Fingerprinting of South Indian bronze idols

Baldev Raj, C. Babu Rao and D. K. Bhattacharya

Medieval South Indian bronze idols are famous for their aesthetic beauty and excellent craftsmanship and are therefore prone to thefts and smuggling. Scientific and comprehensive fingerprinting of these idols is needed for authentic identification when they are retrieved. Such investigations would also enrich our understanding of the metallurgical techniques prevalent in our country during the early periods.

India has a rich and ancient history. Through the ages, an amalgamation of different cultures and technologies has taken place. Many archaeological objects in India are unique and priceless. One example is the class of bronze idols known as *panchaloha* idols found in various temples and museums in Tamil Nadu (South India) and other parts of the country. The idols not only portray excellence in technological terms but represent aesthetic qualities of form that are exquisite. South Indian idols bear the mark of classical tradition in smooth modelling, aesthetic decoration and sound casting.

Protection of such idols and their conservation have attracted attention in recent years because of rampant loss of these idols from temples and their smuggling out of the country. Even when such idols are traced, it is difficult to lay claim on them in a court of law unless adequate and accurate fingerprinting data are available. This legal requirement apart, fingerprinting studies are important to understand the structure and metallurgy of these idols so that India's rich technological history is understood. In addition, characterization of precious ancient idols is important from the point of view of restoration and conservation.

Attempts to characterize such idols have, so far been confined mainly to artistic appreciation and classification with respect to period, school of art, etc. It is only recently that one has become aware of the importance of fingerprinting these idols using modern techniques so that these are not lost.

Scientific investigations on cultural objects

Scientific investigations on objects of cultural heritage are aimed at understanding the style and period of the object, assessing the condition of the object to help in conservation and documenting or fingerprinting of the object. In the West, objects of cultural heritage comprise stone sculptures and paintings, besides coins and potteries. It is therefore paintings and to some extent coins and potteries that have attracted considerable attention. Various facets of paintings like the source of paints, the method and style of painting and whether or not a particular painting is a forgery have been investigated. Low-energy radiography provides a good medium for understanding the structure and style of the paintings. Microchemistry helps in understanding the types, sources and periods of the paints used. Laser holography interferometry using sandwich technique has been employed to detect subsurface defects and study the bonding between pigment and the panel and thus the health of the painting[1]. X-ray fluorescence has been used to study the composition of alloys used in ancient coins[2]. Neutron activation analysis has been used in fingerprinting Altheim Pottery[3].

Examples of cast metallic objects of cultural heritage in western countries are few. Among them is the famous Liberty Bell. Recently when this bell developed a crack, radiography was successfully employed to characterize the crack before restoration work could be undertaken. Radiography has also been employed to authenticate Roman silverware[4].

In India, stone sculptors and cast metallic idols are important objects of cultural heritage. From the period of Mohenjodaro/Harappa through the years of Buddha and later the medieval Hindu periods, excellent examples of bronze idols have been found in many places.

Medieval South Indian bronzes

The medieval South Indian bronzes differ from those of north mainly with regard to the style. In North India, the bronze work seldom departed from conventions already established for stone sculptures. The sculptors in south made full use of the medium (metal) bringing out completely different postures with intricate features These idols were made from *Panchaloha* which refers to a class of alloys consisting of copper, brass, silver, gold

The authors are in the Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, India

and tin[5]. Most of these bronzes, famous for their aesthetic beauty, iconometry and casting quality, are excellent examples of fusion of science with cultural traditions.

Bronze castings (solid or hollow) were made by *Cire Perdue* or lost wax process[6], referred to in ancient Hindu scriptures as *Madhuchista Vidhanam*. Madhuchista means bee wax. Wax model which served as the core of the casting operation was 'lost' or drained out before the actual casting took place. The subject was first modelled in wax, then coated with clay. The wax was then melted out leaving a hollow space into which liquid metal was poured to cast a solid image. If a hollow idol was intended, it would be first modelled in clay. This core would then be coated with wax which in turn would be covered with clay. *Cire perdue*, also known as the master technique, was explained by the Western Chalukyan king Someswara (12th century) in his encyclopaedic work *Manasollasa* in which minute details for making a sound casting are given[5].

