Where Gods Come Alive

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A Monograph on the Bronze Icons of South India

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Vigyan Prasar

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Where Gods Come Alive
(A Monograph on the Bronze Icons of South India)

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"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".

R.Nagaswamy, in 'South Indian Bronzes'

"... Indian Art of all periods is close to life, not only to the life of the Gods but to all creatures on Earth... Although the proportions, pose and gestures of an image were unquestionably based on a strict metaphysical canon designed to ensure its fitness as an object of worship, within this framework the figure was made with an understanding of actual human anatomy, not only in its general articulations, but also in the maker's concern with connoting the essential character of the flesh in terms of stone or bronze..."

Benjamin Rowland, 'Art and Architecture of India'

This Monograph is dedicated to (Late) Dr. S. Paramasivan
who had devoted himself to the Science and Art of
South Indian Bronzes
and
who had been the source of inspiration for us

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Acknowledgements

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Timely help and facilities received by the authors from the Government Museum, Chennai, are gratefully acknowledged. A note of special gratitude should be added for the professional advice and help received from the Curator for chemical conservation, Dr. V. Jeyaraj, whose contagious enthusiasm shaped our visits to Swamimalai and Thanjavur in search of additional information on the casting process. His expertise in conservation and characterisation of antique objects was liberally made available by him for the corresponding chapters in this monograph. The authors wish to place on record the encouragement received from the Collector of the Thanjavur District and Dr. N. Devasahayam, Deputy Director, Government Museum, Chennai; Dr. Marxia Gandhi, Tamilnadu State Archaeology Department, Chennai; and Prof. Dr. M. Gunasekaran, Principal, College of Sculpture, Mamallapuram, in pursuing the studies on bronze icon casting.

The authors owe their gratitude to Shri S. Devasenapathi Sthapati of Swamimalai, for his elegant and authoritative narration of the lost wax casting process and for permitting us to visit his workshop and photograph the actual process of bronze casting. Without his expert advice and discussions, major portions in this monograph would have never become authoritative. Dr. Padmanabhan, Director of Library and Information Services, Tamil University, Thanjavur, helped us in getting access to rare literature that describe the process, while

Mr. P. Perumal, Conservator, of the Saraswati Mahal Library, Thanjavur, helped us locate the original *Shilpashastra* texts for our reference. We are grateful to the kind help extended by the Prince of Thanjavur, Srimanth Babaji Rao Bhosle Chatrapathi, for arranging to visit the Thanjavur Art Gallery and to inspect the icons there. His enthusiasm in pursuing this line of study and analysis transformed into guiding us through the project.

The authors wish to place on record their gratitude to Dr. R. Nagaswamy, for his expert opinion and enlightened discussions, and also for having consented to read through the draft manuscripts of the monograph chapters. His critical study has certainly elevated the standard of the monograph.

The authors are grateful to Shri B. Venkatraman, C.Babu Rao, S. Saravanan and Dr. T. Jayakumar of the Division for PIE & NDT, IGCAR for their contributions to the Chapter on Recent investigations (Chapter 5), and to Dr. U. Kamachi Mudali, Metallurgy Division, IGCAR and Dr. V. Jeyaraj of Government Museum, Chennai, for their valuable contributions to the Chapters on Characterisation and Conservation (Chapters 6&7). The authors are also thankful to Dr. T.R.Mahalingam, S.Sahasranamam of Materials Chemistry Division, Shri K. Swaminathan, P. Kuppusami of Metallurgy Division, Dr. A. K. Tyagi and Dr. S. Rajagopal of Materials Science Division, for all their experimental support.

Dr. Placid Rodriguez, Director, IGCAR had always been a source of inspiration. His vision and keen enthusiasm way back when Dr. Paramasivan visited the Reactor Research Centre (presently IGCAR) resulted in the Centre's involvement in the characterisation and conservation of icons. The authors are grateful to him for his constant encouragement and support.

Baldev Raj
C. Rajagopalan
C.V. Sundaram

Foreword

It has taken us long to come out with this second volume in our series on India's Scientific Heritage: "Where Gods Come Alive—A Monograph on Bronze Icons of South India". But, I believe, the outcome is worth all the time it has taken to materialise. It appears that other series titles, to follow, would similarly take time to appear in print.

One of the major difficulties in our work with this series is to clearly identify specific science & technology areas and topics in our heritage where Indian contributions have been unique, substantial and lasting, backed by enough physical and material evidence. Having identified an area thus, the next major step of locating well qualified, knowledgeable and credible author(s), to write on the same, is no less arduous. What makes it even more difficult is that we require persons who also have a scientific background or a good grounding in scientific methodology, are willing to take on the task and do it in a way which is in line with the spirit and philosophy underlying the series. Thereafter it is waiting, persuasion and more waiting to get the manuscript completed alongwith all the associated materials, before it is processed and readied for printing. Once it goes to the printing press, one has to deal with an entirely different set of issues/problems.

In this particular volume, we are in the general area of materials, mixing of materials to get alloys for specific applications—of icon-casting, as also of finishing and polishing of the icon-surfaces, including repair if necessary. Something that is quite unique about this volume is that while it deals with techniques and technologies employed in India four to nine centuries ago, in making these bronze icons, it also links all this to the modern-day scientific techniques developed and being used for conservation and preservation of our icon-heritage.

Apart from historians, art-lovers, and material scientists and technologists, we do hope that others too would find the book informative and absorbing.

Suggestions and comments for its improvement are most welcome.

Narender K. Sehgal
Director
Vigyan Prasar

Preface

It gives me great pleasure to pen these few lines by way of introduction to this second Monograph in Vigyan Prasar's Series of Monographs on India's Scientific Heritage. Alluringly entitled as "Where Gods Come Alive," this handy volume is based on a thorough scientific and technological study of the bronze icons of South India, particularly from the period of Chola Kings, which are rightly admired the world over today for their aesthetic beauty, sophisticated iconography and unbelievable perfection in casting as well as finishing. This study was undertaken over a period of years by a few dedicated metallurgists and materials scientists, associated, appropriately enough, with one of India's most prestigious and best-equipped Research and Development Laboratories viz., the Indira Gandhi Centre for Atomic Research (IGCAR, for short) at Kalpakam, South India.

Despite their long association with the same institution viz., IGCAR, the three authors of this highly informative and extremely attractive Monograph belong to three successive generations of Indian scientists and technologists. Professor Dr. C.V. Sundaram, who retired some years ago as Director, IGCAR, was earlier Head Metallurgy Division, Bhabha Atomic Research Centre (famous nationally and internationally as BARC), Bombay and adorned until very recently the Homi Bhabha Chair at the National Institute of Advanced Studies, Bangalore. A Chemical Metallurgist renowned for his outstanding contributions in Nuclear Metallurgy, Professor Sundaram could encourage and motivate his younger colleagues to undertake finger-printing of these precious icons, mostly from the temples of Tamil Nadu, utilizing the best of non-destructive testing facilities developed at IGCAR over two decades. Dr. Baldev Raj, now Director, Metallurgy and Materials Group, IGCAR, was the dynamic and inspiring leader behind these prolonged investigations on the centuries-old bronze images of Gods and Goddesses cast by the so-called Lost Wax Process. Among the younger scientists, Shri C. Rajagopalan of the Non-Destructive Testing Division of IGCAR has been an enthusiastic participant in the numerous related experiments at Kalpakkam and elsewhere. Thus, it was Vigyan Prasar's good fortune that a fine blend of experience, expertise and youth could be harnessed to fashion this impressive literary edifice.

A special feature of this volume is the report on the authors' trip to the village of Swamimalai, not far from Thanjavur in Tamil Nadu, and on their direct observation of the age-old art and science of casting bronze icons, still very much alive as a traditional village vocation. The concerned families lay claim to their descent from the artisans who cast bronze icons for the famous Brihadeeshwara Temple built by King Rajaraja Chola nearly a thousand years ago.

Vigyan Prasar's grateful thanks are due not only to the three authors but also to Dr. Jawahar Dhar, CSIR Emeritus Scientist associated with the Indian National Science Academy, for going through the final manuscript meticulously and giving many valuable suggestions for improving it before the actual printing.

The undersigned is beholden to Dr. Narender K. Sehgal, Director, Dr. Subodh Mahanti, Editor-Cum-Chief (Publications) and their many colleagues at Vigyan Prasar, for their continued interest and constructive involvement in bringing out this second volume of the project namely the Monograph Series on Indian's Scientific Heritage.

T.R. *Anantharaman*
New Delhi

Dr. S. Paramasivan
(1903 - 1987)
A Tribute

Dr. S. Paramasivan was born in a village in Thanjavur as the son of Thiru R. Subramanya Aiyar. Dr. Paramasivan had his school education in Madras, took his B.A. in Physics from St. Joseph's College, Tiruchirappalli, and a B.Sc. in Chemistry from the Nizam's College, Hyderabad, which was then affiliated to the Madras University. He worked as a lecturer in a college at Madanapalle in Andhra Pradesh for sometime and later as a lecturer in Physics in a college in Ceylon (Srilanka). He took his Master's degree in Chemistry from the Madras University.

1930 was the year when chemical conservation beckoned him and claimed his attention. Dr. F.H. Gravely who headed the Government Museum, Madras, had been concerned about the conservation of the excellent bronzes in the Museum's collection. They were mostly treasure trove finds and carried on their surface insidious and hard crusts of corrosion products which concealed artistic details and in certain cases, ate into the metal. Dr. Gravely had consulted Prof. Erlam Smith of the Chemistry Department of the Presidency College, and they had decided on the method of electrolytic restoration as most suitable process for conserving these bronzes. They selected young Paramasivan for the task of setting up the Conservation Laboratory of the Museum and designing with the first assignment of designing, installing and operating electrolytic equipment for conservation of bronzes.

Dr. Paramasivan organised the Laboratory and also modified the electrolytic method perfected by Prof. Colin G. Flink in the Metropolitan Museum of Art in New York to suit the restoration of the bigger bronzes in the Museum collection. The conservation work done by Dr. Paramasivan even in those early years of his service in the Madras Museum was of such a high calibre that it drew appreciation from Markhan and Hargreaves who made a special mention of the laboratory in their survey of museums of India published in 1935, and from Sir Richard Gregory, Editor of *Nature,* almost at the same time.

It was about this time also that Paramasivan's sphere of work widened. At the instance of Mr. J.B. Blackiston, the then Director-General of the Archaeological Survey of India, Paramasivan was invited to study the paintings in the Brihadeeswara temple at Thanjavur and submit proposals for their conservation. Dr. Paramasivan carried out a thorough scientific study of the printing and their techniques and prepared a report. This report attracted the attention of Dr. Rutherford J. Gettens of the Freer Art Gallery, a renowned conservation specialist, who invited him to publish the scientific results of the work in "Technical Studies". Dr. Paramasivan also contributed a short note on the subject to *Nature*.

This was the beginning of an important phase of Paramasivan's work in the field of conservation and investigation into ancient materials. Over the next few years, he studied paintings at Sittannavasal, Vajayalayacholiswaram, Tirumayam, Lepakshi, Ajanta, Ellora and a number of other sites. He analysed the composition of the various layers of the wall paintings and identified the pigments used. He correlated all his findings of wall paintings in India and published an execellent review of them in the "Journal of Madras University". He very thoughtfully brought together all his research papers into a thesis entitled "Chemical investigation of Ancient Indian Materials and Industries" which won him the Doctor of Science degree of the Madras University. It was a unique honour as he was one of the very few to get this degree from the University in those days. This thesis is a source of inspiration to those active in the field of conservation and characterisation of Indian heritage.

His extensive and pioneering work had attracted wide attention by this time, and in 1946 he joined the Archaeological Survey of India as an Assistant Archeological Chemist. His studies grew in scope and he made studies of ancient pottery and stone sculptures. When Mr. A. Ghosh became the Director General of the Archaeological Survey of India, he created a South Zone of the chemical branch of the Survey with its headquarters at Hyderabad and placed Dr. Paramasivan in charge of this new zone. The task of the new zone was to concentrate on the conservation of the wall paintings at Ajanta, Ellora, Aurangabad, Lepakshi, Somapalle, Thirumalai, Narthamalai etc. Chemical assistants were appointed at the various sites to work on this project under the guidance of Dr. Paramasivan. An instance of the imaginativeness and originality of Dr. Paramasivan was his suggestion to standardise the descriptions of the colour of paintings by reference to colour cards based on British Standard specifications in which each shade of a colour is denoted by a number. During this time, he also showed how paintings can be stripped from walls and mounted on other surfaces.

Dr. Paramasivan retired from the Archaeological Survey of India in January 1959. But his interest in conservation did not reduce even after retirement. He knew Dr. Homi Bhabha very well and requested him to enable the Bhabha Atomic Research Centre to take up neutron activation analysis of ancient materials. He prepared a comprehensive memorandum on the different types of investigations possible for studying archaeological materials and sent it to the Director of the Bhabha Atomic Research Centre who invited him to Bombay for a discussion. This resulted in the Bhabha Atomic Research Centre starting work on the thermoluminiscence dating of pottery. Another line of investigation which he tried to promote was the use of geophysical methods for detecting buried archaeological treasures. He got into touch with the French Institue in Pondicherry and the Institute De Physique Du Globe at Paris. As a result of this, a proton magneto metric survey was conducted at Kaveripatnam at the mouth of the river Kaveri and at Kambaramedu in Thanjavur District in co-operation with the Archaeological Survey of India.

Another project which was close to his heart was marine archaeology. He tried to bring together Oil and Natural Gas Commission, the Geological Survey of India, the National Geophysical Research Institute, the National Institute of Oceanography and the Naval Defence Laboratory for carrying out a survey of possible treasures submerged under the sea.

Towards the end of his life, the work close to his heart was the fingerprinting of ancient south Indian bronzes. He considered this as the most effective security against theft or replacement of bronzes. By fingerprinting, he meant collecting relevant data about the various characteristics of precious icons through the use of the latest available sophisticated techniques such as X-ray fluorescence, holography, radiography etc. He visited the Reactor Research Centre presently renamed as Indira Gandhi Centre for Atomic Research

(IGCAR), Kalpakkam, in 1984 and was impressed by the extensive facilities and stimulated the scientists to pursue this work. It was an elaborate project which, when achieved, would record the full technical profile of a metal image. Therefore there would be no chance of a fake escaping detection or an antique metal object being passed off as a non-antique. Moreover, it was clear to him that the mass of data that would be generated about metal images by this work would give considerable insights into the history and technique of bronze making in our country.

Dr. Paramasivan had the health and vigour to match his exertions in pursuit of his ideas. Almost till the end, he walked with a quick step and a sure eye. At the age of nearly 79, he braved the high altitude and the chill of Leh in pursuit of his conservation ideals, and it must be recorded that he stood the journey and assignment very well.

His love for the discipline of conservation of art was deep and abiding. In the death of Dr. S. Paramasivan on 15th May 1987, the Scientific Community lost one of the leading Conservation Scientists. Being a torch-bearer in the field of conservation, he remains as an example of dedication, discipline and loyalty to the profession for the present and future generations.

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Prologue

The authors owe a great deal to Prof. T.R. Anantharaman, Project Coordinator of this series of Monographs on India's Scientific Heritage, for suggesting this Title "Where Gods Come Alive - A Monograph on the Bronze Icons of South India", to expound the details of bronze icon making, as practised in the past and in the present.

The choice of the title has been made consciously, in order to focus on the importance of this art in ancient times, the patronage it enjoyed and the impact such icons had in the minds of the worshippers and admirers. This psychological impact in the human mind is a result of a beautiful chemistry, into which ingredients such as royal patronage, love for art, dedication in the profession, faith and belief in Gods and Goddesses and an innate yet subtle feeling of surrender to Him have gone.

Apart from these, an important aspect is the ability of the *Sthapatis (T)* [T in parenthesis means Tamil word and S in parenthesis means Sanskrit word] to transform abstract images of Gods, as described in the *Vedas*(S), *Vedantas*(S) and *Upanishads*(S), into physical entities and offering them not only a human form but also the *bhavas(S)* which inspire the worshipping mind. This is made possible through an empirical, yet thorough understanding of the alloys and processes that go into the casting of bronze icons.

To a population that deeply reveres God and whose day-to-day chores are woven inextricably with religious overtones and related acts, the presence of these exquisite icons in human form, performs magic by recreating their mental images and bringing their beloved Gods and Goddesses to life, before their eyes. Hence the name of the title !

Such a divine experience is the result of a combination of factors, each more important than the other.

The monograph attempts to study these factors from three different angles namely historical, artistic and scientific. In several ways, the treatment of the subject in this monograph is unique, as it attempts to bring these three angles of view to the same plane of understanding. The monograph also attempts to capture the creative spirit and thought processes in the society to produce a product rich in science and technology combined with elegance which in turn brings joy and happiness. It is hoped that the current and future generations would continue to be inspired by the unique ancient Indian heritage. By the same token, the monograph, we assume, would be useful to historians, artists, art lovers and scientists who study and analyse ancient objects.

A number of sources and experts were consulted while preparing this monograph and these are acknowledged separately. The investigations reported in Chapters 5, 6 and 7 have been carried out in collaboration with the Govt. Museum, Chennai. Chapter 5 is authored by Dr. Baldev Raj (one of the authors of this monograph) and B.Venkataraman, Indira Gandhi Centre for Atomic Research, Kalpakkam. Chapters 6 & 7 are authored by Dr. Baldev Raj, Dr. U.Kamachi Mudali of Indira Gandhi Centre for Atomic Research, Kalpakkam and Dr. V. Jeyaraj, Curator, Chemical Conservation, Government Museum, Chennai.

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Chapter 1

Historical Background

Of all the metallurgical accomplishments of South India, the bronze icons* have been among the finest artistic treasures cherished by national, international and private antiquarians around the world. Known for their consummate workmanship, these icons are found in some of the best museums in the world. The authors take a comprehensive look in this monograph at the technological aspects of the ancient South Indian bronzes. When we use the word ancient, we refer to the period from about 3rd century A.D. to about 16th century A.D.

These bronze icons bear the mark of classical tradition in smooth modelling, aesthetic decoration and balanced proportions. Many elegant bronzes from 2nd century A.D. to as late as 17th century A.D. have been well documented and classified according to ornamentation or elegant anatomical features. Famous for their aesthetic beauty, iconometry and iconography, and casting quality of high order, the South Indian icons are excellent examples of the fusion of technology with cultural traditions. The South Indian bronze icons have their own characteristics, and in later centuries some of them are made of *panchaloha*(S) composed of copper, zinc, gold, silver and tin or iron.

In addition to the talent and skill in making bronzes, inherent in the *sthapatis*(T) (the local Tamil name given to a master craftsman who is an expert in either stone sculpting or bronze casting), the pursuit of skill and mastering of the essential technology required sufficient patronage and congenial atmosphere which were provided by the rulers. *Sthapakas*(T) are the chief technical assistants of the *sthapatis*(T) who have also taken important role in assisting them to produce such marvellous artistic wonders.

