site and even today Hindustan Copper Limited, a public sector enterprise of the Government of India, continues to extract copper from this site.

Iron and Steel

The United States Steel Corporation is considered as one of the authoritative sources of reference in the field of steel and in its tenth edition publication 'The Making, Shaping and Treating of Steel' it states *"Some authorities ascribe the original discovery of practical ferrous-metal manufacture to peoples in India at a very early date"*. This statement emphasizes the antiquity of Iron and Steel in India. Further more, the antiquity of Iron in India dating it to earlier than 1000 BC has been suggested in a publication in Nature[11]. The basis for this statement rests on three indisputable and enduring material evidence and symbols of Indian mastery over iron: the traditional iron making by the adivasis or tribes of India continuing as a living tradition to this day in Madhya Pradesh, the impressive rustless Iron Pillar at Mehrauli in Delhi and the invention of crucible steel making as early as 300 BC and continuing up to 1800 AD in Southern India and the forging of these steels into mighty swords, to become famous as the Damascus sword. Despite these recognitions, the date and origin of the beginning of iron workings in India has remained a much debated topic. Some of the scholars, especially those from the western countries, have suggested that Iron came into India from the West. This view has however been strongly contested by Chakrabarti who says "*there is no logical basis to connect the beginning of iron in India with any diffusion from the west, from Iran and beyond* ", and further "*that India was a separate and possibly independent centre of manufacture of early iron.*"[12]

From the radiocarbon dating of some of the iron bearing deposits at Ataranjikhera in Uttar Pradesh and Hallur in Karnataka, dates of around 1000 BC have been suggested[13]. Arun Biswas has further substantiated the antiquity of Iron in India based on both the archeological and literary evidences[14]. However, the antiquity of Iron in India is taken further back in age by Tiwari who suggests a date of 1800-1000 BC for the beginning of iron in India based on his excavations carried out in different parts of Uttar Pradesh[15].

In India, iron metallurgy has undergone a process of evolution, although there is very little data available by way of exact designs of ancient iron smelting furnaces, archaeo-metallurgical studies by scholars have helped in reconstruction of some of these furnaces. Most of the ancient traditions in India have transcended generations and some such technologies continue to be practiced even today by the tribal people. There are a number of tribal groups in India whose main occupation is iron smelting or related to iron working. These groups mainly classified as the Agarias, Asurs, Brijias and Lohars. The iron crafts tradition used by these groups is similar to the age old traditional methods which highlight the Indian traditional iron smelting technology.

Tribal Iron Furnace

One of the exhibits in the gallery is a model of the tribal iron furnace from the Bastar region, which has been

Propagation
A Journal of Science Communication

Fig. 3. Exhibit shows a reconstructed model of an ancient tribal iron furnace from the Bastar region.

reconstructed from references. These types of tribal iron furnaces are mainly used by the Agaria community. The Agarias, a special tribal community in MP and Chattisgarh, continue to smelt iron from iron furnaces whose design goes back to ancient times. The ancient iron furnaces in India have mainly been classified as *bowl shape furnace*, *dome shape furnace* and *shaft furnace*. The iron ores used by the Agarias are mainly hematite or magnetite that occurs in association with lateritic rocks in the form of heavy reddish brown stones. They break these stones into small pieces and clean them of sticking earth. They then mix the ore with charcoal in the proportion of 1:3 and this mixture of iron ore and charcoal is put into the furnace. The mixture is filled up to the top of the furnace and ignited and the mouth of the iron furnace is then plastered. After a continuous blast of one and half hour, the thick molten liquid starts appearing through the waste flute that indicates that the processes of melting of iron has begun. When the flow of slag stops, the bellows are removed. Finally, the bloom of glowing semi-molten iron balls are lifted out with the help of tongs and carried for hammering. After repeated hammering and heating, this iron ball is used for making various implements and household tools.

The techniques of making iron using ancient traditional methods from such furnaces have been very well documented[16,17]. Bastar district is inhabited mainly by two tribes Mundia and Haldi and in many parts of the district people continue to live on their traditional skills for their livelihood and make iron implements like arrow heads, axes and other agriculture implements using age old iron making methods. The *Agarias* of Chhattisgarh have preserved the ferrous technology tradition of early civilization. These people make pure iron by smelting the ordinary iron ore in very small furnaces which are located in their house-premises. The model used in the Tribal Iron Furnace exhibit is largely based on the furnaces used by the Agaria community.