It is interesting to note that after an idol was cast its mould would be destroyed, with the result that no two idols look alike even if they were created by one and the same artist. This approach gave the idols rare individuality. *Sthapatis* prepared these idols by contemplating on hymns known as *dhyanaslokas* describing elaborately the forms of individual idols. The aesthetic part was contributed by the personal experience and connoisseurship of each metal worker according to his capacity. Some of the finest bronzes, thus fashioned, excited wonder and admiration.

The *cire perdue* process in Western Europe during the same period (5th century A.D–17th century A.D) produced spongy or unsound castings. It was difficult to work with these castings or finish them properly for intricate shapes. Medieval Indians however successfully achieved this as a matter of routine[7].

Characteristics of bronze idols

Dimensional characteristics and casting defects contribute to the individuality of an idol. To a lesser extent, chemical composition and physical parameters are also important. The dimensional details correspond to iconometric measurements, major and minor sculptural details, precise contouring of prime features, etc. Casting defects occur during solidification of the casting and are random in nature. These defects, if present, cannot be duplicated, however similar the casting conditions might be. In chemical composition, minor and trace element spectra are unique fingerprints of the idol. They also reflect the nature of the metallurgy employed. Physical parameters correspond to physical characteristics like thermal electromotive force, electrical resistivity, microstructure, residual stress distribution, etc. It should be emphasized that if two specimens have the same physical parameters, they need not necessarily be of the same material. However, if they differ in values that cannot be accounted for by statistics, then they are undoubtedly different. Fingerprinting should incorporate (i) a document acceptable in a court of law, and (ii) a document giving detailed scientific account of the historical and technological aspects of an idol.

Techniques for characterisation of bronze idols

Physical description

This should give broad details of the idol and identify various parts. Photographs of an idol from various viewing directions (front, rear, left, right and top) along with marker scales should accompany this description. Each photograph should be divided into a labelled reference grid. Thus, by referring to the grid coordinates, one should be able to refer to a particular location in the actual idol. This is essential to describe the investigated defects unambiguously and identify