From the 3rd century A.D. onwards, the art and science of casting bronzes received the patronage of the royal dynasties of the Pallavas(T) (300A.D. to 900A.D.), the Cholas(T) (900A.D.to 1300 A.D.), the Pandyas(T) (1200A.D.to1500A.D.), early Vijayanagar, late Vijayanagar and Nayaka(T) kings. The Nayakas(T) (1600 A.D. to 1700 A.D.) who rose to power in the 17th century A.D., are the last dynasty to have consciously patronised the iconic art. The art of making bronze icons and the casting methodology is still adopted today by many a

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* *In this monograph, the term icon is used for any bronze casting, including humans, animals or other inanimate objects. If an icon is cast for the explicit purpose of worship, with eyes open, or while referring to objects that are meant for worhsip, the term idol is used.*

group of *sthapatis*(T) in South India.

Many monographs have been written exploring this important area of South Indian bronzes. One of the most comprehensive treatments, that deals with the *Cire Perdue* casting as practised in Swamimalai today, is to be found in Volume 1, Part VII-A of the Monograph Series of the Census of India[1], commissioned by the Registrar General of India in 1961, and published in 1967. It is to be mentioned here that *Cire Perdue* or lost wax process or *madhu-chisstavidhanam* in Sanskrit all mean one and the same and refer to the casting process. In this monograph we use the term "lost wax process". On stylistic and aesthetic aspects of the South Indian bronzes, excellent treatises are available [2,3]. A recent compendium on Indian bronzes [4] explains the historical, stylistic and geographical distribution of bronzes belonging to various periods. Fig. 1.1 shows the location of the place Swamimalai, where some of the best bronze icons are made even today, in nearly the same way as they were done centuries ago.

What makes the current monograph different from the earlier publications is the approach it takes and the accent it imparts to the technological, metallurgical, testing and conservational aspects of the bronze icons. Emphasis has been laid upon the techniques practised by the *sthapatis*(T) of those times and a comparison is made between the techniques practised during the ancient

Shri Devasenapathi Sthapati hails from a reputed family of *sthapatis*, and according to him, the present nucleus of bronze casters at Swamimalai including him are the descendants (see Figure 1.2) of the craftsmen who migrated from Gingee in the erstwhile South Arcot district to Thanjavur(known earlier as Tanjore)for the Big Temple project and later settled at Swamimalai. He imbibed this divine art from his father, Shri Srikanta Sthapati, right from his childhood and later learnt this art in more formal studies under his paternal uncle Shri Annaswamy Sthapati, acquiring full knowledge of *Kashyapa Shilpashastra*, *Sakalathikaram*, *Manasara*, *Abhinava Darpana*, *Shilparatna* and *Bramkya Chitrakam*. He makes idols mostly for temples, and in the last three decades, he has made thousands of bronzes in Chola style for more than a thousand temples, including those in the UK, Singapore, Malaysia, Mauritius, USA, Canada, Germany and Japan. A recipient of several awards and certificates, Shri Devasenapathi Sthapati was also awarded the coveted National Award as the Master Craftsman in Bronze Casting of Icons, by the Government of India. Shri Devasenapathi Sthapati has three sons, all of whom work with him casting timeless bronze icons.

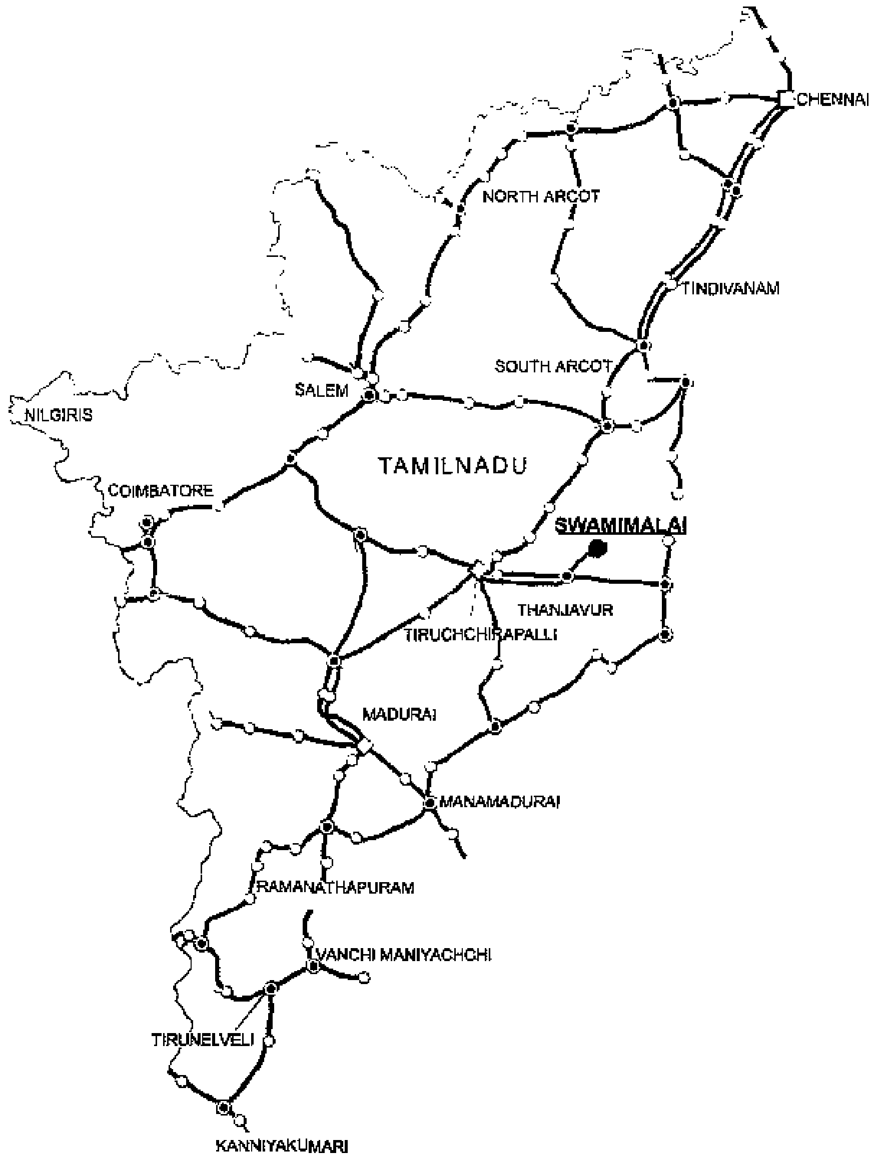

Figure 1.1 Map showing Tamilnadu and Swamimalai

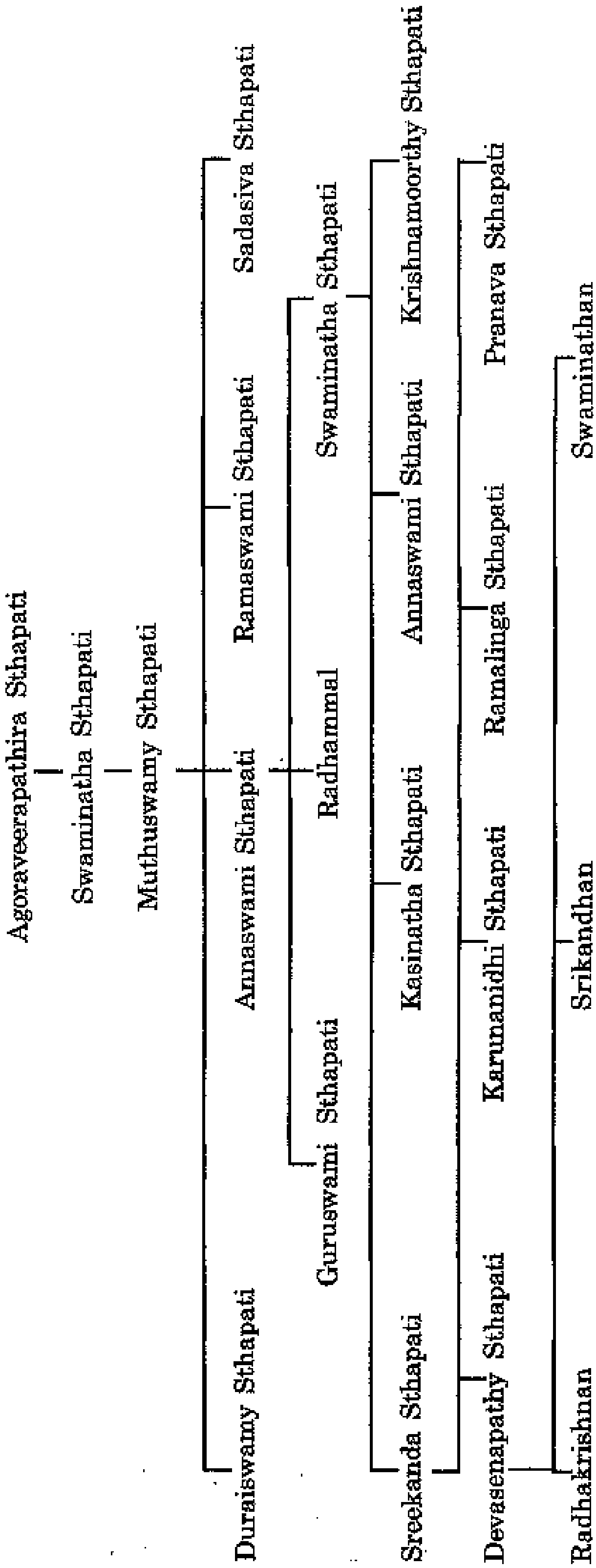

Fig. 1.2 Genealogy of *Sthapatis(T)* of Swamimalai

times and those that are prevalent today. Another important distinguishing characteristic of this monograph is the careful and precise description of the lost wax process and the complete casting technology. The entire Section on the process of lost wax casting as practised today, has been written based on the study of the actual process of present day casting and discussions with the expert Shri Devasenapathi Sthapati. His short life sketch is given in the text box (Page-2). Apart from the above, an attempt has been made to bring out the excellence of these cast bronzes through separate chapters on scientific investigations on representative ancient bronzes. The conservation aspects of such bronzes have also been discussed.

1.1 Historical, Cultural and Stylistic Aspects

Paleolithic, neolithic, bronze, copper and iron age are named after the dominant material used in the technology of those periods. The peak in the casting of bronze icons was attained around 1000 A.D. This was possible, mainly due to the buildup towards this crescendo, during the reigns of several earlier kings and emperors.

The royalty were the prime patrons of *poojas*(S) (prayers offered to the deity, which is usually stationary and made of stone) and *Utsavas*(S) (prayers offered during normal, as well as during special religious occasions when the bronze, gold or silver idol is taken out in procession). The stone deity which is stationary in the temple is called the *Moolavar*(T), while the same God worshipped during the *Utsava* is called *Utsavar*(T). The *Utsavar*(T) is usually made of metal. As per the *Agamas*(S), for every *Moolavar*(T) that is consecrated and worshipped, there must be an *Utsavar*(T) in metal. The *Agamas* also prescribe the type and number of such *Utsavars*(T) to be present in each of the *Shiva*(S) and *Vishnu*(S) temples.

Considering the fact that there are about 40,000 temples in Tamilnadu [5] and the patronage extended to most of these by various kings and emperors, it is no wonder that a large number of metallic, particularly bronze icons were cast over a period of time. The types of icons cast and their sizes and styles, however, depended to a great extent on the ruler of the times and his religious and cultural preferences. Hence, it would be worthwhile to recapitulate the history of South India briefly to know more about the rulers. For the sake of comparison and completeness we also give in Table 1.1 a brief chronology of events in the Indian history [6]. The oldest Tamil *Sangam*(T) period dates back to 3rd century B.C. to 2nd century A.D., when three major dynasties ruled the South Indian peninsula. They were the Cheras(T) with Karur Vanci as their capital, the Cholas(T) with Uraiyur (near

Table - 1.1 : Chronology of events in Indian history

Sl. No.	Period	Culture/Dynasty/King
1.	3000 – 1900 B.C.	Indus valley civilisation, Harappan culture.
2.	1900 – 1200 B.C.	Descent of Aryans into Gangetic Plain and affirmation of Vedic civilisation. Composing of the *Rig Veda*.
3.	1200 – 600 B.C.	Expansion of the Aryan civilisation over the Dravidan and aborigine areas.
4.	600 B.C.	Magadha kingdom reigns in north east India.
5.	563 B.C.	Birth of Lord Buddha.
6.	4th Century B.C. - 4th Century A.D	The great epics *Ramayana* and *Mahabharata* are composed.
7.	326 B.C.	Alexander the Great invades India and penetrates the Indus valley.
8.	268 – 231 B.C	Empire of Ashoka of the Maurya dynasty extended to all India.
9.	1st Century A.D.	Period of Kushan dynasty.
10.	320 – 415 A.D.	Sovereignty of Gupta dynasty — Golden age of Hindu civilisation.
11.	450 A.D.	Invasion of white Huns into India.
12.	606 – 647 A.D.	The reign of Harsha in north India and Pallava dynasty gains power in south.
13.	888 – 1280A.D.	Chola sovereignty in south expansion and conquest by sea of various territories of south-east Asia.
14.	997 –1526A.D.	Islamic invasions into the Punjab and north. *Musalman* dynasties and Khilji and Tughlaq.
15.	1366–1653 A.D.	The south Hindu empire of Vijayanagar.
16.	1526–1707 A.D.	The great empire, beginning with Babur,the founder of the dynasty.
17.	1757–1947 A.D.	Invasion of Chola(T) kingdom by Islamic, Dutch, Danish, French and British Forces.
18.	1947 –	Sovereign India.

Tiruchirappalli) as their capital and the Pandyas(T) with Madurai as their capital. By the 4th century A.D. the Cheras and the Cholas(T) lost power to the Pallavas(T), who ruled from Kanchi as their capital. From about 300 A.D. till 900 A.D. the Pallavas(T) ruled the northern part of Tamilnadu and the Pandyas(T) ruled the southern part.

The reign of Pallavas(T) extended up to about 890 A.D. The names of some of the important kings and emperors of the Pallava (T) dynasty are listed in Table 1.2[5]. Among the Pallavas(T), Mahendravarman (590-630A.D.) and Narasimhavarman I (630-668 A.D.) encouraged arts and culture, which flourished during their reign and continued to do so later till the last of the Pallava(T) rulers, Aparajitha, who was killed in 890 A.D. The Pallava(T) bronzes belong to this period. They had a characteristic style of their own and this school of bronze casting continued at various places till the *Chola*(T) empire came into existence around 900 A.D. Bronze icons which are dated into this period (4th century to 890 A.D.), and some time just after the death of the last Pallava(T) ruler, bear the stamp of the Pallava(T) architectural style. Historians[5] classify the Pallava(T) rule into the following distinct phases, as far as the making of bronze icons are concerned: the early Pallava(T) phase (up to 700 A.D.), the Rajasimha phase (700 -

Table - 1.2 : Some important *Pallava* (T) rulers

Name of the King / Emperor	Duration	Cultural Remarks
Mahendravarman	590 - 630 A.D.	An outstanding Sanskrit poet and artist; earned the title *Chitrakarapuli* (tiger among artists).
Narasimhavarman I	630 - 668 A.D.	Built the stone temples of Mahabalipuram
Parameswaravarman	Second half of 7th century	
Rajasimha Narasimha II	690 - 728 A.D.	Built the Kailasanatha temple, Kanchipuram; the Talagirisvara temple at Panamalai. Nandivarman II (also called Pallavamalla)
Dantivarman	First half of 9th century	—
Aparajitha	—	—

750 A.D.) when the features of the icons resembled that of the sculptures of the Kailasanatha temple in Kanchipuram, the *Nandi* phase (750 - 800 A.D.), the *Danti* phase (800 - 850 A.D.) and finally the Pallava(T)-Chola(T) transition phase (850 - 900 A.D.).

The Pallavas(T), the Chola(T) dynasty slowly rose to power. Even before Aparajitha's fall, the seeds for the great Chola(T) empire were sown. The Cholas (T) were among the greatest rulers of south India. Nearly 23 Chola (T) rulers reigned for over 400 years i.e., from about 850 A.D. to 1275 A.D. The names of some important emperors of the Chola(T) dynasty are listed in Table 1.3. The Chola(T) rule is divided into two main phases namely the early Chola(T) period (875-1075 A.D.) and the later Chola(T) period (1075 - 1275 A.D.).

Among the Chola(T) rulers, the reign of Rajaraja Chola (985-1012 A.D.) and that of his son Rajendra Chola (1012 - 1044 A.D.) are considered to be the most celebrated by the historians for their patronage to arts and religion.

The chronological development and the making of the South Indian bronzes can be clearly categorised into the following periods:

[a] The Pallava(T) period consisting of the five phases mentioned above;

[b] The early Chola(T) period, including the reign of Rajaraja Chola and his son Rajendra Chola and the School of Bronze casting founded and patronised by the Queen Sembian Mahadevi; and

[c] The late Chola(T) period

One of the greatest contributions of the Chola(T) period was the construction of the Brihadeeswara temple at Thanjavur during 985-1012 A.D. The main architect of the Brihadeeswara(S) Temple built by emperor Rajaraja Chola, is Kunjaramallan Rajaraja Perunthatchan. The names of some of the greatest *sthapatis*(T) who built monuments that still stand the test of time are given [8] in Table 1.4. The descendants of Kunjaramallan Rajaraja Perunthatchan had a great role in the construction and consecration of the Airavateswara temple in Darasuram, near Thanjavur, and the temple at Swamimalai. In fact, some of the present day *sthapatis*(T) of Swamimalai, who practice this art of bronze icon making using lost wax process, are direct descendants of those who practised this art during the reign of the imperial Cholas(T). The genealogy of some of the *sthapatis*(T) of Swamimalai are given in Figure 1.2.

The craftsmen of ancient India traced their descent from Vishvakarma(S), the first of all craftsmen and the Lord of all arts. Vishvakarma(S) also known as Mayan(T) in Tamil, is said to be the chief architect of all the best constructions in Lord Indra's abode.