Naikund Furnace

The exhibition also has a model of Naikund Furnace, which goes back to 700 BC. The excavations at

Fig. 4. Reconstructed model of a Naikund Iron Furnace which dates back to 700 BC.

Naikund has revealed special pottery and objects like sword, super head, arrowhead ladle, handled pan, chisel, spike, fish hook, horse bit and bangles etc [18]. The Naikund excavation[19] has also revealed the remains of an old iron furnace. Naikund furnace belongs to the category of shaft type furnaces. The diameter of the furnace is 30 cm and it is 25 cm in height. The base of the furnace was broad and it tapered at its opening on the top. The model of the Naikund Iron Furnace exhibited in the gallery is in the size of 2:1, amplified specifically with the objective of making it more clearly to the visitors. It was constructed with circular clay bricks and these bricks were piled one over the other, the upper surface of the lower brick was convex and lower surface of the upper brick was concave, thus they fitted into each other. A hole was provided at the bottom for tapping the slag. The furnace had two tuyeres, which were made of clay with a heavy mixture of quartz grains and measured 16 cm in length and 2.5/3.6 cm in diameter. These tuyeres were used to pass air into the furnace from the bellows. Two such tuyeres have actually been recovered from the excavation. From the remains of the iron slag that was excavated at site, it can be estimated that Naikund furnace could produce 3 to 3.2 kg of pure iron from 10 to 12 kg iron ore from a single operation. From the detailed archaeo-metallurgical studies, it is now certain that ancient iron smelters of Naikund developed a high level of metallurgical skills. The excavations of the Naikund furnace reveal a plethora of iron objects directly implying that a full time working group of ironsmiths existed at the site. Scientific investigations have been carried out on the objects excavated from this site and these studies have revealed existence of knowledge of steeling and hardening treatment around 700 BC [20].

Delhi Iron Pillar

The excellence of ancient Indian metal craftsmen is revealed from the Delhi Iron Pillar. In recognition of this unique feat achieved by ancient Indian metal craftsmen, Delhi Iron Pillar finds a special place in the gallery. The sight of the Iron Pillar standing in the courtyard of the Quwwat-ul-Islam mosque, adjacent to the Qutub Minar in Delhi, is breathtaking and cannot be missed by any visitor. The Delhi Iron Pillar is singularly featured on the emblem of the National Metallurgical Laboratory, a premier research institution working under the aegis of CSIR, at Jamshedpur, thereby signifying its prime identity as the country's metallurgical pride and heritage. The first detailed scientific study of the pillar was carried out by an eminent British Metallurgist Hadfield, in the year 1912. Ever since, there have been a growing number of studies in which several 'mysteries' of the pillar have been revealed. The Archaeological Survey of India studied the Delhi Iron Pillar with the cooperation of the National Metallurgical Laboratory (NML) in 1961. The results of these scientific studies were summarized in a special issue of the *NML Technical Journal (*Volume 5, 1963). A review of the pillar's corrosion resistance appeared in 1970. Professor T R Anantharaman, one of the doyens of modern metallurgy in India, has also published scientific facts about the pillar[21].

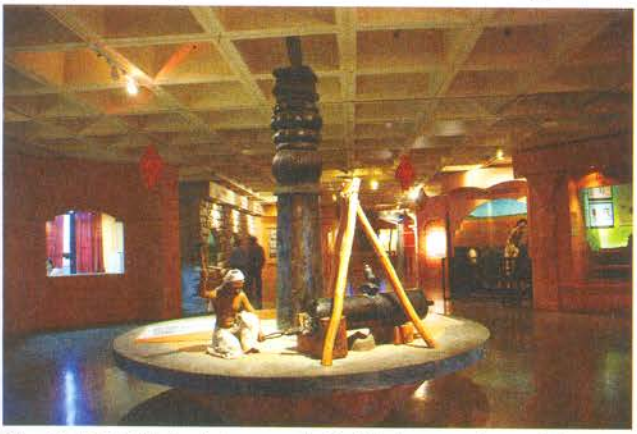

Fig. 5. Exhibit depicts an artistic 3D impression of the horizontal forging technique that was used in forging the massive Delhi Iron Pillar.