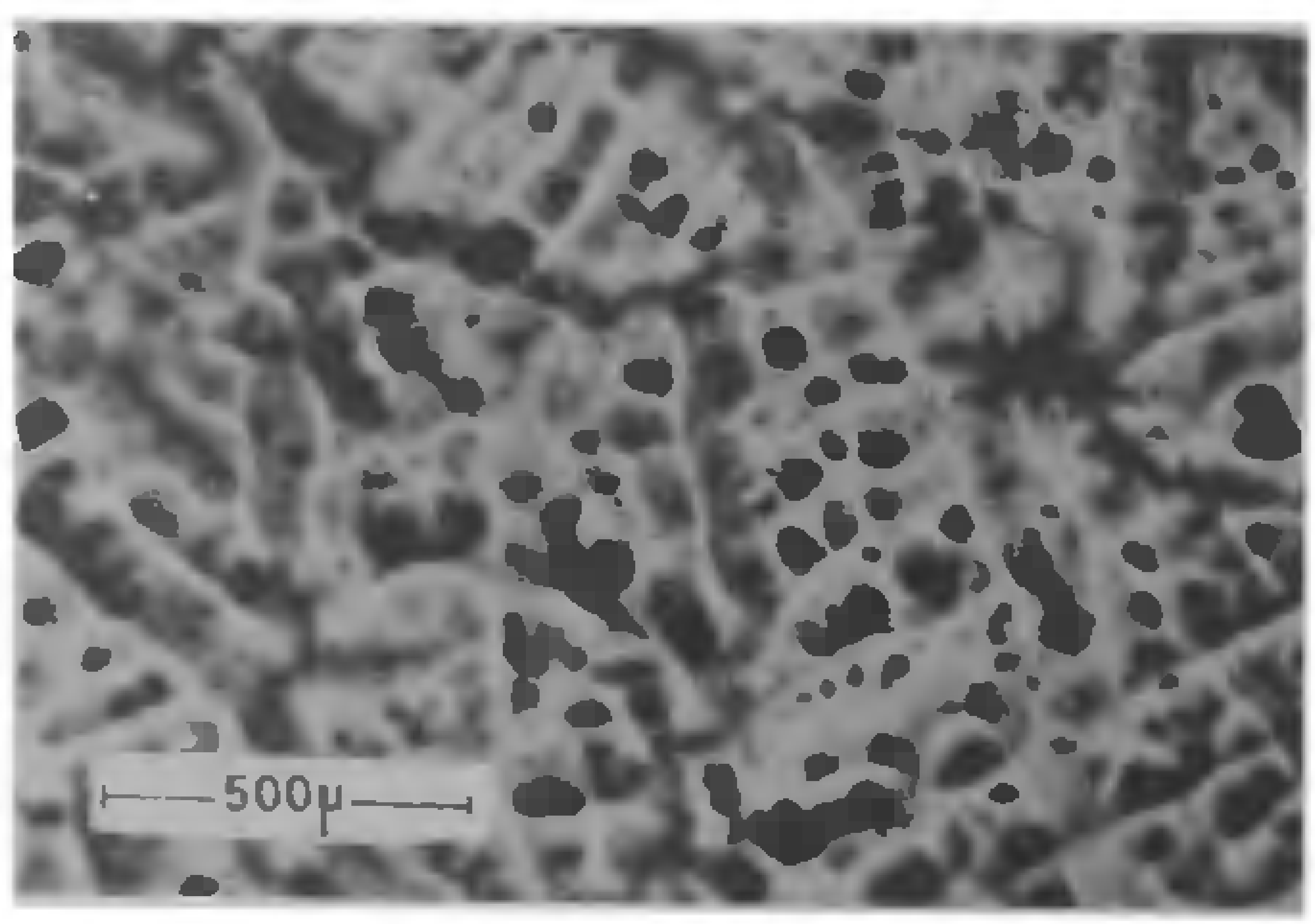

Figure 1. Microstructure of the surface of one of the idols (16th century).

Figure 2. Radiograph showing the alignment studs at the joint of two sections

Figure 3. Radiograph showing the repair in the leg region of one of the idols (9th century).

these locations for later reference. The grid chosen should be such that it is easily constructed either on to a photograph or a radiograph. Microphotographs of intricate sculptural details should be taken. Features like minute curves and relative positions of ornamental contents are unique for each idol. Negatives of the photographs should be stored under recommended conditions.

Bench mark dimensions of the idol measured manually may not be of much use if alterations can be done on the idols. However alterations are not done everywhere on the idol and therefore accurate profiles of those regions which contribute to the intrinsic value of the idol are necessary.

Holography

Three-dimensional characterization

Hologram is a three-dimensional record of an object and holography is a convenient tool for displaying art objects. Valuable objects can be safely preserved and their holograms made available for public display enabling a larger exposure of rare and valuable objects and preventing theft and vandalism. In the event of an idol being stolen and later retrieved, holograms enable an art expert to establish its identity. Since the reconstructed image of the hologram is equivalent to the original, it can be compared with the object (idol) under question. Apart from visual comparison, quantitative point-to-point dimensional measurements are also possible.

Contour mapping by Moire fringes

Contour map is specific for a particular idol. Comparison of an original contour map with an idol (under trial) helps in identification. To contour the idol surfaces, Moire methods are convenient. They are already in use to contour the human body for diagnostic purposes[7]. (See box for details).

Moire contouring

Moire contouring is a method of quantizing the depth of an object. *Moire* in French means watered silk. Moire fringes are similar in appearance to gray patches observed on watered silk fabric. Here the pre-requisite is a transparent grating which shows the oblique view of equally spaced lines. When this grating is projected at a corresponding angle onto a flat screen, again an equidistant grating results. First an exposure of this grating is made on a photographic film. Then the screen is replaced with the object which modulates the projected lines and a second exposure is made on the same film. The resultant image of the object is superimposed with fringes, called Moire fringes. These fringes are contours of constant depth from the reference plane. The depth resolution is appropriately given by Ld/S where L is the distance from camera to object, d the grating pitch and S the distance from camera to projector.

Figure 4. Moire contours on a 9th century idol.