Table - 1.3 : Some of the *Chola* (T) rulers

Name of the King/ Emperor	Duration	Remarks
Vijayalaya	-	-
Aditya	870 - 906 A.D.	-
Parantaka I	-	-
Gandaraditya (the second son of Parantaka I)	-	His wife Sembiyan Mahadevi was instrumental in starting her own school of bronze casting; several of the wonderful bronze master pieces of the Chola(T) reign were cast under her personal supervision. Though widowed at a young age, Sembiyan Mahadevi, lived through the periods of Arinjayan,Sundara Chola, Uthama Chola and Rajaraja Chola, and died in 1001 A.D. Eighteen temples (and the icons in them) were consecrated, under her direct supervision [7].
Rajaraja Chola	985 - 1012A.D.	The greatest of all Chola(T) emperors; built the Brihadeeshwara(S) temple in Thanjavur; though an ardent devotee of Lord Shiva, as an emperor he encouraged the followers of Buddhism and Jainism
Rajendra I	1012-1044A.D	Built the temple of Gangai Konda Cholapuram(T); the style of this temple is the same as that of the Brihadeeshwara(S) temple built by his father.
Kulotunga I (grandson of Rajendra I)	1070 - 1125A.D	-
Vikrama	-	-
Kulotunga II	-	Built the golden towers of the Chidambaram temple
Rajaraja II	-	Built the Airavateswara Temple at Darasuram
Kulotunga III	-	-
Rajaraja III	-	-

Table 1.4 : A few of the greatest *Sthapatis* (T) of ancient south India

Name of the Temple/Monument	Name of the Sthapatis(S)
Stone temples of Mahabalipuram	Kevatha Perunthatchan Thatchan Gunamallan Paiyamizhappan Abaajan
Brihadeeshwara temple,Thanjavur	Kunjaramallan Rajaraja Perunthatchan
Uthiramerur temple	Parameswara Perunthatchan
Thiruvottriyur Thoongaanai temple	Ravi Perunthatchan

True to this tradition, the icon-makers of Swamimalai trace their ancestry to the Vishwakarma(S) community. This mythological association provides them not only a religious background, but a spiritual motivation to excel in their products. As we see from the Table 1.4, the master *sthapatis*(T) were called *Perunthatchan*(T), which literally in *Tamil* means "a great architect". This name could probably have been a title given to the best of the architects in those days.

The distinct development, height of glory and decline of each of these periods can be well seen in the manifestation and style of the bronzes of the individual periods. Patronage of various kings and their dynasties have clearly made a mark on the type and style of the bronzes that were cast during the period.

1.1.1 Effects of Cultural Undercurrents on Icon Casting in South India

As per the Hindu philosophy, God is one, who is omnipresent and omnipotent. He has no shape, He cannot be described nor can He be fully understood. He stands beyond all that anyone can see, feel, operate and understand. This formulation of basic Hindu philosophy lies in several planes of abstract understanding, each tailor-made for the understanding and appreciation of any human being, depending upon his/her capabilities to understand the abstract. In order to bring such an abstract being to a plane which can be understood by ordinary human beings, *Agamas*(S) help in representing God as having various forms, styles, relations, capabilities and powers. Representation of God in human forms that humans can understand is one of the powerful underpinnings of Hindu philosophy. The *Agamas*(S) link the *Bhakti*(S) of the individual human beings to the presence of an abstract, omnipotent, omnipresent God through these iconic representations. Representations give way to rituals and the *Agamas*(S) shift the responsibility of bringing these representations to life, onto the *sthapati*(S) and fixes the various rules for such representation of God.

During the period of the Pallavas(T) and the early Cholas(T), Saivaite saints, Appar, Sundarar, Sambandar and Manickavachakar sang hymns praising Lord Shiva. From the Vaishnavaite school, several Alvars were present during this period singing the praise of Lord Vishnu(S). These saints took upon them the task of enforcing this link between the devotees and the Gods, through hymns which were the essence of the content and purpose of the *Agamas*(S). Presence of these saints, their closeness to royalty and frequent visits to various temples in south India had its own impact in kindling the need for such representations of Gods, through casting of icons, as per the *Agamas*(S).

The number, the style and the type of icons cast were purely determined by these cultural undercurrents. Emperors and kings who were influenced by this cultural movement, chose to consecrate a number of temples and idols in strict adherence to the preaching of the saints and the *Agamas*(S).

1.1.2 Stylistic Aspects

The style of an icon is an empirical entity, that manifests itself in the icon, notwithstanding the rigorous *Dhyanashlokas*(S) and the *Talas*(S) that serve as the guiding principles of icon casting.

Variations in style are present, even among the same class/group of icons, say that of a group of Nataraja(S) icons, for example. These variations, however, do not pertain to the differences in the physical dimensions of the icon such as height, weight, width, etc.

Different styles are often a result of one or more of the following criteria:

a. Different schools of bronze casting;
b. Bronze icons cast at different geographical locations;
c. Bronze icons cast for different worshipping purposes;
d. Bronze icons cast based on different mythological context; and finally
e. The fertile imagination of the *sthapati*(T).

The variance in the style can be amply explained, by taking, say, the standard representation of the Lord Nataraja in His cosmic dancer pose. To quote Nagaswamy [5]:

> This particular form of the Dancing Shiva(S) first occurs during the Chola(T) period, and is one of its greatest gifts to the world of art. Unsurpassed for rhythm and beauty, power and grace, it became an image consecrated in all Shiva Temples of South India. Beyond the artistic form lies a profound meaning, to be comprehended at many levels. Shiva is the Creator, the Sustainer; it is He who dispels ignorance, grants solace and finally the Destroyer. He dances the universe

into existence and sustains it with His rhythm; then dances it into destruction. The Nataraja in *Ananda Tandava* symbolises these acts. Creation is sparked by the vibration of the drum in the right hand; protection or sustenance by the open palm of the front right arm, a gesture of assurance that grants freedom from fear. The dwarf representing ignorance is trampled under the right leg. The left front arm points downward, to the lifted left leg, the solace of the worlds. The fire in the left arm dissolves the universe. The aureole represents the cosmos, the sun, moon and stars revolving in perpetual and fiery motion.

Within this framework of Cosmic Dance representation, innumerable variations in style are practised by the expert *sthapati*(S). In order to understand these variations in style, each and every icon should be looked upon as a snapshot of the continuous Cosmic Dance, that freezes the Lord's movement in an icon, forever. Such variations in style could come up as one or more of the following aspects of the Cosmic Dancer pose:

a . Representation of the snake.
b . Representation of the *Prabhava*(S) (the aureole).
c . The length of the hair plaits.
d . Flowers in the head, if any.
e . The flow of hair as a result of the Cosmic Dance.
f . The jewels on the head.
g . The presence or absence of Ganga(S) on the head.
h . The jewels worn by the Lord.
i . The type of ear rings worn.
j . The expression (*bhava*(S)) on the face.
k . The position of the four hands.
l . The objects in the four hands – their representation.
m. The way in which the *dhoti*(S) (a simple piece of cloth usually white in colour and worn around the waist) is worn.
n . The flow of the *dhoti*(S) as the symbolic representation of the progress of dance.
o . The placement of the legs in the pose—their relative positions.
p . The presence or absence of the dwarf underneath.
q . The hairstyle and the pose of the dwarf.

These seventeen aspects are just indicative of some of the stylistic aspects. We can appreciate that in the case of the representation of Lord Shiva as the Cosmic Dancer, one could find a number of variations in the seventeen aspects mentioned above. If one considers the South Indian bronze icons in its entirety, one could as well imagine the variations in style that are possible.

Symmetry have always been a part of the aesthetic perception of artists. In many icons, the *sthapathis*(T) seem to have exploited the role of symmetry as a contrasting background for displaying the more exciting and dynamic features. Taking the famous example of Cosmic Dancer itself [9], we can observe that it has very symmetrical, circular *prabhavalli*(S) with the flickering flames arranged in a very systematic pattern. However, what enhances the icon is not the *prabhavalli* but the central figure of Nataraja.This figure of Nataraja slender in form, dynamic in tension of its twisting hips and the gracefully crossed balance of its arms and legs appears beautiful, delicately balanced, but is not symmetrical. In short, while the symmetry of the whole arrangement appears pleasing to the eye, it is the asymmetrical dynamic forms that gives the vitality to the icon. Such asymmetrical features in symmetrical backgrounds have also been observed in western sculptures such as the sculpture by Michelangelo in the New Sacristy in the Church of San Lorenzo in Florence (also known as Firenze) [9].

Historians identify the period of a bronze icon based on a number of established stylistic aspects. Ornaments, type of clothing, anatomical features are some of the stylistic aspects studied in detail. For example, the tassel of the *dhoti* makes a loop and falls in between the legs for Lord Shiva, in the Pallava(T) school of bronze art. The sacred thread worn around the shoulders is thick. The icon's face is usually squarish and the dwarf beneath the Lord's feet faces the front. As opposed to this, the waist garment in the Chola (T) bronzes is merely ornamental, with the tassel loop on the sides. The garments are cast as having very fine textures. The dwarf faces sidewards and the face is rather oval and supple. It is mentioned [5] that even among the contemporary *sthapatis*(T), there could be marked variations in style. Considering the fact that Queen Sembiyan Mahadevi and Emperor Rajaraja Chola belong to the same family and same times, their styles of casting bronze icons were quite distinct! While those who worked under the supervision of Sembiyan Mahadevi cast icons with sharp features (sharp noses, knees, etc.), those cast under the supervision of Emperor Rajaraja Chola for the Brihadeeshwara and other temples were not slender but commanding and powerful [5]. Both schools of casting co-existed at the same time.

During the long reign of the Pallavas(T) and the Cholas(T), a number of schools of bronze casting existed throughout south India. The most important schools among them are Kumbakonam (Swamimalai and Tandanthottam), Kanchipuram, Chidambaram, Pudukottai,Kongu Nadu, Paruthiyur, Thiruvenkadu, Thirukkar avasal, Gangaikonda Cholapuram and Thanjavur [5].

Table-1.5 gives the general stylistic characteristics of these bronze icons, compared over a period of 10 centuries, from Pallava

(T) to post-Vijayanagar period [10].

1.2 Literary Evidences

Though bronze icon casting using the lost wax process is historically a recent phenomenon, the processes of solid casting and the hollow casting have been referred to in the literature at various places. In the *Rig Veda*(S) there is a reference to hollow casting of images [11]. In the *Yajur Veda*(S) which was compiled after the *Rig Veda*(S), there is a reference made to tin, lead and silver with which ornamental bowls were made [12]. Such references are also found in the *Upanishads*(S) [13].

There are references to the process of casting in the great epic *Ramayana* [14], in Balakanda(S), as follows:

"bimbad ivoddhrtau bimbau ramadehat tathaparau"

"The twin sons of Rama were like two (cast) images produced, as it were, from the (original) image, the body of Rama"

Here *bimbat*(S) represents the original model from which the mould is prepared, and *uddhrtau*(S), the cast produced.

In *Mahabharata* [15], the following description appears that relates to the process of casting. In the *Asvamedhikaparva*(S), verse 18.8 mentions that,

"yatha hi lohanisyando nisikto bimbavighragam,
upaiti tadvaj janihi garbhe jivapravesanam"

which translates to, "as liquid iron being poured out assumes the form of the image (in the mould into which it is poured), such you must know is the entrance of soul into the foetus".

These two Indian epics, namely *Ramayana* and *Mahabharata* contain a number of instances where descriptions of icons that replicate humans, are given [16]. In *Mahabharata* it is found that *Dhritarashtra,* in rage embraced an iron replica of Bhima, upon which it was smashed to pieces. In *Ramayana,* when Rama wanted to perform a sacrifice, he was advised to make a golden replica of Sita, as the sacrificial rites required that his wife be present for the sacrifice who was then banished.

In *Ratnagothravibhaha*(S), the lost wax process for casting gold images is alluded [17] as follows:

"hemno yathan tahkva thitharya purnam bimbaum bahir mrnmaya meksya santam |
antarvisuddhyai kanakasya tajjnah samcodayed avaranam bahirdha ||"

meaning, "In the manner as seeing the complete image (*bimba*) inside of liquefied gold and outside covered of clay, the knower of the process (*tajjnah*) casts (or removes) away the outer covering for the cleaning of the gold (image) inside".

Table 1.5: General stylistic characteristics of south Indian bronzes

Characteristics/ Period	Pallava (T)	Early Chola (T)	Late Chola (T)	Vijayanagar	Post-Vijayanagar
Body Characteristics	Elongated face, Drooping Eyelids, Prominent Chin, Wide Nose, Thick and full lips.	Pleasing and Gentle Expressions. Prominent and Sharp nose. Natural eyes, Oval Faces, Slender Body.	Gentle yet stiff proportions, Prominent knee caps.	Conventional body. Angular proportions, Chest differentiated from abdomen, Oval faces, Smiling , Slim waists and wide hips Long neck, Eyes wide open.	Artificial body with exaggerated curves, Triangular faces, Well modelled and groomed fingertips.
Headgear and Hairstyles	Simple	Elaborate hairstyles. Lots of plaits. Curled hairstyle at the back. Each of the Gods have characteristic headgear styles			
Ornamentation and Jewellery	Little earrings, Huge necklaces	Large number of ornaments on arms, wrists and ankles, Short, round and heavy necklaces.	Abundant yet delicate jewellery, Long earrings falling on neck, Necklaces are short, Girdle with tassels and festoons.	Decorative jewellery, Long necklaces Elaborate girdles, Presence of loops in girdles, particularly in Nataraja icons.	Novel designs, Loud jewellery.

(Contd.)

(Contd. Table 1.5)

Characteristics Period	Pallava (T)	Early Chola (T) Late Chola (T)	Vijayanagar	Post-Vijayanagar
Accessories	Simple and realistic emblems in the hands, *Vishnu's (S) Chakra* facing inwards and held between thumb and index finger, Shiva's axe with long handle and held in the fist.	*Vishnu's (S) chakra* with flame-like projections, Held between index and middle fingers, Shiva's battle-axe held between two fingers. Axe decorated flames and tassels.	Ornamented emblems with unrealistic shape, *Vishnu's(S) chakra* with flames and bows, held facing outwards. Shiva's axe with short handle like club,	—
Drapery	Middle loop of girdle hangs between legs, Sacred thread may fall over right forearm after passing across the chest.	Graceful, clinging close to the body, Dhoti or lower garment with a wheel design	Elaborate, formal and conventional	—

Plate 1.1
Dancing Girl excavated from Mohenjo-daro

There are also evidences to prove that metal casting was in vogue in India even about 5000 years ago, from the excavated bronze statue of a dancing girl (Plate 1.1) from Mohenjo-daro [4,18]. This vivid figurine is 10.8 cm in height and is shown standing with her left leg slightly flexed. She has been identified as an aboriginal from southern Baluchistan because of the similarity of her physiognomy with the terracotta female figurines from Kulli. The figure of dancing girl though simple in form has attracted the attention of many and has been a source of inspiration for others. Historians have researched on this figure just as the painting of Monalisa. What holds us to this small art piece is still a wonder but the more wonderful fact is that this piece more than 5,000 years old has not deteriorated. Some historians have concluded that it was the Harappan civilisation that gave rise to naturalistic human sculpture that was one of the most brilliant features of later Indian art [4]. Bronze and copper pins belonging to the period 2500-1500 B.C., unearthed from excavation sites of Mohenjo-daro and Harappa also indicate that they were made using the lost wax process. Excavations at Taxila have brought out gold and copper ornaments, cast using the lost wax process, belonging to the period 327-325 B.C. [19]. However, the actual process of metal casting has been recorded only after the beginning of the Christian era[20]. *Agni Purana*(S) and *Matsya Purana*(S) of the Gupta period have described in detail, the technique of casting bronze images[21].

A group of bronze images found in Kolhapur belonging to the 2nd century A.D. and the fragmentary images of Buddha excavated from Amaravati belonging to the 3rd century A.D. indicate that there has been a continuum in the art of icon making using the lost wax process[22]. A small hollow cast bronze bull excavated from Gandhara, belonging to the period 3rd to 4th century A.D.[4,23], is another example of the use of this technique by ancient Indian metal smiths.

In the south, a bronze icon of mother goddess, estimated to have been cast about 3000 years ago, has been excavated at Adichchanallur [24]. Recently, in the excavations at Kodumanal, a place near Erode in Tamilnadu, several bronze and iron objects have been discovered, belonging to the megalithic burials of 300 B.C. Among the bronze objects excavated, mention must be made about a rare bronze icon of a tiger, studded with semi-precious stones.

The most elaborate treatise on the lost wax process of metal casting is the *Shilpashastra*(S) recorded in the 68th Chapter of the Manasara(S) believed to have been compiled during the Gupta period. This Chapter is titled, Madhuchchhishtavidhana(S). The relevant passages from this Chapter are given below[16]:

Vimvānām tu madhūvchchhistam(sta)kriyam
Samyog Vakshyateadhuna 1
Śaivaṁ pāśupataṁ chaiva (kālā) (ia) mukhām mahāvratam 2
Vāmaṁ cha bhairabhaṁ chaiva tantravat (ntrokta)
jyotih shatkramāt 3
Agastyaḥ Kāśsyapaśchaiva Bḥrigu Gautama Bhārgavaḥ 4
Gālava i(sche) ti rishayaḥ proktāh karshaṇādyarcha
(diracha) nārthakam 5
Tattattantravasatsarvaṁ kuryāt shat saṁpadāspadam 6
Tattattantraviparitaṁ ched vipatyaṁ (ttim) nityamāvahet 7
Anuktaṁ tantra tantreystu grāhyaṁ dosho na vidyate 8
Viśvakarmā cha Viśvecha (Śah) Viśvasāram
(rah) Pravodḥakah 9
Vṛitaśchaiva Mayaśchaiva Tvashtāchaiva Manurnalaḥ 10
Mānavin Mānakalpaścha Mānasāro Vahuśrutah 11
Prashtā cha Mānavodhaścha Viśvavodho nā (na) yaścha tathā 12
Ādisāro Viśālaścha Viśvakāśyapa a (śchai) va cha 13
Vāstuvodho Mahātantro Vāstuvidyāpatistathā 14
Pārāśạriyakaśchaiva Kālayūpa maharishiḥ (ḥrishiścha) 15
Chaityākhyaḥ Chitrakaḥ A (schā) varyaḥ
Sādhakasārasamhitaḥ 16
Bhānuśchendraścha Lokajñah Saurākhyaḥ śilpivittamaḥ 17
Tadeva (te eva) rishayaḥ proktā dvatrimsatiḥ Saṁkhayā 18
Tān gotravaśājñātvā śilpi (ṇah) sarvatrayogyakam 19
Śuklapakshe athavākrishṇe sarvamāseshu kārayet 20
Śubhayoge sunakshatre sumuhūrte sulagnake 21
Mantravatkārayet gardhe (tre) sthapatis(T)thāpakāvubhou 22
Madhūchchhisṭaṁ yojayechehhilpi śāstraṁ(strataḥ)
kārayekramāt 23
Yathārūpam tathā dhyātvā sthapatyājñaiścha (jñayā)
vardhakī (kih) 24
Yanmadhūchchhisṭavimvasya pañchavarṇeyralaṅkritam 25
Kshaṇikā (ka) veramevaktaṁ chalaṁ chāpyachalaṁ tathā 26
Tasmātsarvaprayatnena tatradosho na vidyate 27
Akshaiḥ sfatiksāmyuktam lūtabhājanameva cha 28
Hastena sarvavimbānāṁ tāmrapatreṇa yojayet 29
Athavā pakshakānāṁ tu pakshamuūlena vinyaset 30
Nakhās (kha) sarveshu padau cha samýuktam tu mṛige
(tāmre) na cha 31
Athavā śikhaśalyaṁ syād bhūshanaṁ cha viśeshhataḥ 32
Sftikaih ratnasaṁyuktaṁ jinapātrena vinyaset 33

Amū (Āmra) kadrumasarveshāṁ yuktya varṇaṁ samāśritam 34
Dārūkilaiścha Vimvānaṁ yatfa (d ba) lārtham tuyojayet 35
Ādravadravya (saṁjuktaṁ ta) smād doshamevaṁ na vidyate 36
Sarvālaṅkārasaṁyuktaṁ veraṁ grāmapradakshiṇam 37
Yajamānādi saṁvekshya sevyaṁ tatrārchanaṁ bhavet 38
Tasmād devatārthaṁ saṁgrāhya chānyagrāme vilāsayet 39
Paśchāttu śilpiśālaś (lām) cha veramevam praśasya (viśya) te 40
Mānonmā napramā nena sobhayechchilpi (lpa) vittamah 41
Dvitryaṅgulā (lam) dhikaṁ vātha madhūchchistena lepayet 42
Tadūrdhe mrittikāṁ lepya soshayettad vichakshaṇaiḥ 43
Tat piṇḍamuttā payedv ā madhūchchiṣtodgamaiḥ punaḥ 44
Karturichchā yathā lohaidhṛittaḥ (tam) etatpraviśyati (śasyate) 45
Purṇayejjalaṁ samprokshya tyaktvā tadhardhamrittikah (kam) 46
Vimvaṁ sarvāṅgaṁ samśodhya śvetagandhā (ndhenā)mulepayet 47
Tatpīṭhopari saṁsthāpya pushpamālai (lyei) ralaṅkṛitam 48
Grāmaṁ pradakshinṇam kuryātsarvamaṅgalaghoshaṇaiḥ 49
Śilpiśālām praviśya (śanti) kāryeduktavaktramāt 50
Tasyopāṅgavihīnaṁ chetpunaḥ santānakaṁ bhavet 51
Śiro vā madhyakāye (yaṁ) hinam chet visrijetpunaḥ 52
Kartriśilpyachalaṁ chittaṁ kārayetpurvavad bhavet 53
Chalaṁ Chittaṁ na kuryyāchchetsthānanāśam dhanakshayam 54
Anekajanmakritaṁ punyaṁ kshiprameveṁ vinaśyati 55
Tasmāt sarvaprayatnena putaś (putaṁ) cha kārayetsudhiḥ 56

The meaning of these verses are given below:

(1) The casting of idols in wax (*madhuchchista-kriya*) will now be described fully.