Although the present location of the pillar is in the precincts of the Qutub Minar complex, it is now very well established that this was not the original location of the pillar. The pillar was actually forged during the Gupta period around 5th Century AD using the horizontal forge welding technique and was originally located at Udayagiri, in present day Madhya Pradesh[22]. The Delhi Iron Pillar is testimony to the marvellous metallurgical knowledge that existed in ancient India. Scores of scholars from across the globe have studied as to how this edifice has managed to defy the natural laws of corrosion and remain rustless for more than 1600 years. It is in recognition of this marvellous character of the pillar that Anantharaman called it the Rustless Wonder. The unique quality of the pillar which has made it to remain rustless despite being exhibited in outdoor conditions are the right choice of the mix of material ingredients used in forging this pillar[23, 24]. This unique quality of the Iron Pillar makes it as one of the metallurgical wonders of the world. The exhibition has therefore a dedicated exhibit to show case the features of the Delhi Iron Pillar, which include its history, its manufacturing process, corrosion resistance, the bell capitol top, missing piece atop the pillar etc[25]. The exhibit in the gallery has a replica of the Bell Capitol Top of the Delhi Iron Pillar since this part of the pillar exhibits some outstanding metallurgical skills of the craftsmen who forged this marvellous part of the pillar[26]. The display is supplemented with scientifically rich information on various aspects of the pillar. The visitors can also notice a *Chakra,* an additional feature, on top of the Bell Capitol in the model displayed in the gallery while no such object is actually seen on top of the original Delhi Iron Pillar. This additional object, the *chakra,* has specifically been added on top of the Bell Capitol based on the research findings of Prof R Balasubramnium, who through his research findings has come to the conclusion that a Chakra object was actually on top of the original pillar and may have been displaced/lost on its transit while it was moved from its original location to Delhi[27]. Special emphasis has been laid on the Delhi Iron Pillar exhibit in the gallery and this exhibit finds a central place in the gallery mostly because the Centre is located in the city where the pillar is presently located and majority of the visitors may have actually seen the Delhi Iron Pillar yet they don't know how unique this

Fig. 6 A. The Bell Capitol Top with the missing Chakra atop the Delhi Iron Pillar.

Propagation
A Journal of Science Communication

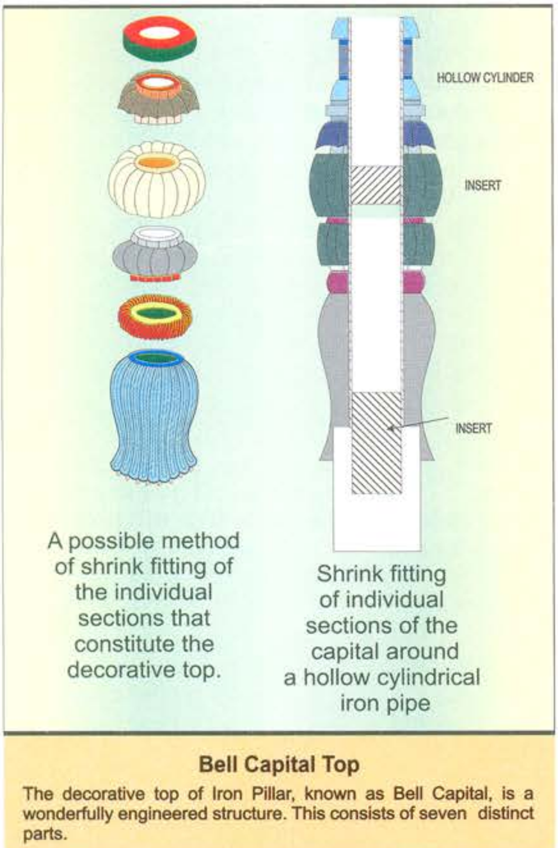

Fig. 6 B. Image shows the components of the Bell Capitol Top and the type of fitting technique used in fabricating the same.

object is and what are its specialties. The exhibit also has a scaled down model of horizontal forging technique, a method now confirmed to have been adopted for making this pillar[28].