X-ray energy spectrometry (XES)

In XES, the specimen is excited with high energy primary radiation The primary radiation induces characteristic X-radiation These are detected by suitable detector and their energy is analysed by a multichannel analyser (MCA) In portable configuration of the equipment, a radioactive isotope, in the form of an annular ring, acts as source for exciting primary radiations The detector is placed at the centre The specially designed holder serves as a shielding during handling and between the detector and primary radiation. X-ray spectra are insensitive to chemical or physical state of the atom. X-ray energy spectrometry is completely non-destructive and the spectra are relatively simple to analyse It needs minimum sample preparation and can analyse a wide range of elements Also the range of measurable concentration is wide (100% to 0 1 ppm) With the advent of semiconductor detectors and personal computer-based multichannel analysers, interfacing the system with a computer is straightforward

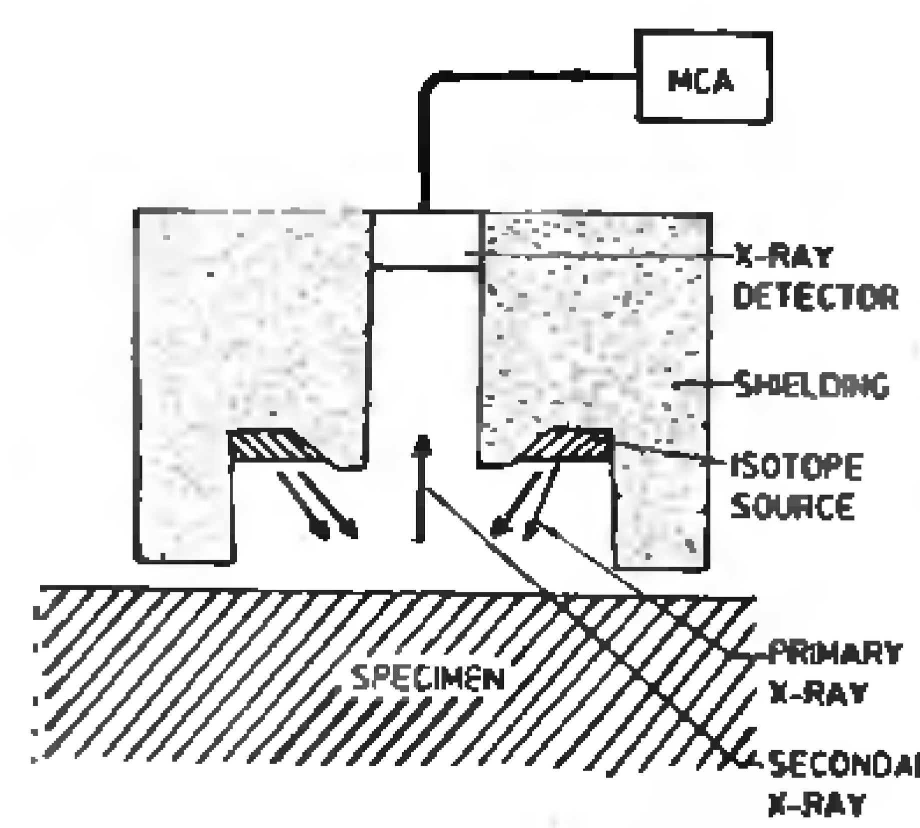

Figure 5. Schematic of portable XES system.

Analysis of chemical composition

Non-destructive methods like X-ray energy spectrometry (XES) or methods like laser-excited emission spectroscopy, neutron activation analysis (NAA) and mass spectrometry, where the sample required is only a few micrograms, are suitable for this purpose. These samples can be taken from inconspicuous parts of an idol. However during casting, segregation could take place and therefore the samples may not always truly represent the whole idol. Also these techniques give information on surface layers prone to alteration by deliberate or natural means. To overcome such sampling difficulties, whole region techniques like X-ray energy spectrometry (see box) and neutron activation analysis techniques can be adopted.

XES is ideal for fingerprinting the chemical composition of the idol. It has speed and qualitative and quantitative information about an idol can be easily obtained. It is thus useful for studies on the evolution of metallurgy by providing valuable information on the chemical composition of the idols and at different locations of the same idol.

NAA provides information on the origin of the ore and the existing metallurgical processes and is therefore useful for trace analysis. NAA of samples taken from idols can be carried out in a laboratory where a neutron source is available. Specific instruments can ensure uniform neutron fluence to activate the material of the idol for whole body NAA. An essential requirement for reliable estimation of chemical composition for whole body NAA is calibration for non-uniform activation due to thickness variations of the idol.