(2-3) Shaiva, Pahupata, Kala-mukha, Mahavrata,Vama and Bhairava: these are the six respective *jyotis* (light) phalli (of Siva) as laid down in the Tantra (scripture).

(4-5) Agastya, Kashyapa, Bhrigu, Gautama, Bhargava, Galava and others are said to be the sages (whose idols are made) by this treatment (of casting in wax, Karshana) for worship (construction).

(6) All those six (groups of phalli and idols) should be made according to rules of their scriptures with a view to acquiring prosperity.

(7-8) If the opposite of what is prescribed in those sciences be followed, it would always cause danger and difficulties, but if what is not laid down in those sciences be adopted (for improvement) there would be no defect in that.

(9-20) Vishvakarma, Vishvesha, Vishvasara, Prabhodhaka, Vrita, Maya, Tvashtri, Manu, Nala, Manavin and Manakalpa, very celebrated Manasara, Prashta, Manabodha, Vishvavodha, Naya, Adisara, Vishala and Vishva-Kashyapa, Vastubodha, Mahatantra, Vastuvidyapati, Parasariyaka, the great sage Kalayupa and those named as Chaitya, Chitaraka, Avarya, together with Sadhakasara, Bhanu, Indra, Lokajna and Shaura who are the best artists: they are stated to be sages and are thirty-two in number; they are thus known by their surnames; these artists are competent for all kinds of artistic work.

(21-22) In the bright or dark fortnight of all months, on an auspicious moment of auspicious *lagna* (meeting), *nakshatra* (stars) and *yoga* (conjunction), both the chief architect (*sthapati*) and the chief assistant (*sthapaka*) should make the pit (for casting the image) with the usual incantations (*Mantra*).

(23) Then the artist (sculptor) should besmear wax over the idol as stated below.

(24-25) The sculptor (Vardhaki) at the command of the chief architect (*Sthapati*) should think over (meditate) the correct image and purify with the five powders the idol to be cast in wax.

(26-27) This (process) is recommended for the transitory idol, stationary or moveable, therefore it should be made with all care and attention so that there may not remain any defect or flaw.

(28) The eyes (of the idol) should be furnished with crystal and covered with spider's net.

(29-30) The hands (arms) of all idols should be covered with a copper-leaf or that should be fixed at the root of the wing of those which have wings.

(31-32) All the nails and the two feet also should be fixed with a copper leaf and optionally the crown of the head and particularly the ornaments should be fixed with a peg.

(33-34) The crystal and gems when inserted (to eyes etc.) should be covered over with a leather bag discreetly besmeared with the powders of all the trees, namely, the mango, etc.

(35-36) In order to make them strong the idols should be furnished with wooden nails, even if they (i.e., the idols) be made of materials liable to be melted, there will be no defect in that.

(37) Adorned with all ornaments, the idol should be taken round the village.

(38) This should be shown to the worshippers who would want to worship it.

(39) Therefore, for the sake of the selection of the God, the idol may be taken from village to village.

(40) Afterwards, (i.e., if the idol be approved of) it should be taken into the studio of the artists.

(41) The best artist should measure it along the length,

height and width.

(42-43) (After correct measurement) it (the idol) should be besmeared with wax upto some two or three *angulas*; upon that (coating) it should be (again) besmeared with earth, and then it should be dried up by the experts.

(44) That idol, should be dried up and besmeared with a new coating of wax again.

(45) If the master so wishes, it may be covered with metals (iron); that is preferred.

(46) The half, besmeared with earth, should be left out and the rest should be washed with water by sprinkling.

(47) The whole body of the idol should be purified, and besmeared with white sandal and perfumes (after completion).

(48-49) It should then be placed upon a seat (throne) and be adorned with flower garlands; and it should be again taken round the village (for approval) amidst all auspicious sounds.

(50) (After the approval of the villagers and artists) it should be taken into the studio of the artist and the processes mentioned before should be repeated again.

(51-52) If (in the process) the idol's minor limbs are broken, they should be made again, but if the head or the middle body be damaged, the whole idol should be made afresh.

(53) If the master or the sculptor himself is not quite satisfied it should be changed and made again.

(54-56) Nothing should be accepted which would leave behind a hesitating mind, because it would cause the loss of place and wealth, and the merits acquired through many births will at once be destroyed; the wise (artist) should, therefore, cast the idol free of all defects with all care and attention.

The Tamil and Malayalam versions of the translation of this chapter of *Manasara* is presently being used as the guidebook for lost wax metal casting [24]. The *Shilpashastras* contain very elaborate rules in the form of verses or *dhyanaslokas* that describe the spiritual features of the icon to be cast and mention the *lakshanas* or the formulae that aid casting of the icon. Together with the *dhyana-shlokas*, the *lakshanas* and the inherent experience in the art, the *sthapati* casts the icon [11].

Another important work, belonging to the later period of twelfth century, is called *Abhilashitarthachintamani* also called *Manasollasa*. This work, authored by the Western Chalukyan King Somesvara Bhulokamalla (1127-1138 A.D.) presents a clear picture of metal casting. The relevant portions from this important work and their translation are presented here, as found in [25]:

"Navatalāpramāṇena lakshaṇena samāvṛitam
pratimām kārayet pūrvam uditena vichakshaṇaḥ
sarvavāyavasam Pūrṇām kiñchitpitām dṛiśoḥ priyām
yathoktair āyudhair yuktām bāhubhiścha yathoditaiḥ
tatpṛishtḥe skandhadeśe cha krikatyām mukutetha vā
kāśapushpanibham dīrgham nālakam madanodbhavam
sthāpāyitvā tataśchārchām limpet samskrityā mṛidā
mashim tushamayim ghṛishtvā kārpāsam śataśah kshatam
lavaṇam chūrṇitam ślakshṇam svalpam samyojayenmridā
vāratrayam tadāvartya tena limpet samantataḥ
achchhas syāt prathamo lepaḥ chhāyāyām kritaśoshanaḥ
dinadvaye vyatite tu dvitīyas syāt tatah punaḥ
tasmin śushke tṛitiyas tu nibido lepa ishyate
nālakasya mukham tyaktvā sarvamālepayenmṛidā
śoshayet tam prayatnena yuktibhir buddhimān naraḥ
sikthakam tolayedādāvarchālagnam vichakshaṇaḥ
ritya tāmreṇa raupyena hemnā vā kārayet tu tam
sikthād ashṭaguṇam tāmram rītidravyam cha kalpayet
rajatam dvādaśaguṇam hema syāt shoḍasottaram
mṛidā samveshṭayed dravyam yadishṭam kanakādikam
nālikerākṛitim mūshām pūrvavat pariśhosayet
vahnau pratāpitamarchāsiktham nissārayet tataḥ
mūshām pratāpayet paschāt pāvakochchishṭavahninā
rītistāmram cha rasatām navāngārair vrajed dhruvam
taptāngārairvinikshiptai rajatam rasatām vrajet
suvarnam rasatām yāti pañchakritvah pradipitaih
mūshāmūrdhani nirmāya randhram lohaśalākayā
saṁdaṁśena dṛiḍham dhṛitvā taptam mūshām samuddharet
taptārchānālakasyāsye vartim prajvalithām nyaset
saṁdaṁśena dhṛitām mūshām tāpayitvā prayatna tah
rasam tu nālakasyāsye kshiped achchhinnadhārayā
nālakānanaparyantam sampūrṇam viramet tataḥ
sphoṭayet tatsamipastham pāvakam tāpaśāntaye
śitalatvam cha yātāyām pratimāyām svabhāvatah
sphoṭayenmṛittikām dagdhām vidagdho laghuhastakaḥ
tato dravyamayi sārchā yathā madananirmitā
jāyate tādṛiśī sākshād angopāngopaśobhitā
yatra kvāpyadhikam paśyechchāraṇaistat praśāntayet
nālakam chhedayechchāpi paśchādujjvalatām nayet
anena vidhinā samyag vidhāyārchām śubhe tithau
vidhivat tām pratisḥthāpya pūjayet pratyaham nripah

The translation of which reads as follows [16]:

According to the *navatala*(S) measurement, as mentioned before, the expert should first prepare the image (i.e., the model), complete with all the limbs, yellowish in colour, beautiful to look at and with the weapons and arms as prescribed.

After placing wax tubes of the length of a 'dhatura' flower on the back, on the neck or the crown (of the image), (the artist) should besmear the image with refined clay.

To clay should be added charred husk finely rubbed, cotton severed a hundred times and a little salt finely powdered. All these (when mixed with clay) should be (finely) ground on a smooth stone and (the paste) should be applied three times all over and round (the image).

The first layer (of clay) should be transparent (and thin) and should be dried up in shade. After a couple of days a second layer should again be applied. When dry again, a thick third coating needs to be applied.

One should besmear that whole (image or the model) with clay leaving the mouths of the tubes open; and the wise man should dry up (the clay coatings) with care and judgement.

The expert should first (i.e., before beginning the process, just mentioned) measure the wax of the image, which would have to be made in either brass, or copper, or silver or gold.

Brass and copper should be taken ten times that of wax, (if the metal is) silver (then) twelve times and (if the metal is) gold (then) sixteen (times).

(Then one) should encase the metal, either gold or one that is desired, with clay and the coconut-shaped crucible (thus formed) should be dried up in the aforesaid manner.

Next (one) should melt away the wax (from the mould) by heating the image (i.e., the mould) in fire and should afterwards heat the crucible in cinders.

Brass and copper melt surely with (the help of) cinders just kindled. Silver melts with (the help of) glowing cinders while gold with (the help of) cinders flaming fivefold.

After making a hole with an iron rod on the top of the crucible and holding it tightly with a pair of tongs (one) should bring the heated crucible (out of the cinders).

(One) should place a burning wick in the mouth of the tube of the heated (mould of the) image.

After bending carefully the crucible, held tightly by the tongs, (one) should pour molten metal into the mouth of the tube in a continuous stream and should stop when it is full to the brim of the tube.

The adjacent fire should be put out for the purpose of cooling (the mould with the molten metal). When the image (i.e., the mould) gets naturally cool, the expert should break up the clay (mould) very carefully.

Then the metal image (thus prepared) verily resembles that in wax, endowed with similar limbs and other details.

When there is seen anything superfluous that should be put right with *Charana;* the tubes should also be cut away and after that (the image) would have to be finished.

After making an image by this method, the king should instal it on an auspicious day according to the usual rites and should offer daily worship to it.

One of the other texts in this subject, *Shilparatna,* dating back to medieval periods, among other things, makes a mention of the types of clay that were used in the ancient period in the lost wax process of icon making [26]. It states that:

"The various grades of clay required fall into the following five categories:

a. **Very hard clay** : Clay plus powdered pottery tiles and nut water.

b. **Medium clay** : The above mixture should first be dried, then pounded on a pounding stone to fine powder and mixed with dung.

c. **Soft clay** : Three parts of clay plus one part of powdered pottery, mixed together on a grinding stone.

d. **Fine clay** : The above mixture is again pounded on the grinding stone with an admixture of dung.

e. **Crucible-making clay** : Husks which have been burned to powder and cotton fabric pounded to powder, are mixed together in equal parts, and in turn, pounded on the grinding stone. The crucible is to be made of the above mixture and arranged by means of thin wire and thread.

Types of clay used in the present day are listed and described in Section 4.11.

The list of books on *Shilpashastra,* that are now available are listed in Table - 1.6.

Table 1.6 : *Shilpasastra(S)* Texts Available Today

Kashyapa Shilpashastra
Sakalathikaram
Saaraswatiya Chitrakarma Shastra
Shilparatna
Brahmia Chitrakarma Shastra
Mayamata Parts I and II
Manasara Parts I and II
Srithathvanithi Parts I,II and III

All of these books are translated and reprinted by the Sarasvati Mahal Library, Thanjavur, Tamilnadu.

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Chapter 2

Evolution of Casting Practices

Most of the ancient bronzes have been cast as images of gods, goddesses, portraits of kings and queens, saints etc. There are only a few castings that are everyday objects used by people. These bronze icons are cast either as a single entity or a group of icons, usually placed over a pedestal, that would serve both as a stable platform and also as an artistic expression.

Generally, the icons (sometimes, parts of a single icon), and the pedestals and the surrounding halo structures, are made separately and are then joined together to form a single piece of exquisite style. In such cases, the size, volume and proportions of the individual objects need to be harmonised with the overall structure of the final icon. Considering the fact that none of the ancient *sthapatis*(T) had sophisticated measuring or visualising tools, this is an elegant achievement.

2.1 Styles, Intricacies and Form

One of the most striking aspects of the ancient south Indian bronzes is the true and authentic representation of human and animal anatomy, and other accessories to the last detail. The expertise of the *sthapatis(T)*, in bringing out finer details of each part of the icon has been much appreciated, and is the prime reason for the value of these icons. These ancient South Indian bronzes bear the mark of classical tradition in smooth modelling, aesthetic decoration and high proportions.

Each and every icon is made in full accordance to the *shilpasastras* (texts that grammatically define the form and style of the icons) [3]. The *sthapatis*(T) have developed over a period of time, a heuristic relationship between the amount of wax used in making the wax model and the amount of molten alloy that needs to be used for making the icon. That no other analytical relationships are used for this purpose, is a testimony to the empirical expertise of these *sthapatis*(T). Similarly the heating up of the clay shell to a specific temperature (which is usually not measured), before pouring the molten alloy, speaks about the qualitative yet comprehensive empirical knowledge of ancient *sthapatis*(T).

The *shilpashastras* (extracts of some of which are given in Section 1.2), give broad outline of how each God or Goddess is cast into icons. They mention usually about the macro-features of the idol. The micro-features of the idol, such as the type of clothing, type of hair style, the standing or sitting posture, the style of displaying wrists, palms and hands (known commonly as the *hastas*), the look on the face, expression of emotion, etc., are entirely left to the imagination of the artisan. If one scans a number of bronze icons made during this ancient period, it is this aspect that speaks about the cultural and technical excellence of any artisan. However, it is a commonly accepted fact that *sthapatis*(T) belonging to one particular school of casting tend to cast icons in a particular fashion, that helps us in categorising the styles.

The initial wax mould of every icon is made with great care, with due attention to the structure and size of its parts. For each of the parts, an empirical association is made, which intuitively suggest to the artisan as to how the final proportion of the part should look like. This empirical associations are based on keen observations on the human (or animal, as the case may be) anatomy, with a purpose of replicating the part to the last perfect detail. For example, when a *Kannagi* statue was to be cast for worship, traditional descriptions of the icon were not available and the *sthapati*(T) made a number of models based on his imagination and in tune with the features described in literature. From these models, one of them was chosen for the final wax model. These associations are called *lakshanas* and there are 32 of them mentioned in the *Agama Shastras*. However, these associations are not scriptural constraints but offer the artisan a broad yet accepted guideline. The last word in any such representation of a part lies with the artisan himself offering him the highest manoeuvrability of his creative genius. These associations, for some of the human parts are given in Table-2.1. The Tamil names of various terms are given in italics.

The most important aspect that gives a unique signature to any icon, and its style, is the fact that each casting process is non-repeatable, since both the wax model and the clay shell are lost forever, after each icon is cast. It is because of this fact, that it is impossible to find two icons (cast in this process) to be identical. Each icon thus becomes a *designer* icon.

The style of medieval South Indian bronzes differs from those of the north mainly owing to the adaptation of the style to the technique by South Indian craftsmen. In North India, the style in bronze work seldom departed far from conventions already established for stone sculptures [27]. Another important aspect that differentiates North Indian bronzes from south

Table - 2.1 : Various empirical associations of the parts of an icon

The Part / The Icon	The Association or the *Lakshana*
Leg (particularly those of females)	*Kendai* fish
Lord Shiva's face	Hen's egg
Lord Vishnu's (S) face	Duck's egg
Kataka Hastam (*Hastam* is the representation of the human palm and fingers, specifically in the dance postures; these are also called *mudras)*	Crab
Nose	Gingily (*Thuthi*) flower
Upper lip	Bow
Lower lip	*Kovai(T)* fruit
Eye brows	Neem leaf
Eyes	Fish
Ear	Lily flower
Chin	Mango stone
Neck	Conch shell
Thighs	Banana tree trunk
Knee cap	Crab
Shoulders	Elephant's trunk or banana tree trunk
Male figure / torso	Bull's face
Female figure / look	Deer's figure and looks

Indian ones is the composition of the alloy. In South India most of the bronzes were rich in copper, and for ritual purpose small amounts of gold and silver were added (composition given in Section 2.4.3), whereas in North India, eight components (*Ashtaloha*(S)) in significant amounts were used, namely, gold, silver, copper, iron, lead, mercury, zinc and tin [28].