Legendary Wootz Steel

Crucible steel making technique was developed primarily in South India and this led to the production of the legendary Wootz steel which was used to fashion the Damascus blades with a watered steel pattern that exhibited super-plastic properties[29]. Wootz steel production required precise technical knowledge since it had to be forged in a narrow range of 650^0-850^0 C and not at the white heat of 1200^0 C to get the desired fine grain structure and plasticity[30]. Because of this unique property, Wootz steel fulfills the description of an advanced material of the ancient world[31], since it is an ultra-high carbon steel which exhibits properties such as super plasticity and high impact hardness. It is for these special characteristics that this material of antiquity was highly sought after in different parts of the world and its special characteristics made it a right candidate for producing outstanding quality Damascus swords. Persians were among the major buyers of Wootz steel ingots from India which in turn were exported to the European countries from Persia. One such consignment exported to Dutch (Netherlands) from India consisted of 20000 Wootz steel ingots as recorded by T L Lowe.

The specialty of the Wootz steel is such that this material can not be surpassed even by advanced materials of the current era. The characteristics of this wonder material was so unique and intriguing that it found a special place in western science and scores of studies, including one by the legendary Michael Faraday[32, 33], were conducted on Wootz steel during the 18th and 19th centuries. Importance of the production of Wootz steel in South India can be gauged by the fact that by the late 1600s shipments running into tens of thousands of Wootz ingots were traded from the Coromandel Coast to Persia. The scale of production of Wootz steel was almost on an industrial scale in what was still an activity predating the Industrial Revolution in Europe. The popularity of this material can be further seen in the works of Arab scholars. Arab Edrisi, an Arab scholar of the 12th century mentioned that the Hindus excelled in the manufacture of iron and that it was impossible to find anything to surpass the edge from Indian steel. He further goes on to add that the Indians had workshops where the most famous sabres in the world were forged. There are also records from the Arab world where excellence of Hinduwani or Indian steel has been enumerated and this has been discussed in the works of Egerton[34].

It is in recognition of this unique contribution of India that an exhibit on Legendary Wootz steel finds a prominent place in the gallery. The exhibit contains a reconstructed model of a Buchanan furnace, known

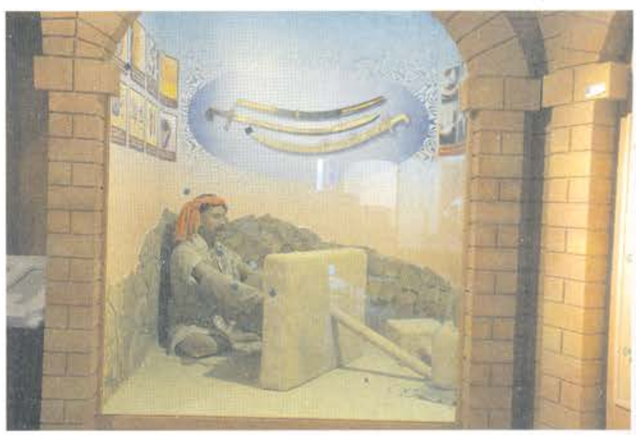

Fig. 7. A reconstructed model of a Buchanan furnace, known after Francis Buchanan, forms a part of the Legendary Wootz Steel exhibit.

after Francis Buchanan, a Surgeon to the Governor General of India, whose mastery work in 1807 on the survey of south India resulted in his monumental work *"A Journey from Madras through the Countries of Mysore, Canara and Malabar"*. Buchanan noticed, during his journey across South India, metal craftsmen producing crucible steel using a particular furnace which he documented and this furnace is now known after his name and classified as the Buchanan Furnace. The model of the Buchanan Furnace in the exhibit is duly supplemented with research findings on the uniqueness of the Wootz ingots and how this Wootz steel was used for producing the world famous Damascus swords. The method used by ancient Indians for producing Wootz steel ingots has also been duly presented[35].

The process of Wootz crucible steel making was very much associated with the South Indian part of the subcontinent including Sri Lanka[36]. The strange word Wootz was coined when European travellers from the 17th century onwards came across the making of steel by crucible processes in Southern India in the states of Tamil Nadu, Andhra Pradesh and Karnataka. Wootz is an anglicized and corrupted word for the local Kannada and Telugu word *ukku* meaning steel. The megalithic site of Kodumanal, 300 BC, in Tamil Nadu was one of the ancient sites for ferrous crucible processing. This date also supports an early literary reference to steel from India and Mediterranean sources including the one from the time of Alexander (300 BC) who was said to have been presented with 100 talents (a Greek measurement/unit for mass equivalent to 26 Kgs) of Indian steel[37]. There is also a preliminary identification of a sample of high carbon steel of the composition of Wootz of around 1.5% carbon from megalithic Andhra Pradesh. These are tentatively the earliest known identifications for high-carbon crucible steel any where in the world.