In-situ metallography

In-situ metallography can be carried out at convenient locations not detrimental to the sculptural value of the idol. Either portable microscope or replica technique can be used to understand the probable metallurgical procedures adopted in making these idols. The microstructure of the identified region in the idol is a unique fingerprint. [see box for details]

In-situ metallography

Normally microscopic examination is carried out on cut specimens, which are then polished and etched with suitable etchant, either by swabbing or electrochemical means, to bring out the microstructure. However, it is possible to extend this technique to large objects without cutting any specimen out of it. Here the surface is prepared for microscopy using a portable polishing unit similar to flexible hand-held abrasive wheel but with better control on speed. Also, provision is required to interchange different grade abrasive wheels. Thus, the same unit can be used till the final polishing is achieved. A replica of the surface is taken using cellulose acetate film. The film is softened in a suitable solvent (acetone) and is evenly pressed against the etched surface. The surface of the film takes the contours and shapes of the microstructure. The film is peeled off after the solvent is dried off and observed under a microscope. Alternatively, the microstructure can be observed directly with a microscope. Quality portable microscopes are now available which can be positioned conveniently on the object itself.

Physical parameters

Physical parameter of an object is a function not only of the constituents but also of the condition under which the parameter is measured. Therefore, only parameters that are less sensitive to experimental conditions and in which measurement conditions can be controlled to get unambiguous results should be employed for fingerprinting. Thermal electromotive force, electrical conductivity and hardness are examples. Physical parameters, though less important for fingerprinting, are still useful as the data can supplement other investigations and help towards better understanding of the metallurgy of the idol.

Radiography

Radiograph is a two-dimensional projection image of an object using penetrating beams such as X-rays, gamma rays and neutrons. Digital image processing extends the radiographic capability to three-dimensional imaging (tomography). Portable conventional X-ray units up to 450 keV are available which can examine bronze idols up to 100 mm thickness. Microfocal X-ray radiography systems can extend the detectable size of defects down to 10–25 μ. Gamma radiography using higher energy sources like ^{192}Ir, ^{137}Cs and ^{60}Co is suitable for thicker regions of an idol.

Idols normally have intricate shapes and large thickness differences. Various combinations of current-voltage-exposures are necessary to ensure adequate sensitivities and for detecting defects in the regions of interest. Once internal features have been detected using conventional radiography, suitable parameter combinations can be used to record high definition images by using microfocal radiography and digital image processing.

Our experience

The present authors investigated and fingerprinted bronze idols of different periods (9th century to 16th century) by optimising many techniques. Precision photographs were taken using a monorail large format camera. The photographs and scaled grids superimposed on them were used for reference in all subsequent investigations. Holography has been found to be useful in order to compare the actual object with the reconstructed image.

Very small quantitites of material samples were collected from inconspicuous regions of these idols for chemical analyses. Some of the results are presented in Table 1. Contrary to popular belief, no trace of gold was found in these idols. Copper was found to be present in pure form (99%) in samples as early as the 9th century. Also, there had been a gradual increase in the addition of alloying elements presumably to improve casting quality and to get the desired finish.

An increase in hardness was observed towards the later periods. Measurements of physical parameters like hardness, electrical conductivity and thermal electromotive force indicate that the main body of the idol was treated differently compared to a pedestal or other ancillaries like *prabhavali* (ornamental arch). Radiography and *in-situ* metallography also corroborate this

South Indian bronzes

Images of deities in South Indian temples are of two types namely *sthirabera* (fixed image) and *chalabera* (moving image). The former, an image of the deity in sanctum, cannt move and has to be seen and worshipped in the cell. *Sthirabera* is usually carved out of stone. *Chalabera* is intended to be taken out in procession during festivals. These images are made of a metal called *panchaloha*. Almost all South Indian temples teem with these bronze idols. *Panchaloha* is an admixture of five metals copper, brass, tin, silver and gold. Thus the expected major constituent elements will be copper, zinc, tin, silver, gold and perhaps lead associated with corresponding ores. No particular composition of these elements can be fixed, since it has evolved from time to time and depends on where the alloy (*Panchaloha*) is employed. It also depends on the origin of the ore and the extent of refining done to obtain the constituent elements. Though silver and gold are ascribed as constituents, their percentage was insignificant in the specimen in which chemical analysis was carried out (Table 1). These specimens were collected from inconspicuous places of the idols. During interaction with *sthapathis* (sculptors), we were told that silver and gold are added in the melt while pouring into the face region of the casting.