2.2 Comparison of Bronze Castings from South India and Abroad

The excellence of the bronze icons that are cast by this method, has been compared with those produced in Europe. In Hadaway *et al's* treatise [29] titled "Illustrations of Metal Works in Brass and Copper mostly in South India", the authors observe: "The *Cire perdue* process which is commonly, it might be said almost universally, used for either simple or intricate work, in India, usually produces, when manipulated in western countries, a spongy and unsound casting almost impossible to work upon successfully and finish properly. In the west, when this process is used, the object is to obtain a casting, which requires as little finishing as possible, but it is always at the expense of the soundness of the whole mass, for to obtain the delicacy of the original wax model so fine, an earth must be used that it allows of no general ventilation of the mould. This finishing which the European hopes to avoid (but always at the expense of the soundness of the casting) by the *Cire perdue* process is, in India, taken as a matter of course." From this account we understand that the European casters laid more emphasis on not having to polish the icon after casting. In the process, the cast icon itself was not sound enough.

2.3 Metallurgy of Copper and its Alloys

There are over 160 types of copper minerals, and the commonly found copper ores are based mainly on sulphides. Copper ores are found in most parts of the world and they may be either at great depths which necessitates underground mining or near the surface, making open cast working possible. Apart from ancient India which had mastered the use of copper, artefacts found indicate that copper was widely available in the fourth millennium B.C. in Sumeria (modern Iran and Iraq), Israel and Egypt, the countries with which ancient India had trade, war and cultural linkage. Until the smelting of iron became popular, the adventitious presence of tin in copper led to the deliberate production of the tin bronzes around 2500 B.C.[30].

The copper minerals are associated with compounds of other metals of commercial importance, such as lead, nickel, zinc and smaller amounts of the precious metals, gold, silver and platinum group, which are worth recovering. It is also interesting to note that copper tends to collect with other metals in groups, particularly copper-silver-gold with arsenic, antimony and bismuth; copper-nickel-arsenic; copper-nickel-cobalt-iron and copper-zinc-lead, all associated with sulphur; copper-gold-tellurium with chlorine compounds. A typical analysis of a high grade product prepared after mineral beneficiation, flotation and concentration operation would be generally : copper - 50%, sulphur - 20%, iron - 10%, and silica - 12.5%, plus small amounts of alumina, magnesia and lime, with many precious metals present in the ore. The typical composition of the copper[30] along with the other metals after smelting operation from the high grade ore would be :

Metal		%
Copper	-	96 to 99.5
Silver	-	0.7
Gold	-	0.04
Iron	-	0.02 to 0.3
Nickel	-	0.01 to 0.8
Sulphur	-	0.01 to 0.2
Oxygen	-	up to 0.7
Lead	-	0.003 to 0.3
Zinc	-	0.002 to 0.2
Arsenic	-	0.004 to 0.2
Bismuth	-	0.001 to 0.003
Antimony	-	0.004 to 0.2

Copper of this purity would be too brittle and porous for any further fabrication or usage and must therefore be further refined. After refining [30] including a deoxidation step the typical analysis of the refined copper would contain :

Metal		%
Copper	-	98.5 to 99.8
Silver	-	0.02 to 0.2
Gold	-	0.001 to 0.03
Iron	-	0.001 to 0.03
Nickel	-	0.02 to 0.6
Sulphur	-	0.001 to 0.003
Oxygen	-	Nil to 0.3
Lead	-	Trace to 0.1
Zinc	-	not known
Arsenic	-	0.004 to 0.3
Bismuth	-	trace to 0.008
Antimony	-	Trace to 0.3

It should be noted here that inspite of high purity smelting/refining operations copper is always containing certain metals as impurities, in particular, one can note that arsenic could not be reduced even after the smelting/refining operations.

2.4 The Alloy Bronze and its Importance

2.4.1 Transition from Copper to Bronze

In the pre-Vedic period, there is evidence to show that pre-Harappan cultures have used copper to a certain extent. In the Harappan culture, metal workers knew the technique of using copper, bronze and lead, apart from silver and gold. Lost wax casting was not only known but was practised with a great zeal. Copper ore was obtained from Afghanistan and Rajasthan, while lead ore was obtained from Ajmer area [31]. Copper sheets were shaped into vessels and bronze was used for casting purposes, by the 'Lost wax' process. Among the tool specimens unearthed from Mohenjo-daro, 70% were found to be unalloyed (1% of tin) and 14% were alloyed (8-12% tin). From this it is inferred that Harappan metal smiths could not maintain the correct proportion of tin while alloying. Tin ores were known earlier than those of zinc. Thus the first alloy that would have been prepared was some sort of bronze and not brass.

Copper and arsenic (3-4.5%) alloy was also used by Harappans in the place of low-grade bronze. They knew the art of cold working and annealing of metals. Mention should also be made about Copper-Hoards, which are artefacts nearly a thousand in number, dating between 1700 and 1000 B.C. found from as many as 34 archaeological sites in India. These copper objects vary in form and can be classified into different classesm.[20]

The use of copper continued into the post-Vedic period and during the Classical Age (600 B.C. to 740 A.D.) Indian metal smiths achieved excellence in copper metal working during this period [32]. A solid copper bolt (over 61 cm in length and a circumference of 35 cm at the centre and 30 cm at the ends), found in the Rampurva Ashoka Pillar near Nepal border, reveals an advanced workmanship. In the Classical Age, the Chinese pilgrim, Hiuen Tsang, has given a description of how brass was being extensively used in India and has spoken of a huge copper image of the Buddha (24.2 m in height) and a brass temple being built by Harsha. A remarkable sculpture of the Classical Age, which sheds light on the copper metal-working of the time, is the huge statue of the Buddha (2.25 m in height and nearly a ton in weight), probably belonging to the fifth century A.D. This was unearthed in the ruins of a Buddhist monastery at Sultanganj in Bihar in 1864 by an engineer of the East India Company and is now in the Museum and Art Gallery of Birmingham. The statue appears to have been cast in two layers. The workmanship of coppersmiths is such that, through the veil of the statue, the physical form of the Buddha could be seen.

2.4.2 Choice of the Alloy - Why Bronze?

History of bronze age in North India seems to date from a far more ancient past. Study of copper and bronze history reminds us that metal workers certainly knew the distinct varieties of copper and its alloys. They also knew which variety was suitable for which application. They knew that crude copper had to be refined to ensure sound castings in closed moulds. Their knowledge included the role of arsenic and antimony to increase hardness, role of lead in increasing the fusibility of casting alloy etc. An interesting aspect about the icons under study is that most of them have been cast only in bronze. The reason for this could be many, the most important being [a] castability, [b] workability after finishing the casting, [c] polishability, [d] melting point of the alloy (requirement of large quantity of molten alloy) and of course [e] availability of raw materials, ore, etc.

From the *sthapati's*(T) point of view castability, workability, polishability and melting point should have been the overriding factors. The shine what one gets in bronze is generally not available in brass and other alloys that were prevalent in those times. This also should have been a major reason for choice of the alloying addition for obtaining the desirable results.

The other important reason is the scriptural command of the *Agamas(S)*, that prescribe metal to be used for casting idols for worship. For example, the ancient text *Agni Purana* states [33] that "one (image) made of wood gives greater merit than what is made of clay; one made of terracotta yields greater than a wooden one; one made of stone yields greater than (one) which is made of terracotta; images made of gold and other metals yield the greatest religious merit."

2.4.3 Composition of the Alloy - The Specifications

Though the term 'bronze' icons is used throughout the monograph, it must be mentioned that chemical analysis of the icons by the present and various other authors have shown that this usage may not be acceptable from a purely metallurgical viewpoint. Typical variations in composition is shown in Table - 2.2 and Table-2.3 respectively.

It is to be noted here that the tin content of the icons are insignificant in some cases. The significance of the metal objects examination was the trace element analysis which was considered to play an important role in the technical excellence of the bronzes. However, Dr. Hall of Oxford University points out as "our experience at Oxford in this field tended to show that such analysis are a waste of time" [4]. This was so because extensive melting and reuse of scrap leads to a blurring of trace element identity. Most of the samples are taken from or near the surface, and the expected drawback of such analyses is that with passage of time, the composition of alloying elements vary at the surface due to their extensive interaction with the surroundings. All the above points make the characterisation study of the icons a very delicate and difficult

Table - 2.2 Chemical composition of some icons [34]

Elements	9th century	13th century (Icon)	13th century (*Prabhavalli*)	16th century
Copper(wt%)	95.60	94.50	94.50	89.40
Tin(wt%)	0.88	1.10	1.80	3.40
Lead(wt%)	0.34	1.00	3.35	2.88
Iron(wt%)	0.13	0.05	0.10	0.52
Zinc(ppm)	15.00	40.00	103.00	2646.00
Antimony(ppm)	476.00	1747.00	5309.00	3095.00
Silver(ppm)	541.00	596.00	1659.00	823.00
Arsenic(ppm)	1295.00	1785.00	3341.00	1394.00
Nickel(ppm)	436.00	415.00	552.00	636.00
Bismuth(ppm)	85.00	164.00	503.00	351.00
Cobalt(ppm)	45.30	135.00	100.00	114.00
Manganese(ppm)	5.80	< 0.80	< 0.80	1.80
Total	100.20	97.10	99.80	97.10

job to be carried out.

At this juncture, it must be noted that in Tamil, majority of these icons are referred to as *'Cheppu Thirumaenigal'*, meaning icons made of copper (*'Cheppu'* in Tamil means copper and not bronze). Bronze is known as *'Vengalam'* in Tamil. The *sthapatis*(T) no doubt knew the existence of bronze alloy. If this is the case how did the term bronze icons come into force? We infer that the term 'bronze' icons is a misnomer, used universally to refer to these ancient south Indian icons. However, in the absence of a uniform nomenclature, the colloquial term 'bronze' is universally used to represent even icons made with varying compositions. We follow the tradition, yet point out the differences in the compositions. Also, the apparent variations in the composition of the alloy used for casting, (particularly in lead, or the presence or absence of zinc) as mentioned in this monograph, are due to differing sources of information and experiences of the *sthapatis*(T).

It is also mentioned [5] that most of the early bronze icons were made of either reddish or golden copper, with copper content being more than 90%. The quality and quantity of copper used declined from about 14th century A.D., with the knowledge of a number of alloying additions for achieving the desired charactmcs of the icon.

Now-a-days icons are also cast consisting *'Panchaloha'* ele-

Table 2.3 : Chemical composition of ancient bronze Icons

Bronze Icon	Period	Tin wt%	Lead wt %	Zinc wt%	Iron wt%	Arsenic wt%	Antimony wt%	Silver wt%	Nickel wt%	Bismuth wt%	Copper wt%
Pradosha Murthy	1200 A.D.	1.1	3.6	0.93	0.29	0.14	0.21	0.17	0.496	0.51	balance
Bhudevi I	1300 A.D.	5.0	5.4	0.79	0.27	0.24	0.22	0.725	0.512	0.114	balance
Bhudevi II	1200 A.D.	1.5	4.5	1.08	0.13	0.11	0.21	0.606	0.539	0.59	balance
Somas kandar	1200 A.D.	3.0	4.0	1.5	0.13	0.12	0.26	0.275	0.379	0.73	balance
Swamimalai Icon	1997	-	3.0	10.7	0.17	-	-	-	-	-	balance

ments. This term is derived from Sanskrit in which *"Pancha"* means five and *"loha"* means metals. *"Formerly, these consisted of the following metals which were considered to be auspicious - copper, silver, gold, zinc and tin or iron. Gradually however, gold and silver were deleted for obvious economic reasons, although even today a client may commission an image to be cast in the original five metals for special devotional purposes"[1,26].* The quantities of metal, wax and other raw materials required for each icon, as we mentioned earlier, depend on the size of the icon. According to the empirical approaches developed by these *sthapatis*(T), for every gram of various materials required to produce the wax model, 8 grams (gms) of metals were required (7.25 gms copper, 0.5 gms brass and 0.25 gms lead).

The bronze icons that are cast using the *lost wax* process can be classified broadly into two categories: those that are used (to be used) for worshipping and or *pooja* purposes and those that are cast mainly for display and ornamental purposes. The composition of the both categories contains copper 82%, brass 15% and lead 3% [1], whereas in the former category, gold and silver are added for ritual purposes in proportions depending on the quantity offered.

The exact composition of these alloys, determined as per the present day precise scientific studies are described in Chapters 6&7 on "Characterisation" and "Conservation", later in the monograph.

2.4.4 The Role of Gold and Silver or their Absence

Though gold and silvers were in use for a longer time as compared to copper, the *sthapatis*(T) chose copper alloy (bronze) for their castings. Though the composition of bronze is known to be varying, the *sthapatis*(T) could still achieve more or less consistent results in casting quality. That they could achieve this consistent quality of the product, through rigorous trial and sheer imagination, is a testimony to their perseverance and capability to excel.

The practice of using gold / silver for specific parts of the icon (such as face) has prevailed. This addition of gold/silver was only to specific parts in the icon, to improve their glow, lustre and finish to impart a strikingly beautiful look. However, as one can readily observe, to add a specific metal to a specific portion of the mould is indeed difficult. It is said [35] that the ancient *sthapatis*(T) achieved this feat by placing the mould horizontally, face down, in which a hole (to pour the molten liquid) is provided right above the facial region. Before pouring in the molten bronze alloy, the liquid gold/silver is poured from this orifice, in appropriate measure, which reaches the facial region instantly (since the mould is placed horizontally, face down). The casting, and the subsequent breaking of the mould, results in the icon which has more gold in its facial region. The face is thoroughly finished and polished leading to a consummate look. This practice is in existence to date.

Based on the scientific investigations by the authors themsleves and various others, it can be concluded that gold and silver are always added to the icons during the fabrication process due to ritual and traditional reasons. However, the variations that have been observed in the percentage of these metals could be due to :

1. Depending on the *sthapati*(T) and the purpose of the icon, use of gold and silver quantities varied. However, to add lustre to facial features and to enhance the divinity, these precious metals were added to the face through the horizontal casting process.

2. Icons made for the kings can be expected to have larger concentrations of gold and silver which would have been provided by the royal treasury in generous quantities. Similarly, icons made for worship could also contain higher percentage of gold and silver due to liberal contributions by the rich and the public.

3. Traditionally, crude copper itself always contains gold (<0.04 wt%) and silver (<0.7 wt%) as impurities. Through refining it has not been possible to remove these. Even the "electrolytically refined pure copper" developed after 19th century contains significant quantities of these elements. The percentage of these in the icons is thus bound to vary depending on the period and the type of copper used (origin through either ore or scrap).

In the context of the above description, we can appreciate the wide variations in compositions of copper alloys universally referred to as south Indian bronzes.

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Chapter 3

The Lost Wax Casting Procedure

Bronze castings (solid or hollow) were made by *'Cire Perdue'* or 'lost wax' process. *Cire* in French means 'wax' and *perdue* means 'lost'. The process in ancient Hindu scriptures, such as *Manasara* described in Section 1.2, has been referred to as *madhuchchishtavidhanam* (*madhuchchista* means bees' wax). The wax model prepared according to the *Agamic shastras,* served as the core of the operation and was 'lost' or drained out before the actual casting took its form after the model.

For this purpose, the object was first modelled in wax, then coated with clay. Next the wax was melted out leaving a mould behind into which the liquid metal was poured to cast a solid image. But if a hollow image was intended, the object would be first modelled in clay and then the core was coated with wax and in turn covered with clay. This was used for casting after the wax was drained out by heating. This method is also called the master technique. Thus, after the casting of an image, its mould is destroyed, with the result that no two specimens of bronzes are alike even if they are by the same *sthapati*(T). The making of images in this process is indeed laborious. But the importance of this method cannot be overestimated when it is realised that each item is characterised by a rare individuality and provides the possibility of continuous improvement, aesthetics and technology—a hallmark achieved by ancient *sthapatis*(T) as a matter of course and being advocated by modern quality management gurus like "Deming."

3.1 Measurements for Casting

The need to fabricate such intricate icons (which in most cases have complex geometry) in accordance to strict '*tala*(S)' measurement systems, forced the *sthapatis*(T) to utilise the process of casting rather than any other mode of fabrication.

The *tala*(S) can be considered as a specific system/set of measurements. There are a number of *talas*(S) such as the *Pancha* (five) *tala*(S) or the *Nava*(nine) *tala*(S). The overall structure, size and figure of the icon is arrived at based on the placement of certain dots as per the *Agama Shastras*. The inter-dot distance and the number of dots for a given organ or the icon as a whole is fixed based on the type of icons. These *tala*(S) systems are described in detail in the *Kashyapa Shilpashastra,* which is a tamil book used as a reference by the Swamimalai *sthapatis*(T). Another book that is used by the *sthapatis*(T) is *Chirppa Chennool* [36].

Tala(S) is the unit of measurement, which is the distance between the hair line and the gnathion. Each *tala*(S) is divided into 12 *angulas,* one *angula* being equivalent to the breadth of the finger. For making smaller icons required for private worshipping or *poojas,* the measurements were done in *angula* or inch units while for making bigger icons required for temples and public worshipping or *poojas* foot or 12 *angulas* were used.

The icons are divided into ten categories according to the ranges of their length, measured in terms of the *tala*(S) units. The largest icons belong to the category of *dasa tala*(S) (*dasa* means ten) and the smallest ones being to the category of *Eka tala*(S) (*Eka* means one). Within each of the *tala*(S) category there are three classes or measures which are termed *Uttama* (superior), *Madhyama* (intermediate) and *Adhama*(inferior). The *tala*(S) units, their classes and measurements are given in Table 3.1

Table 3.1 The Different *talas(S)*, their categories and measurements

Category	Class	Measurements in terms of Angulas
Dasa (Ten) *tala* (S)	*Uttama,*	124
	Madhyama	120
	Adhama	116
Nava (Nine) *tala* (S)	*Uttama*	112
	Madhyama	108
	Adhama	104
Ashta (Eight) *tala* (S)	*Uttama*	100
	Madhyama	96
	Adhama	92
Sapta (Seven) *tala* (S)	*Uttama*	88
	Madhyama	84
	Adhama	80
Shasta (Six) *tala* (S)	*Uttama*	76
	Madhyama	72
	Adhama	68
Pancha (Five) *tala* (S)	*Uttama*	64
	Madhyama	60
	Adhama	56
Chatus (Four) *tala* (S)	*Uttama*	52
	Madhyama	48
	Adhama	44
Tri (Three) *tala* (S)	*Uttama*	40
	Madhyama	36
	Adhama	32
Dui (Two) *tala* (S)	*Uttama*	28
	Madhyama	24
	Adhama	20
Eka (One) *tala* (S)	*Uttama*	16
	Madhyama	12
	Adhama	8

Each of the icons, such as *Vinayaka* or *Karthikeya* should be based on a certain *tala*(S) system of measurements, depending upon the size of the icon. However, in each category, whether an icon would be prepared according to the length laid down for *Uttama* class, *Madhyama* class or *Adhama* class is not arbitrarily decided. In the *Shilpashastras*, different classes have been assigned to the different deities and the dimensions of the icons follow the same. The icons of *Brahma, Vishnu*(S) and *Shiva*, the high gods of Hindu Trinity, are always made to the dimensions of *Uthama Dasa Tala*(S); Goddesses *Durga, Lakshmi* and *Saraswati* are made to the dimensions of *Madhyama Dasha Tala*(S); and other Gods like the *Ayyanars*, Shanmugha and the Nava Grahas (the nine planets) are made to *Adhama Dasha Tala*(S).