Bronze Statues

Medieval South Indian Bronze Idols, also known as *panchaloha idols*[38], especially the idols of various deities including *Natraj*, are internationally acclaimed for their elegance, aesthetic beauty, iconographic details and distinctive metal craftsmanship. These idols not only portray technological excellence but also represent aesthetic qualities of forms that are exquisite and unique only to South Indian bronze icons[39]. Many of these treasured bronze idols can be found in temples across South India and also in different museums in India and abroad specially the Government Museum in Chennai. These bronze icons have been recognized for their unique identity. In the year 2007 and on the eve of the 60th year of India's independence, a special exhibition of the Chola Bronzes was organised at Royal Academy of Arts in London. This exhibition, "Chola: Sacred Bronzes from Southern India" enticed one into the intricate world of Chola bronzes (ninth to thirteenth centuries AD) that fluidly captured in bronze the sensuous visions of Tamil poet-saints. These icons epitomized aspects which lie beyond the artifact and its visual appearance.

It is in recognition of this unique ancient metal tradition, which is continuing to be practiced even today, that we have included one exhibit to cover this metal crafts technology. The exhibit has on display a sequence of the objects that form different stages in the

Fig. 8. The Chola Bronze exhibit (with the statue of Natraj) supported by a film which shows the process involved in making Chola bronze statues.

making of the South Indian Bronze idols/icons and also the raw materials that are used in the making of these icons. The display is well supplemented with information and a specially made video which depicts the process involved in making bronze statues in traditional style, the period of which goes back to more than 2000 years.

The specialty of the bronze icons can best be understood in the words of R Nagaswamy[40], a notedSouth Indian historian and an expert on South Indian bronzes, who says *"The bronzes were part of sacred architecture, the living legacy of an unknown master artist who rendered these subtle and fluid forms as a means of expressing the divine. Made in accordance with codified principles, and sanctified by worship, these images were the link between Man and his God"*. This traditional metal crafts of South Indian

Propagation
A Journal of Science Communication

bronzes is believed to be in practice since at least 2000 years. The metal craft centres in Kanchipuram, Kumbakonam and Madurai in Tamilnadu, which produce these stunning statues, have shown a remarkable continuity of this traditional crafts. The first archeological material evidence for the bronze castings in India however go back to the period of Harappans during which the famous *Dancing Girl* statue cast in bronze was found in Mohenjodaro which is 4500 years old. The 10.8 cm long bronze statue of the dancing girl was found in 1926 from a house in Mohenjodaro and this object is presently preserved in the National Museum at Delhi. The material evidence of the bronze statue from South India is seen from the bronze objects (presently preserved in the Government Museum, Chennai) obtained from the excavations at Adichanallur in Tirunelveli district of Tamilnadu. The continuing tradition of bronze statue in South India begins from the Pallava period (3^{rd} to 9^{th} century AD), this craft however reached its zenith during the Chola period (9^{th} to 13^{th} century AD), during which very high quality bronze icons of deities were made in large numbers. This tradition was further encouraged by the Vijayanagara kings during the 15^{th} and 16^{th} century[41].

Bronze statues of South India were mostly made using the solid casting or Lost Wax method (cire-purdue process) as per the process mentioned in the texts of *Shilpa Shastra* which presents the steps involved in the making of bronze statues in original sanskrit form[42,43].

Zinc Smelting

India's primacy in brass and zinc metallurgy is now well established and the archeological evidence suggests that Indians were the first to begin zinc smelting using the distillation process some times during 5^{th}-4^{th} century BC[44]. Indians were also the first to produce industrial level production of Zinc at the Zawar mines in Rajasthan between 13^{th} and 18^{th} century long before the much credited Industrial Revolution in Europe. Zinc smelting in Europe began only in 1730 when William Champion, of the champion process fame, began production of zinc using a process which bear striking similarity to the one used in the Zawar mines[45]. This point of view that Champion may have learnt of the process of zinc smelting from the works of the ancient Indians is further substantiated by Paul Craddock who says *"Champion was notoriously close with details to Indian process at Zawar; possibly a third party described the general principles of the process to Champion"*[46].