Table 1. Chemical compositions of some idols

Elements	9th century idol pedestal	13th century idol pedestal	13th century idol *prabhavali*	16th century idol pedestal
Cu(wt%)	98 60	94 50	94 50	89 40
Sn(wt%)	0 88	1 10	1 80	3.40
Pb(wt%)	0 34	1 00	3.35	2.88
Fe(wt%)	0.13	0.05	0.10	0.52
Zn(ppm)	15.00	40.00	103 00	2646 00
Sb(ppm)	476.00	1747 00	5309.00	3098 00
Ag(ppm)	541 00	596 00	1659 00	823 00
As(ppm)	1295 00	1788 00	3341.00	1394 00
Ni(ppm)	436.00	418 00	552.00	636 00
Bi(ppm)	88.00	164.00	503.00	351.00
Co(ppm)	45.30	135.00	100.00	114 00
Mn(ppm)	5 80	< 0 80	< 0.80	1.80
Total	100.20	97.10	99 80	97.10

Copper was analysed by electrogravimetry, lead, tin and iron by atomic absorption spectroscopy, and all trace elements by inductively coupled plasma mass spectrometry.

phenomenon. It was established that the main body of the idol was given greater importance. Radiographs of the main body showed slight defects compared to those of ancillaries, where the defect density was high.

Most microstructures reveal typical cast structures (Figure 1) and the presence of large shrinkage cavities in ancillary structures. This indicates that the casting quality of the main body was better compared to ancillaries.

What might have been the quality indicators to the *sthapatis* of this bygone era? It is an interesting question that should be investigated and discussed.

Interestingly the present authors found that some of the idols were made from a larger number of sections than expected. Radiography reveals the presence of alignment studs for some of the idols (Figure 2). These would have been extremely useful while handling hot metal structures during welding. An ingenious design feature indeed!

A unique repair region was discovered in one of the idols in which one of the legs was found to be repaired/mended. This is evident in Figure 3 showing that the optical density was different and that an alloy of lower density was employed for repair.

Data and records management

The vast data generated and the associated records (photographic, holographic, radiographic etc..) contain valuable technical and legal information. These have to be preserved for posterity, and therefore, need to be compiled systematically for easy retrieval and preserved under adequate conditions and security.

Concluding remarks

Several non-destructive techniques useful to characterize South Indian bronze idols have been discussed. Our studies establish the importance of scientific and comprehensive fingerprinting of bronze idols which are part of our rich metallurgical heritage. Such investigations could enrich the understanding of our history and enlighten the world about the metallurgical technology that existed in ancient and medieval India.

Acknowledgements. The authors thank the late Dr S. Paramasivam, former Curator, Government Museum, Madras who introduced this unique and exciting subject to B. R. We thank Dr V. S Arunachalam, Scientific Adviser to Defence Minister, Dr P. Rama Rao, Secretary, DST, Shri C. V. Sundaram, former Director of IGCAR, and Dr P. Rodriguez, Head, Metallurgy and Materials Programme, IGCAR for their constant interest and support. Thanks are due to our various colleagues for assistance in our investigations. Dr V. N. Srinivasa Desikan, Curator, Government Museum, Madras and Ms Sarada Sreenivasan also helped in our efforts.

1. Amadesi, S., D'Altorio, A and Paoletti, D., *Appl. Opt.*, 1982, **21**, 1889
2. Pollard, A. M., Proceedings of the 24th International Archaeometry Symposium (eds. Olin, J. S. and Blackman, M. J.), Smithsonian Institution, Washington, D. C., 1984, p. 267.
3. Aitchison, S. and Ottaway, B. S., Proceedings of the 24th International Archaeometry Symposium, (eds. Olin, J. S. and Blackman, M. J.) Smithsonian Institution, Washington, D. C., 1984, p. 321.
4. *Br. J. of NDT News Desk*, 1990, **32**, 219.
5. Sivaramamurthi, C., *Marg—In praise of Tamil Nadu Heritage*, Marg Publications, New Delhi, p. 56.
6. Ramachandran, T. N. and Gravely, F. H., *Museum Bulletin*, 1932, **1**, 9.
7. Hadaway, W. S., Thurston, E. and Asari, V., *Illustrations of Metal Work in Brass And Copper—Mostly South Indian*, Madras Govt Press, 1913, p. 9.
8. Leder, O. and Haymokurz, *Acta Stereologica*, 1987, **6**, 763.