The normal practice of assigning different tala(S) to different other Gods, Goddesses and objects are summarised in

Table 3.2 The *Tala (S)* assigned to different Gods, Goddesses and objects

Name of the God / Goddess / Object	The Assigned *Tala (S)*
Minor Gods - *Ashta Vasus*	*Uttama Nava Tala*(S)
Celestial Nymphs - *Apsaras*	*Madhyama Nava Tala*(S)
Demons - *Asuras*	*Adhama Nava Tala*(S)
Mortals	*Ashta Tala*(S)
Devils	*Sapta Tala*(S)
Dwarfs	*Shasta Tala*(S)
Lord *Ganapati*	*Pancha Tala*(S)
Children	*Chatus Tala*(S)
Marginal Gods - *Kinnaras*	*Tri Tala*(S)
Marginal Gods - *Kimpurushas*	*Dui Tala*(S)
Marginal Gods - *Kurmam*	*Eka Tala*(S)

Table - 3.2. The proportions of the *Uttama Dasha Tala*(S) as laid down by the *Shilpashastras* are given in Table - 3.3.

The tala(S) system mentioned above gives information about the "length" of various parts and objects. The information about the "width" or the "girth" is also mentioned in detail in the *Shilpashastras*. These categories of guidelines are listed in Table - 3.4.

Table - 3.3 : The measurements of the *Uttama Dasa Tala*(S)

Various Parts of the Icon	*Uthama Dasa Tala*(S) Measurements in *Angulas*
Total length of the icon from the crown of the head to the foot	124
Length of the forehead	4
Length of the face from eyebrow to chin	13.5
Length of the neck	4
Length of the chest from the neck to the nipple	13.5
Length of the stomach from the nipple to the navel	13.5
Length of the hip from the navel to the pubis	13.5
Length of the thigh from the pubis to the knee	27
Length of the knee cap	4
Length of the lower leg from knee to ankle	27
Length of the foot from ankle to the bottom of the foot	4
Length of the upper arm from the top of the scapula to the elbow	27
Length of the lower arm from the elbow to the wrist	22.5
Length of the hand from the wrist to the tip of the middle finger	13.5

Table - 3.4 : The various other lateral dimension guidelines of the *Tala*(S) system

Category	Description
Mana	Relates to the proportion laid down for each measurement
Pramana	The measurement of the breadth or of the horizontal expansion of each image
Ummana	Relates to the thickness or depth of the image
Parimana	The measurement of the circumference of various parts of the figure
Upamana	The relative measurement of the different parts of the body from each other and from the line of axis
Lambana	The measurement of the surface elevation of different parts of the image

3.2 Lost Wax Casting—The Various Sequential Steps

What strikes the discerning observer of these bronzes is the methodology the ancient *sthapatis*(T) developed, probably over a period of several centuries, to arrive at the right combination of the metals to form the requisite alloy, the procedure for casting, and the repair and finishing technology. These metal-smiths had mastered the art of *Lost Wax* casting to such an extent, that the excellence of their craftsmanship had no contemporary competition from anywhere in the World.

The various sequential steps in the lost wax casting, as practised by the ancient *sthapatis*(T) are listed below:

a. Making of the *Odiolai*(T) (Plate 3.1)
b. Preparation of the Wax
c. Getting ready the wax model (Plates 3.2-3.5)
d. The making of the mould over the wax model (Plate 3.6)
e. Heating the mould, melting and draining the wax
f. Getting ready the liquid metal alloy and heating the mould to higher temperature
g. Pouring the liquid metal alloy inside the mould (Plate3.12)
h. Cooling the mould and opening it
i. Bring the cast icon outside followed by finishing, engraving and polishing (Plates 3.13 and 3.14) and
j. Installation and opening of the eyes of the icon.

These ten steps in the making of the cast icon, are exactly the same as practised in Swamimalai today and are described in the next section. However, the reader may observe that minor variations exist between these methodologies and those prescribed in the *Shilpashastra* texts (described in Section 1.2). These variations are not much in the actual method of casting, but on the rituals to be performed, before, during and after casting.

However, one ritual, which is not mentioned in the extracts from the *Shilpashastras* given in this monograph is the ceremony of "opening of the eyes" of the icon that is made. This is one procedure, not mentioned in the extracts of lost wax casting, yet followed in a rigorous manner.

3.3 Description of the Various Sequential Steps in Lost Wax Casting

The methodology of casting, as practised today at Swamimalai, is the same as that practised by the *sthapatis*(T) who cast some of the most beautiful and stylistic bronze icons of the ancient

Pl. 3.1 Use of *Odiolai*(T) for the purpose of fixing the various measurments of the Icon

Pl. 3.2 Shaving off excess wax from various parts of the Icon

Pl. 3.3 The basic wax model before fixing the hands

Pl. 3.4 Fixing the limbs(made separately) with the torso of the wax model

Pl. 3.5 A complete basic wax model ready for clay coating

Pl. 3.6 The first coating of clay using *Vandal Munn*(T)

Pl. 3.7 The mould from which wax is removed
(note the iron wires that strengthen the mould)

Pl. 3.8 Fuel for heating the crucible and melting the alloy

Pl. 3.9 The charge

Pl. 3.10 Various tools used during melting of alloy (tools for holding the crucible, mixing the alloy)

Pl. 3.11 The red hot pre-heated mould is buried under the ground with its mouth open

Pl. 3.12 The molten alloy is poured inside the red hot buried mould

Pl. 3.13 The icon, obtained after breaking the mould, is worked with to bring out the finer features

Pl. 3.14 The master *sthapati*(T) finally brings out the facial features with great care

south India. The various steps are described briefly in the following paragraphs.

a. Making of the Odiolai(T) : The *Odiolai*(T) is an indigenous, unique and precise measurement tool made from a strip of the coconut leaf (Plate 3.1). The reason for choosing this leaf was due to its stability in maintaining the measurement markings without any change even after it becomes dry. If any other leaf was used shrinkage of such leaves due to drying introduced significant changes in the measured markings. The making of the *Odiolai*(T) and how it is used for fixing the various dimensions of the icon are described in detail under the section on measurement systems (section 4.8). The length of the *Odiolai*(T) and the placement of the markings on it (made by foldings) are predetermined by the *sthapati* after determining the *tala*(S) to be used for the icon. In Plate 3.1, the master *sthapati*(T) is bench marking the *Odiolai*(T) he made with a standard scale for confirming the markings made.

b. Preparation of the Wax: Bees wax was mixed with *Kungilium*(T) or dammar (rosin powder) and groundnut oil in the proportion 4:4:1, and used for the purpose of making the initial model. Dammar was ground and mixed with groundnut oil. This was heated over an oven and converted into a thick liquid, after which, scrapings of bees' wax was added to it. After mixing this combination fully, this was sieved into cold water, and used for making the model of the icon to be cast.

c. Getting Ready the Wax Model: This is one of the crucial stages of the making of the icon. The prepared wax mixture is heated in hot water and lumps of it are used to make different parts of the icon. Excess wax is shaved off from these lumps as determined by the *Odiolai*(T) measurements (Plate 3.2). The experienced *sthapati*(T) uses his hands for obtaining the initial shape of the parts such as the icon's torso, limbs, head (with or without crown) and other accessories such as pedestals, etc. These parts are usually made separately and are joined together to get the final, yet coarse wax model (Plates 3.3 - 3.5). During the process of preparing the various parts and while joining them, a strict vigil is kept on the adherence to the *tala*(S) measurements. Scrapers and files are used to remove excess wax and for bringing out finer features on the wax model (Plate 3.4). Plate 3.5 shows a complete basic wax model made ready for clay coating. Care is taken to make sure that the model is made in such a way that wax would melt inside the mould as expected and would flow out easily without any obstruction. Wax rods and wax runners are used for this purpose and their number and sizes are determined by the size of the final icon.

d. The Making of the Mould: The making of the mould is the second most important step in the casting of the icon. In this step, the wax model is first covered with alluvial soil mixed with water. A number of coatings over this are subsequently given to the model using coarse soil, one over the other, depending on the size of the icon to be cast. Smaller icons may require two or three coatings while larger ones would require three or even four coatings. The mixture of clayey sand used for each of the coating is slightly different, starting from a very fine mixture for the first thin coating, and progressively becoming coarser and thicker for the second, third and fourth coatings. Successive coatings are applied, only after the previous coatings dry, after placing the mould in a shade so as to prevent the wax model from melting prematurely.

The first coating on the wax model is by far the most important coating of the mould. This is done using alluvial soil called *vandal mun*(T) obtained from the banks of the river Cauvery mixed proportionately with water[1]. This is applied on the wax model as a thin coating, by hand, while administering the right amount of pressure on the wax model. The first coating has to imbibe the finer details of the wax model, should never allow any air bubbles, and should withstand the heat of the hot liquid metal when it is poured into the mould. Hence, the first coating and its physical properties become very important. The alluvial soil collected from the river Cauvery plays a crucial role in determining the physical properties of this first coating. However, some *sthapatis*(T) use only the *vandal mun*(T) for the first coating [35].

The second coating is made with a coarser paste, with a type of sand called *padi mun*(T), obtained from the paddy fields and is mixed with sand in the proportion 1:2. This mixture is made with water to obtain a good paste. The third coating is also made with this mixture, after the second one dries.

If the icon to be cast is larger, then a fourth coating is also applied, which could even be reinforced with broken earthen wares/iron or steel wires, so as to impart the necessary strength to the mould. Plate 3.7 shows a typical mould strengthened using iron wires.

Initially the icon is placed on a bed of sand covered with a thin white cloth with its face facing the sky (Plate 3.6).

After covering the icon with the soil paste as described above on the frontal side, the assembly is dried under the sun, before it is overturned on the same bed of sand to cover the back portions of the icon. The soil coverings on the front and back portions are so done with precision that no partition is seen between the two after the entire operation is complete.

The mould is made in such a way that the opening for the wax to flow is not covered. In general two orifices will be present in the mould, one used to fill it with the molten alloy and the other to facilitate the removal of air from the mould as the molten alloy enters it.

e. Heating the Mould, Melting and Draining the Wax: The prepared mould is dried under the sun and then heated gradually to remove the wax from inside. Cow dung cakes are used for heating the mould. Depending upon the size of the mould, it usually takes between 30 minutes to 60 minutes of intense heating to melt the wax and remove it. The melted and outflowing liquid wax is collected through a chute, which is usually recycled after removing the impurities.

Once the wax is thus removed, the mould can be immediately used for filling with the molten alloy, or can be preserved for filling later on an auspicious date.

f. Getting Ready the Molten Alloy : Meanwhile, the alloy is melted in the right proportion as required. For every part (in weight) of the wax used, eight parts (in weight) of metal components is to be used, is the empirical formula practised by the *sthapatis*(T). The components of the alloy are placed inside a tumbler shaped crucible and is heated intensely for several hours. Plate 3.9 shows the charge used for obtaining the requisite alloy. As the initial metal scrapings melt, further scrapings are added till the required quantity of the liquid metal is obtained. Coke is also added to the molten alloy for deoxidation purposes. Air is blown in the furnace air using an electric blower. Cow dung cakes and coke (Plate 3.8) are used to increase the temperature of the crucible in the furnace. Fuel is constantly and regularly added to the furnace to maintain the required temperature.

g. Pouring the Molten Alloy Inside the Hot Mould: Prior to pouring the liquid metal alloy into the mould, the mould itself is heated to high temperatures, for three important reasons, namely [i] to prevent explosion of the mould when the high temperature liquid metal enters an otherwise lower temperature mould, [ii] to remove air bubbles fully and [iii] to prevent the liquid metal from cooling immediately upon entering the mould, thus ensuring the shapes that are dictated by the mould.

Once the mould is very hot, it is planted onto the surface of the earth, with its mouth (for receiving the hot metal) pointing upwards (Plate 3.11). Planting the mould onto the surface of the earth prevents the mould from cooling and also makes the mould immobile. When the red hot mould is planted onto the surface of the earth, it is done at an angle (and not vertically), so that the molten alloy flows into the mould and does not go directly to the bottom, thus avoiding splashing.

The liquid metal is held in the tumbler-shaped crucible with a strong pair of forceps and is poured into the mould in a thin stream through a funnel filter (Plate 3.12). The thin stream offers additional gap (apart from the second orifice) for the trapped air inside the mould to escape fully so that when the pouring is complete and the mould is full, there is no air gap/bubble inside the mould. During the process of pouring the liquid metal inside the mould, a sack pad is held at the beak of the crucible, so as to prevent slag and other floating impurities from getting inside the mould. The sack pad is held in a way to close the mouth of the crucible allowing only a small gap for the molten alloy to flow through. In this way, the outside cooler air is not allowed to enter the crucible thereby preventing the molten alloy from getting cooler.

h. Cooling the Mould and Opening it : The mould, once filled with the liquid metal, is allowed to cool for several hours before being broken. If it is required to break the mould earlier, it is quenched with water after cooling for a period of about three hours (though this is not recommended by the *Shilpashastras*) [36]. In ancient times, most of the castings were witnessed by the kings and at times the moulds were broken open immediately by fast quenching with water in order to expose the cast icon to the king before he leaves the place where icons were cast. *Sthapatis*(T) consider the breaking of the mould as equivalent to a true "birth" of the icon and hence pursue this process with due reverence. It was also said that the powder collected or the remains of the furnace were used as *vibhuti*(T) by those witnessing the casting as the icons of their Gods were made from such places. The portion of the mould that holds the head of the icon is broken first, to bring out the head of the icon first. The other portions of the mould are broken subsequently.

i. Bringing the Cast Icon Outside, Finishing, Engraving and Polishing: The cast icon that is removed from the mould is still crude. Clay particles that may be sticking onto the cast are removed. Connecting rods, support structures and protrusions are also removed. Finer aspects of the icon are brought out using chisels and a wide variety of scraping tools (Plate 3.13). Engraving tools are used to bring out ornaments and jewellery on the body of the icon, which is then washed in tamarind water and soapnut water to impart a shine on it. The icon is finally brushed with fine brass wire in order to polish it. Plate 3.14 shows the master *sthapati*(T) bringing out the most intricate feature on the important part of the icon namely the face of the icon. It must be mentioned that working on the face and enhancing its look is done mainly by the master *sthapati* and no one else. Once this stage is over, the icon is ready for installation.

j. **Installation and "Opening of the Eyes":** Installation and "Opening of the Eyes" are considered important ceremonies by the *sthapatis*(T) [36]. This step, however, is mainly for icons that are made for worship in a temple. The icons for which eyes are opened (the procedure is described below), are to be worshipped and for these icons daily *pooja* (prayers and offering) are mandatory. Those icons which are made for ornamental purposes or for purposes other than worshipping or installation in a temple, eyes are opened at the workshop itself by the *sthapati*(T) [8].

The steps involved between getting ready the icon and "opening the eyes" of the icon are listed in Table 3.5.

A few of the steps listed in the Table 3.5 are described below, as these are crucial steps in making the "Gods Come Alive !" in front of the devotees !

Before the cast icon is installed and its eyes opened, prayers are offered to the icon by the principal priest after placing nine types of precious stones on the body of the icon at its head, forehead, neck, chest, stomach, feet and hands. This prayer is called *Angaratnanyasa.*

The installation of the idol, i.e., the firm placement of the idol on the pedestal at the *sanctum sanctorum* of the temple, is in itself an important stage. The size of the pedestal and that of the *sanctum sanctorum* are carefully calculated and constructed. The central line of the pedestal, the central line of the *sanctum sanctorum* and the central line of the entrance to the *sanctum sanctorum* should all be on the same plane, which cuts the *sanctum sanctorum* and the entrance to it, into equal halves. The direction in which the installed idol looks is also decided based on strict *shastras* and tradition. Before the final installation, the idol placement is checked for any misalignment or slant. These are measured and their absence is ascertained using a plumb line.

Table 3.5 : The steps in installing and consecrating an Idol

a. Transferring the Icon from the *Sthapati*'s workshop to the temple.
b. To lay the Icon on a bed of cereals, covered on all the four sides by screens. This procedure is called *Dhaanyadhivasam*.
c. To take the icon, three days (five or even seven days, sometimes) before the consecration, place it in either a tank or a river, and offer prayers. If the icon is placed in a tank, then it is filled with clean water mixed with a variety of perfumes and sandal paste. This is called *Jalathivasam*.
d. To lay the icon on a bed with pillow, which is known as *Sayanathivasam*.
e. To make ready the pedestal, its position in the *sanctum sanctorum*, etc.
f. To place a number of cereals, chemicals and gems into the pedestal in a prescribed manner. This is known as *Bijanyasa, Dhatuniyasa* and *Ratnanyasa*, respectively.
g. Placing the icon on the pedestal. Checking for its accurate positioning.
h. Securing the icon on the pedestal, which is known as *Bhandana*. For stone icons the procedure is *Ashtabhandana* and for metallic ones, it is known as *Jatibhandana*.
i. Opening of the Eyes and Invoking the God by tapping at the body parts where the five senses are present.

The fixing of the idol onto the pedestal is in itself a very elaborate procedure. Before fixing the idol onto the pedestal, the pedestal itself is prepared in a manner that will allow placement of nine precious stones and cereals into it in a specific order. The type and nature of placement of these precious stones vary between *Saivaite* and *Vaishnavaite* idols. This order is shown below. The pedestal is designed to have nine smaller "pits" for placing the nine gems.

Topaz	Diamond	Sardonyx
Sapphire	Ruby (Maanickam)	Pearl
Cora	Emerald	Chrysoberyl

Placement of the Nine Gems for Saivaite Icons

Sardonyx	Pearl	Ruby(Maanickam)
Ruby (Padmaragam)	Topaz	Diamond
Sapphire	Emerald	Coral

Placement of the Nine Gems for *Vaishnavaite* and *Shakti (Kali)* Idols

Apart from these nine gems, nine types of chemicals (*Dhatuniyasam*) and nine types of seeds (*Bijaniyasa*) are also placed on the sides of the pits in the pedestal, before fixing the idol onto the pedestal.