A staggering 100,000 tonnes[47] of zinc was produced at the Zawar mines from 13^{th} to 18^{th} century. The smelting of zinc in such large scale of production was one of the most challenging technologies of the pre-modern world in which modern industrial practices had to be adopted using applications of scientific techniques for producing hundreds of thousands of tones of zinc[48].

Extraction of zinc is difficult unlike other metals. Normally, metals like lead, copper, tin, etc are smelted in a simple furnace and collected as molten mass at the bottom. Zinc cannot be smelted in simple furnaces since at high temperature conditions, zinc, with its low boiling point (907°C), vaporizes and re-oxidizes and gets lost in air. Therefore, zinc extraction requires a different process for smelting the ore and for retaining the vapour and condensing the same. As early as the 12^{th} century AD, India produced the metallic zinc by the sophisticated distillation process at Zawar in Rajasthan. Zawar, 45 kms south of Udaipur city, was the major producer of zinc and an advanced zinc mining and smelting activity flourished in this area during the 13^{th} to 18^{th} century AD. It is therefore no wonder that even today Rajasthan is the principal producer of zinc in India and one of the leading companies of zinc production in India, the Hindustan Zinc Ltd, started its commercial mines operation from Zawar mines in the year 1983. Extraction of zinc metal from its ores had posed problems during the earliest times in other countries in the world and metallic zinc was rarely reported in antiquity. The technique of reverse distillation process used in ancient India for smelting of zinc and its manufacture is also described in several early Indian alchemical works of the mediaeval period including the 13^{th} century *Rasa Ratna Samuccaya*. The word used in this document to describe the distillation process involved is *tirakpatnayantra*, which translated literally, means "distillation by descending". This ancient Indian text has a detailed description of the process of high temperature distillation that was developed and applied in this country for extraction and purification of the zinc metal from the ores. There are also other earlier ancient texts, Rasarnavam Rasatantram (500 BC) and Rasaratnakara (2 century AD), which contain descriptions on zinc[49].

Zinc distillation furnace at Zawar: a model reproduced at the gallery

In recognition of the magnificent and unparalleled contribution of ancient India in zinc smelting, an exhibit consisting of a model (replica) of the ancient zinc smelting furnace from the Zawar mines has been developed and showcased in the gallery. This exhibit

Fig. 9. Zinc smelting exhibit with the reconstructed model of *Koshti* ancient Indian Zinc furnace.

is adequately supplemented with visually rich information and some original retorts from the excavation sites of Zawar mines. The model reproduced in the gallery is based on the archaeological excavation carried out by Hindustan Zinc Ltd, British Museum and University of Baroda which has unearthed intact ancient zinc distillation furnaces at Zawar with banks of between three and seven furnaces each of which held 36 retorts. The photographic remains of excavations at Zawar are also shown in the exhibit. These furnaces were used to carry out one of the most sophisticated pyrometallurgical operations for extraction of zinc. The distillation furnace, a model of which is shown in the exhibit, is divided into two parts. A lower condensing chamber separated by a perforated plate and the main furnace chamber. Retorts containing the zinc ores are also displayed in the model. The furnace has small holes alternately and this served the purpose of passage of air into furnace and for the burnt ash to drop through. The whole area in front of the furnace was paved with large bricks. Each of the furnaces shown in the exhibit could produce between 20 and 25 kg of zinc metal per day.

The Retorts (originals from the excavation sites of Zawar) displayed in the exhibit consist of a cylindrical portion and a tapering portion at one end and these retorts resemble the shape of a Brinjol. A zinc ore separated by hand picking was roasted in air, to convert to zinc oxide. Roasted mass together with reducing agents and fluxes such as charcoal, dolomite, salts etc were ground and made into small balls using organic material as binder and were filled in the cylindrical portion. This was done not only to stop the charge from falling out of the retort when it was initially inverted in the furnace, but also to facilitate escape of zinc vapour formed during firing. The exhibit also has a visual showing the patent drawing of William Champion, from which the visitor can form an intellectual hypothesis that Champion was perhaps influenced by the techniques of ancient Indians used in Zawar mines.

(to be concluded in Part III)

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