Ashtabhandanam involves the grinding of certain well-known domestic chemicals, which when crushed in combination becomes a paste. This paste is applied between the idol and the pedestal. When dried, this paste becomes as hard as metal. *Jatibhandana* involves the securing of the (metallic) idol with the pedestal by pouring liquid gold (or silver) around the crevices of the icon-pedestal joint. This is later polished and finished in a manner that the idol-pedestal joint is invisible

When the icon is cast, the eyes and the eyelids are also cast, but the eyeball and the "vision" (i.e., the "look") are not cast. The ceremony "Opening of the Eyes", involves the procedure by which the *sthapati*, using a chisel made of gold and a hammer made of silver, carves these contours and makes the icon "look" at the world. Present day *sthapatis(T)*, however, may not use golden chisel and silver hammers. This procedure of "Opening the Eyes" is the same for both stone and bronze icons, though in the case of bronze icons, this ceremony is done at the workshop of the *sthapati* itself once, and again by the person who offers the *pooja* (*the poojari* or the head priest) at the temple, after the installation. For stone icons, this is done at the temple after placing the icon on a bed of offerings (cereals, flowers, jewels, etc.)

The "Opening of the Eyes" is done on an auspicious day and at an auspicious time. The right eye is opened first and then the left eye is opened. During this ceremony, no one except the *sthapati*(T) is expected to be near the icon. After the opening of the eyes, the *sthapati*(T) goes on to open the five senses and nine orifices of the human anatomy on the idol. Once the eye opening ceremony is over, there are prescribed things the idol should see, in a prescribed order. They are in the following order: back of a holy cow (the cow should be with its calf), green paddy sprouts, virgin girls, married women, nine types of cereals, mirror, *sanyasi*, vedic pundits, devotees, and finally the master. After seeing each of these, a screen is placed before the idol (so that the idol does not see anything in between) before the next thing is shown in the prescribed order.

The head priest then invokes the God (of the idol) praying Him/Her to reside in the idol, and then names the idol. After this the idol is considered fully installed and can be worshipped.

The ceremony of "Opening the Eyes" is very elaborate, full of religious connotations and only the most important aspects are mentioned here. For a full account of the ceremony, the reader is referred to the reference [36].

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Chapter 4

The Swamimalai Tradition: Some Observations on Present Day Casting

Though the rules and regulations laid down by the *Agamas(S)* are followed strictly in casting the bronze icons, the procedure itself has undergone minor changes with respect to the rituals, the tools used and so on, keeping in tune with the changes of the times. Swamimalai, which has thoroughly guarded the procedure and practice of icon casting using the *lost wax* process is no exception to these fine yet effective changes.

Some observations on present day casting procedure are detailed in this Chapter.

4.1 The Fuel

Present day *sthapatis*(T) use better fuel for heating and accelerate the process of heating by using electric air blowers. Coke is used as fuel today. About 8 tonnes of coke is used as fuel in an year in a normal workshop that produces about 36-60 bronze icons of varying sizes. Apart from this modification, all the other ingredients, their composition and methodology remain the same.

4.2 The Raw Materials

All the raw materials are obtained by the Swamimalai *sthapatis*(T) from the nearby town of Kumbakonam. The town of Kumbakonam is known for brass vessels. The raw material for making the icons are obtained from here as vessels (either old or new, depending upon the purpose of the bronze icon cast) in the case of brass and as coil wire in the case of copper.

The main raw materials used by the *sthapatis*(T) are listed in Table - 4.1 :

4.3 The Wax Used

The wax used for making the basic figure of the icon is bees' wax which is purchased from the nearby villages. To this *Kungiliam*(T) or (dammar) resin powder is added for binding purposes. It is made out of a resin obtained from the bark of the trees. For 1 kg of bees' wax equal amount of dammar and half a litre of groundnut oil is required. This is the basic wax used for making the main body of the icon, to which other ingredients such as the paraffin wax, candle wax and coconut oil are added depending upon the type or part of the wax

Table - 4.1 : Raw materials used by the *Sthapatis (T)*

Category	Raw Materials
Primary Raw Materials (Metals and Alloys)	Copper, Brass, Lead, Tin, Zinc, Silver and Gold
Secondary raw materials (wax model preparation)	Bees' wax, Dammar, paraffin wax, candle wax, groundnut oil and coconut oil
Tertiary raw materials (mould preparation and heating)	Charcoal, firewood,cowdung cake, metal wires, tamarind and clay.

figure made. In order to bring out the minute details in an icon, honey wax is added in equal proportions to this basic wax to obtain a soft wax. This soft wax enables the artisan to bring out very fine features such as intricate jewellery, clothes, hair styles, etc., of the icon.

The various quantities of the raw material required for the manufacture of icons depend on the size of the icon that is cast. However, as a thumb-rule, the *sthapatis*(T) of Swamimalai use 8-10 kgs of primary raw materials (metals and alloys) for every kilogram of the secondary raw materials used for preparing the wax model.

4.4 Solid and Hollow Casting

The icons that are exclusively kept for worship at temples or in other places are invariably made as solid casting whereas those needed just for display or ornamental purposes could be cast hollow. Similarly, in the icons that are cast for worship, no joints are allowed, whereas in those made for ornamental purposes, this is not a taboo.

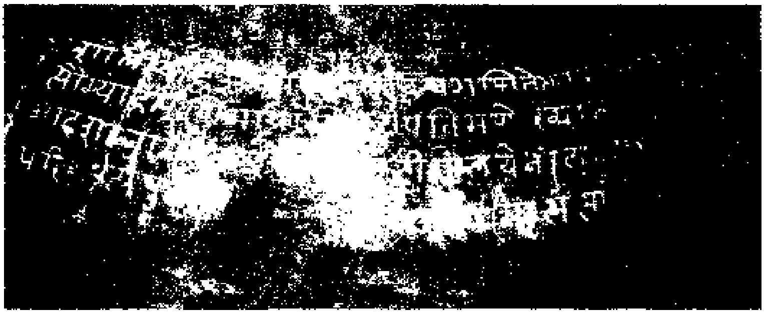
4.5 Defect Detection, Repair and Recasting

After the icon is cast, if some defects are found in the icon (by visual examination), these are corrected depending upon the location of the defect in the icon. If the defect occurs in one of the auxiliary -parts of the icon, such as the pedestal, jewellery, dresses, weapons and flowers, then the defect is repaired or recast to the extent possible without destroying the part. On the other hand, if the defect occurs in any part of the body of the icon that is being cast for worshipping purpose, then a new one is cast. The damage made on the body of the icon is considered as inauspicious and treated to be unworthy for worshipping. However, if a defect is observed in any icon that is being worshipped, then it is (and can be to the extent possible) repaired *in situ* with minimal alteration to the icon. The major type of defect that is encountered in the casting of these icons is the presence of the air bubbles in the cast figure. Though there are two openings made in the mould—one for pouring the hot metal and the other for the enclosed air to escape—many a time the flow of liquid metal may result in the entrapment of small air bubbles. In such cases, depending upon the extent of the defect, the type of icon and the purpose for which it is cast, the portion with the defect is recast/repaired locally or cast afresh.

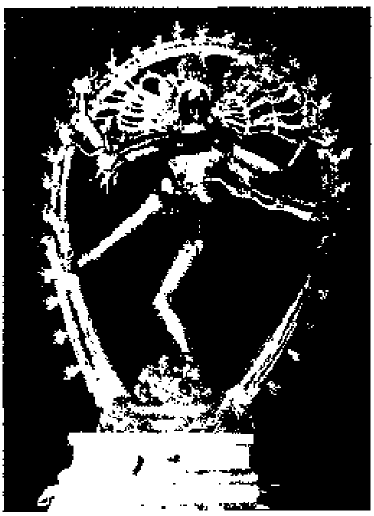
The thumb rule for *in-situ* repair of icons under worship is generally as follows: If the same defect were to be present in a human being whether he/she would live or not. If, for example, a limb is lost, the human being can survive. In this case, repair is permissible if recasting is not possible. If the body/chest/head is lost, the person would die. In this case, the icon has to be recast. It cannot be repaired.

The invasion of *Chola*(T) kingdom by others have made greater impact on the artistic and cultural aspects of that region. Islamic, Dutch, Danish, French and British invasions have also caused greater damage to the artistic icons and treasures preserved for many centuries. Many of the valuable icons and treasures were taken away from the *Chola*(T) kingdom to their respective countries or regions. Significant damages were made to the icons that were worshipped or displayed in galleries. Incidentally, many of the precious icons and treasures were preserved underground and other hide outs such that they were recovered at later stages for the purpose of worshipping and display. Natural conservation, as well as planned conservation steps taken while such icons were kept under soil or along with other preservatives, provided greater stability for such objects. Today, many of the excavations and accidental discoveries revealed such precious icons left by them during those days in an admirable look and with wonderfully developed aesthetic surface layers called *patinas* providing very high antique values.

A classic example of repair work is the *Adavallan* Nataraja idol, cast during the construction of the Brihadeeshwara temple in Thanjavur, by the great *Chola*(T) emperor, Rajaraja *Chola*(T) according to the epigraphic evidence of his kingdom during 995 A.D. This idol is still under worship in the temple. In the later part of 19th century, one of the legs of the idol broke. The king of Thanjavur at that time was Shivaji Rao II. His queen, Kamatchi Bai Saheb took interest in the idol during 1884 A.D. and requested that the idol be repaired [37]. A



Pl. 4.1 Inscription indicating the repair of "*Adavallan*(T)"
"Salivahana Sakam 1806 Dharana year, Wednesday full moon day, by the order of king Sivaji and the instructions of Smt. Kamatchi, the damaged portion of Adavallan (Naatharasan) idol at the Big Temple was examined, repaired and installed by Shri Nagarajan."



Pl. 4.2 Photograph of "*Adavallan*(T)" Icon of Thanjavur showing the snake under the Lord's feet

Sthapati(T) called Nagarajan of that time, repaired the leg and made an extra snake to curl below the Lord's feet in order to fill a probable gap and to give stability to the icon. There is an inscription in Marathi behind the *Peedam*(T) to give support to this information (Plate 4.1). The *prabhavalli* of the icon was also recast (which still shows a discontinuity). This idol is shown in Plate 4.2. This idol is probably the only one in the whole world which has a snake under its feet [8]. It is to be noted that in large Nataraja icons and other icons, the *prabhavalli* is further reinforced with an iron rod bent in a semi-circular fashion. Instances of this iron rod being exposed to atmosphere and getting corroded, damaging the *prabhavalli* have been often observed.

Recasting of icons for repair purpose is done in an interesting way. For example, if the right hand of an icon is broken due to some reasons, the mould is prepared only for that part and attached to the right arm. A hole is made from the shoulder of the right arm through the right hand until it meets the mould region. The molten alloy is poured from the top of the hole which completely fills up the mould and then also the drilled hole in the right hand up to the shoulder region. Thus a good joint is made between the existing portion of the right arm of the icon and the newly cast portion providing smooth transition between the repaired and recast regions.

4.6 Special Procedure for Finishing the Face

It is said that the face of any icon, as one can intuitively observe, is the most important part of the icon. While the rest of the body parts of the icon are made by most of the *sthapatis*(T), the shape and "look" of the face of the icon is finalised (both in the wax mould and also in the final metallic cast) by the most experienced of the *sthapatis*(T). Also, while the facial expression is made onto the wax mould or polished into the metallic cast, the artisan takes extreme care. In most cases where such intricate facial expression is to be brought to life on the icon, the artisan performs his job very early in the morning so as to apply his utmost undistracted attention in the best of his moods. This work usually starts early in the morning. Even in bringing about the best of facial features in the icon, it is said that the nose, eyes and the lips are the ones that demand the greatest attention from the artisan. It is mentioned [8] that the state of the *sthapati's*(T) mind is reflected on the face of the icon. The *sthapati*(T) contemplates the exact facial features, as per the *bhava* expected in the face, and carves it out on the icon by reciting and deeply involving himself with the *Dhyanashlokas* of the particular icon being made.

4.7 Colouring the Icons

Of recent interest is the phenomenon of colouring the icons, either to give different look to the icons or to make them look like old antiques. Several methods are adopted to impart a colour onto the surface of the icon. The popular colours that are imparted are green, black or copper-red. This is similar to the colours of *patina* discussed later in this monograph. It is known that *patinas* can enhance the beauty and value of the icons multifold. To obtain a green image, a mixture of equal parts of copper sulphate, ammonium chloride, ferrous sulphate are ground and mixed with groundnut oil and applied onto the image. Subsequently, the image is washed with water. For obtaining a black *patina* like appearance, the icon is immersed in nitric acid for a couple of hours and is then applied with a paste of soot from a kerosene lamp and melted candle wax. To obtain a copper red colour, ammonium chloride and red clay are mixed in the ratio 1:4, ground together thoroughly and applied. The icon is then washed with water, leaving a red colour on it. It must be mentioned that colouring was not a part of the ancient practice of casting bronze icons.

4.8 The *Odiolai*(T)

The *Odiolai*(T) is a strip of the leaf of a coconut tree (Plate 3.1), which is used as a tool for measuring and fixing the various dimensions of the icon that is being cast. The uniqueness of this indigenous "tape" is that, for fixing the dimensions of each of the icon that is cast, a new leaf-strip is used. The length of the leaf strip is the length (height) of the icon that is cast. If the height of the icon is more than that of the leaf strip available, then multiple leaf strips are used. Markings are made on it using one of the *tala*(S) measurement systems, and these markings are unique to the icon that is being cast, which is seldom repeated for casting another icon. Hence, a new leaf-strip is used for each and every icon that is cast, making each of the cast icons unique in their size and dimensions. This is in addition to the uniqueness that is built-in due to the fact that the mould of every icon is broken when the icon is brought out after cooling, thereby forcing the *sthapatis*(T) to make a new mould for every icon cast.

Markings on the *Odiolai(T)* are made by initially folding the leaf-strip into two and this process is continued successively so as to get a variety of markings in the proportions 2, 4, 8, 16, 32 and 64. These proportionate markings are used for fixing the dimensions of the various parts of the icon that is cast.

The uniqueness of these measurements lie in the fact that no two of the leaf-strips will be identical and nor will they be accurate by today's standards of measurement. Yet, this procedure, produces some of the most stylistic and perfectly proportioned icons.

In the case of sculpting in stones, the methodology of measurement is based on a measuring stick called *muzhakkol*(T) (*muzham* in Tamil means half of an arm's length and *kol* means stick). This system of measurement is slightly different from that of the *Odiolai*(T). However, in stone sculpting practice, one *muzham* is considered to be of several "finger widths". Different *muzhams* have different finger widths namely, 24, 25, 26, 27, 28, 29, 30 and 31. Each of the glorious temples in Tamilnadu have been built with a certain *muzham*(T) as the basic unit of measurement. For example, the Brihadeeshwara temple in Thanjavur is built on the basis of 24 "fingerwidth" *muzham*(T). The temple at Thiruvannamalai is also built on this basis. The Chidambaram temple has used the 25 "finger widths" *muzham*(T) as its basis. Unlike the *Odiolai*(T), which is used as the basis for the icon casting alone, the *muzham*(T) is used both as a unit of measurement for the stone sculptures and for the construction of temples. There are specific ways to fabricate a *muzhakkol*(T), which is slightly elaborate as compared to that of the *Odiolai*(T). However, the methods for calibrating the *muzhakkol* and that of the *Odiolai*(T) are nearly the same.

4.9 Size and Age of an Icon

As per the *Agama Shastras*(S), the size and the age of the icon are calculated using a number of parameters. This procedure has not undergone much change over the years.

The size of the icon is determined based on the presence or absence of certain matches in the parameters (match-parameters) of the properties of the star of the God for whom the icon is cast, the place of installation (the location of the *sanctum sanctorum*), name of the place and the star of the place, and the star of the *sthapati*(T), each calculated from the almanac. As we saw in the *tala*(S) system of measurement, the size of the icon also subsequently determines the various relative sizes of the organs in the body of the icon such as the forehead, shoulders, stomach, chest, limbs, foot, etc.

The science of the calculation of the size of the icon is called *Aayathi Kanitham* in Tamil. This science regulates the size of the icon through the match-parameters. A maximum of sixteen match-parameters are usually calculated and studied.

If all the sixteen match-parameters are matching favourably, then the match is called *Poorna Aayathi*. If ten of them match, then the match is called *Dasa Aayathi*. For six, it is called *Shatayathi*.

In casting icons that are to be used for worship in a temple, the calculation of these match-parameters is of paramount importance for the *sthapati*(T). Normally, *sthapatis*(T) look for the maximum number of best matches before embarking upon the determination of the size of the icon and the casting process. It is worth mentioning here that the matching of horoscope done predominantly in India, between prospective brides and grooms, is exactly equivalent to the matching process described here for icons (refer Chapter 6 in [36]).

The 'age' of an icon (not exactly the chronological age) is also determined using these factors and this 'age' is used to determine when the temple in which the icon is installed and the icon itself should be reconsecrated. The periodicity with which this is done is usually twelve years as per the *Agama Shastras*(S).

4.10 Tools and Artefacts as used by present day Metalsmiths

It must be mentioned that the tools and implements used by the *sthapatis*(T) are simple and their measurement systems are dependant and imaginative. Most of the tools are manufactured locally and none of the modern tools are used in the icon casting process, except a few electric blowers in the place of traditional blowers.

The various indigenous tools used by the *sthapatis*(T) (Figure 4.1) are listed in Table 4.2. Each of these tools have a definite purpose and the *sthapatis*(T) are skilled experts in using the right tools for the right purpose.

The *Odiolai*(T) is the most important tool of all and it has been described in detail in Section 4.8. The description of other tools and their uses are detailed in the following paragraphs.

The spatula is a flat spindle shaped tool, usually made from the core of an aged tamarind tree by the *sthapatis*(T) themselves, which is used for shaping the wax model to the required form and relief. The speciality of this tool according to the *sthapati*(T) is that it will not absorb or release heat while shaping the flexible wax. Knives are used at the time of wax modelling to remove unwanted portions of the wax model. These knives, usually made by the *sthapatis*(T) themselves, are made of straight or curved steel blades,

Table 4.2. The various tools used by the *Sthapatis*(T)

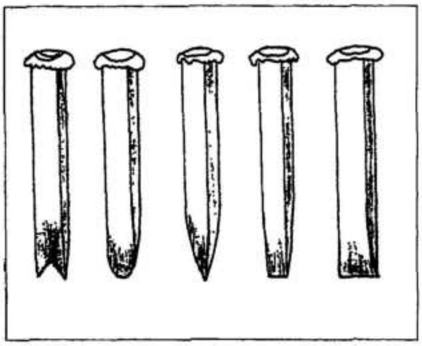
The Tools		
The Odiolai(T)	-	The leaf strip
Mezhuku Kuchi(T)	-	Spatula
Mezhuku Kathi(T)	-	Knife (to cut wax)
Seevuli(T)	-	Scrapper
Measuring Scale		
Mezhuku Thadi(T)	-	Foot Rule
A pair of Compasses		
Pathikkol(T)	-	Soldering Iron
Chuthial(T)	-	Hammer
Vettirumbu(T)	-	Chisel
Nagasi Pokka(T)	-	Engraving Tool
Aram(T)	-	Files
Koradu(T)	-	Forceps
Ulai(T)	-	Air Blower/Furnace
Kuvalai(T)	-	Crucible
Arippu(T)	-	Sieve
Metal Vessels to process wax		Funnel Filter
Mugatthuni (T)	-	Sack Pads

covered at one end by cloth to prevent the *sthapatis*(T) from hurting themselves. The handle of the knives are about 9 inches long while the steel blades are about 2 to 3 inches long. Steel scrapers are used by the *sthapatis*(T) to impart a sharper relief on the wax model. These could be without handles and could be as long as 9 inches.

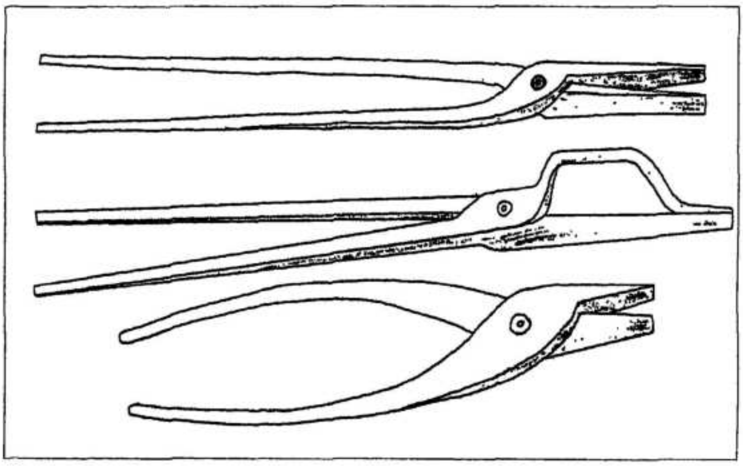
The measuring scale, the foot rule and the pair of compasses are usually bought from the local markets. They are used for measuring, preparing wax plates by rolling and for drawing circles on the wax plates, respectively.

The soldering iron is not an electrical one, but consists of an iron rod fixed in a wooden handle. This iron rod, heated over a stove (fired by charcoal) and is used to melt the edges of wax parts locally, in order to fix them onto other parts to make joints (such as the joint between the shoulder and the upper hand) of the wax model.

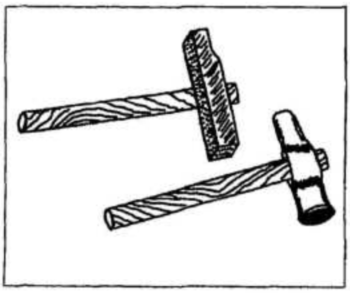
Hammers of different sizes are used to give final shapes to the cast icon. The heavier hammers are used to fix the icon to the pedestal while the lighter ones are used for chiselling and engraving. Chisels are used for cutting unwanted metal rods



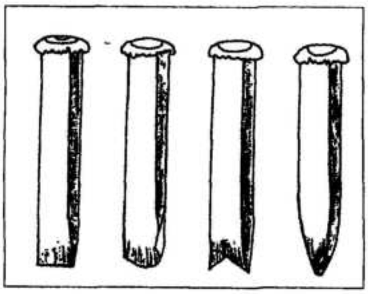
A. Types of engraving tools



B. Large forceps used to handle the crucible



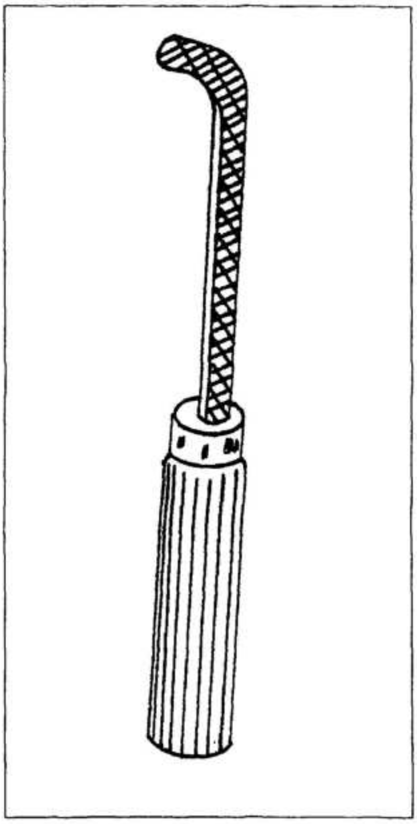
C. Types of hammers



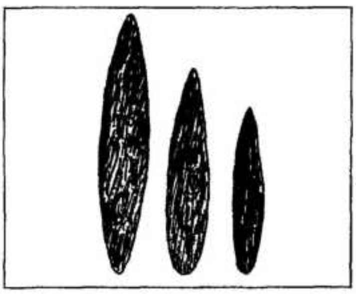
D. Types of chisels

Fig. 4.1 Various indigenous tools used by the *Sthapatis*(T)

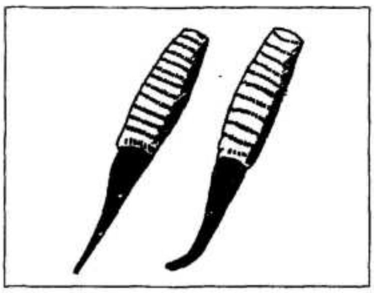
(contd.)



E. Pathikol(soldering iron)



F. Mezhuku Kuchi



G. Mezhuku kathi

Fig. 4.1 Various indigenous tools used by the *Sthapatis*(T)

after the icon is cast or for bringing out the reliefs in the body of the icon. Chisels of various sizes and tips are used for specific purposes. Chisels are used along with the hammers for cutting and shaping cast icons. The engraving tool, made of steel, is used for making various designs on the surface of the cast icon. These engraving tools are used in the same manner as the chisels.

Probably, the only change that has occurred in the tools side, is the use of automated air blowers for the furnace. The ancient *sthapatis*(T) who enjoyed royal patronage, were using leather blowers, which are worked by the human hand. Later on, *sthapatis*(T) used mechanical blowers that were powered by turning a large wheel, like that of a cycle. Currently, electrical blowers have replaced the leather and mechanical blowers. Plate 3.10 and Figure 4.1 show some of the tools used during melting of the alloy (tools for holding the crucible, mixing the alloy, kindling the fire, etc.).

Earthen or pyrite crucibles, purchased from Rajmundhry of Andhra Pradesh state, are used for holding and pouring the

Table- 4.3 : Origin, characteristics and properties of the clay used by the *Sthapatis*(T)

Name of the Clay	Origin	Features
Vandal Mun(T) (*Mun* means Alluvial soil)	Banks of the river Cauvery; Mixed with water; Applied in the first thin coating	Imbibes the very fine aspects of the wax model; should retain its form, when the wax melts away; should be strong enough to withstand high temperatures, even when the liquid metal is poured inside the mould and cooled fastly.
Padi Mun(T)	Taken from the paddy fields; Mixed with coarse sand and water; Applied for the second and subsequent coatings	Should be strong enough to protect the integrity of the mould during wax removal, heating the mould to red hot temperature and no cracking should occur when the liquid metal is poured inside the mould or when it is cooled fast.

molten metal or alloy. These are handled using large forceps. These crucibles are shaped in a manner that look like a tumbler so that they can be placed into the furnace easily. These crucibles have beaks that aid easy flow of molten metal into the holes of the hot mould, without spilling.

Sieves are used for sieving the molten wax. Though metallic sieves are available, a majority of *sthapatis*(T) still prefer cloth ones. Metal vessels are used mainly for processing the wax and to collect molten wax that emanate from the heated mould.

The funnel filter is a metal ring with a piece of cloth sewn around it. It serves as a funnel through which the molten metal is poured into the hole of the earthen mould. The sack pads are made of discarded jute bags. These are held at the mouth of the crucible (in between the crucible and the hole in the earthen mould) in order to prevent any of the slag or floating impurities from entering into the mould. The sack pad is a very simple gadget and it is rather fascinating that it is capable of preventing any floating impurities from entering into the mould. The sack pad is held in position by a person with the help of an iron/wooden rod.

4.11 The Clay

As mentioned earlier, the clay that is used for making the moulds, have different origins and properties, depending upon the coating for which they are used. A summary of their origins and features are given in Table - 4.3.

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Chapter 5

Scientific Investigations on South Indian Bronzes

(Baldev Raj, B.Venkataraman* and V.Jeyaraj**)*

It can be observed from the previous chapters that most of the ancient science and technology of casting the icons was rather qualitative, empirical and adhoc with rather small amount of theoretical underpinning. None had thought of formulating a procedure and deriving the precise flow-chart which could then be tested and implemented. One reason for this could be that in those times, to take things out of their normal context and to study them probably appeared to ancients as violating the religion. In the absence of these procedures of formulating and validating understanding i.e. the scientific method, it is very hard to make systematic progress and to discard or improve upon any particular practice. As Whitehead once said, "The essential discovery of modern science was the scientific method itself". It is the appreciation and practice of scientific method which in the modern context, is considered to lead to the progress of science. However, the science and technology of South Indian bronzes is heuristic and empirical, but rigorous in practice to achieve consistency and excellence.

South Indian bronzes are scientific and art marvels which reflect the rich cultural heritage of our country. Scientific investigations on objects of cultural heritage are undertaken with a variety of objectives in mind. The most important of these include :

1. Understanding the style, period, structure and metallurgy of these icons so that India's rich technological history is understood.
2. Assess the condition of the icon to help in restoration and conservation.
3. These bronzes famous for their aesthetic beauty and excellent craftsmanship are prone to thefts. These investigations help in scientific and comprehensive fingerprinting of icons needed for documentation and authentic identification when they are retrieved.

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** Government Museum, Chennai

Figure 5.1 summarises these multifaceted requirements which require an integrated approach. The most conventional approach which can give solution to all the requirements indicated in the figure is through the use of Non-Destructive Testing (NDT) techniques. NDT techniques as the name implies are techniques that have been developed to determine the quality of components without causing any harm to them. A variety of NDT techniques are available today, which are being successfully employed in various industries to assess the quality and to ensure the integrity, safety and reliability of plants and components. A few of these techniques have also been successfully applied for the investigation of objects of cultural heritage such as sculptures, paintings, monuments, etc., world wide. Table-5.1 below lists some of the major NDT techniques used for investigations on objects of cultural heritage and their capabilities.

In the western world, objects of cultural heritage mainly comprise of stone sculptures, paintings, coins, silverware and potteries. Bronze objects are few compared to what we have in our country. NDT techniques have been widely used mainly as a tool to aid restoration and conservation applications. In Italy [38]:

Table - 5.1 Major NDT techniques used for investigation of art objects

Sl No.	Techniques	Capabilities
1.	Precision Phototgraphy	Dimensions measurements and record of intricate details
2.	Holography	3-D Characterisation
3.	Moire Fringes	Contour Mapping
4.	Laser Excited Emission Spectrometry	Chemical Assay
5.	Mass Spectrometry	Chemical Assay
6.	Activation Analysis	Trace Analysis of Elements
7.	X-Ray Energy Spectrometry	Chemical Composition
8.	In-situ Metallography	Microstructural Characterisation
9.	Radiography/ Tomography	Internal Defects, Joints, Repair regions
10.	Physical Parameters Thermal emf. Electrical Conductivity, Hardness	Characterisation of Materialand Thermo-mechanical treatment

a. X-ray fluorescence has been used on paintings such as "S Paolo" to study the type of paints and pigments used by the artist.
b. Gamma ray gaging has been used for assaying the composition of silver coins.
c. Holography has been used on "Capitolinian Horse" to identify the areas sensitive to environment stress.
d. Radiography has been used on "II Pugilatore (The Boxer) of Ist century BC" to define the constituents, identify the sequence of fabrication and repair and document typical flaws and their causes.

Computerised tomography has been used at the BAM institute, Berlin in Germany [39] to:

a. investigate the fillings in an excavated coin treasure jug from Switzerland
b. investigate Damascus swords
c. simulate the reconstruction of the Head of Egyptian queen Teja

Apart from these, other interesting investigations include :

a. radiography of the famous Liberty Bell to characterise the crack that had occurred in it before the restoration of the bell could be undertaken [40];
b. authentication of Roman silverware by radiography [40]; and
c. digital radiography and computed tomography of ancient Chinese cast bronze at the Cincinnati Art Museum in Ohio [41].

In India, as part of the DST project on fingerprinting of ancient South Indian *panchaloha* icons, a number of icons pertaining to the period between 9th century and 16th century A.D. belonging to the Pallava, Chola and Vijayanagara periods have been studied. Of the above mentioned NDT techniques, four have been identified as the major ones to be used for investigation, namely precision photography, X-and gamma radiography, X-ray emission spectrometry and *in situ* metallography. While precision photography maps the overall icon and its intricate external features, radiography records the internal details, typical flaws and also provides information on the constituent and morphological elements and sequence of fabrication and repair. X-ray emission spectrometry provides information on the chemical composition of the icon while *in-situ* metallography characterises its microstructure. Thus, on the whole, an icon is fingerprinted by the use of

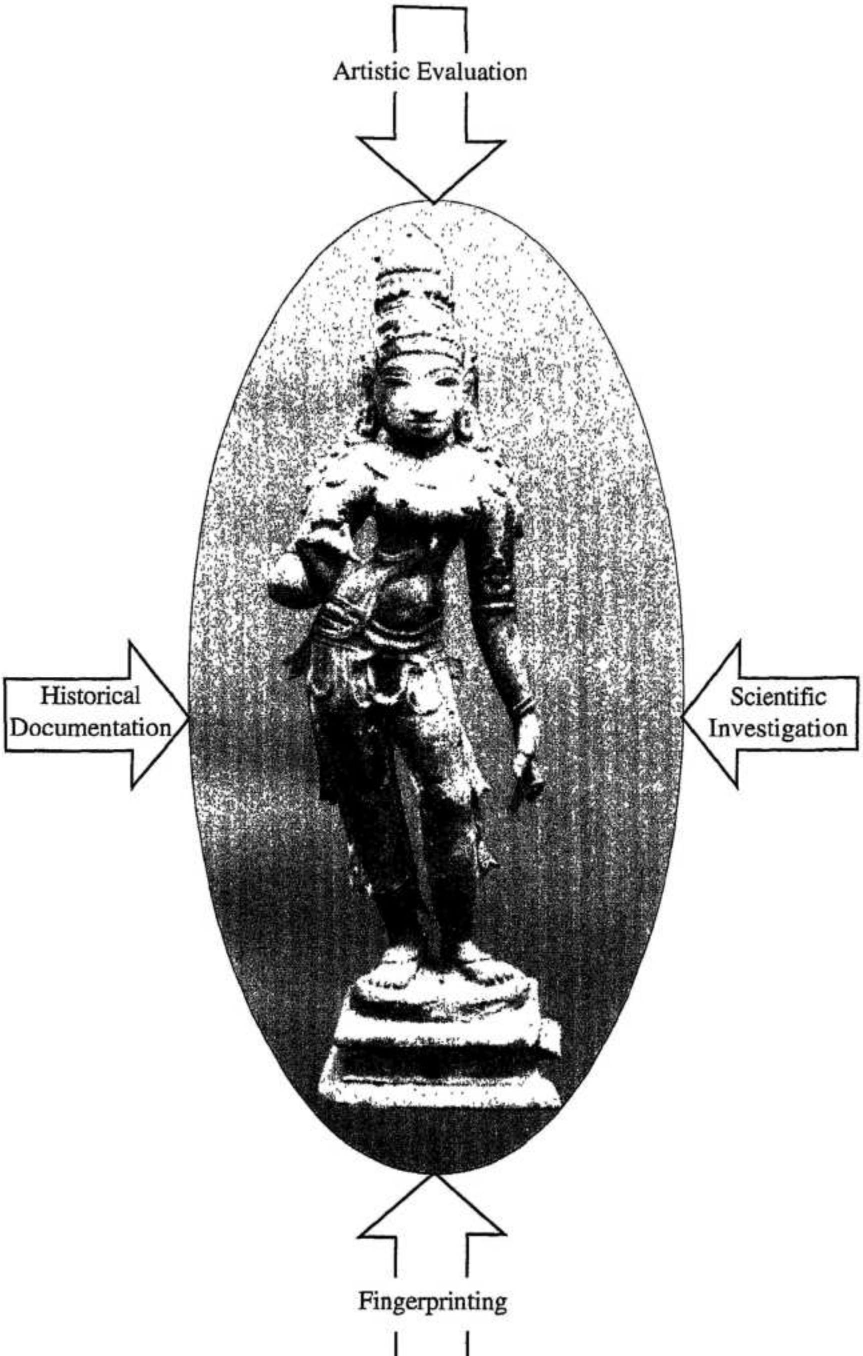

Fig. 5.1 Integrated approach to characterisation of South Indian bronzes

Table 5.2: Physical Description of some of the Icons

Sl No.	Idol	Excavated From	External Features
1.	Srinivasa	Kanchipuram	Standing on a double *padmasana* over *abhadrasana*. Nose is chipped off. Conch is broken and missing
2.	Bhudevi	Yenampalan, East Godavari Dist	Standing in Tribhanga pose. Holding lotus in her right hand. Wears larger makuta.
3.	Ayyanar on the elephant	Kandiyur	Seated on an elephant with four tusks and an attendant at the back. Seated in most traditional way. Ankusa present in the right hand. Usual image.
4.	Sridevi	Trichy Dist.	Standing on a round pedestal over a *bhadrasana*. Usual pose, Breast band present.
5.	Crawling Krishna	Vellore	Crawling with *kondai* on the head. Usual pose.
6.	Ayyanar	Kuhanur Thanjavur Dist	Standing on a round pedestal. Sharp nose. Fan like hair arrangement is present. One row of necklace and sacred thread present. Two hands. Lower garment is ornamental.
7.	Devi	Kandirathirtham Trichy Dist	Standing on a lotus pedestal over a square *bhadrasana*.Hair is arranged like a *kondai*, sharp nose. Two rows of necklaces present. Two hands, ornamental lower garment present.
8.	Sita	Madras	Standing, hands are not proportional . The anatomy is stiff. The drapery and ornaments are heavy.


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Pl. 5.1 Photographs of some of the investigated Icons
(for description see Table 5.2)

these techniques. Detailed analysis of these results also provides a deep insight into the metallurgical practices of yesteryears and helps overcome many a misnomer. The other techniques such as conductivity and hardness measurements lend a supporting hand in the investigations and lead to a better understanding and appreciation of the technology.

More than about 100 icons have been investigated in the current project. Precision photographs were taken using a monorail large format camera. The photographs and scaled grids superimposed on the icons were used for reference in all subsequent investigations. While it would be difficult to present the results for individual icons, detailed analysis of the results has revealed that many of the observations can be generalised. The photographs of some of the icons that have been investigated are presented in Plate 5.1. A brief description of these icons is given in Table - 5.2.

5.1. Results of NDT Investigations

5.1.1 Radiography

Icons are basically cast structures. During the process of casting, discontinuities or flaws are likely to be created due to a variety of reasons. Radiography is the best technique for the detection of internal features/flaws in castings. Depending on the casting process, the location of the defects if formed would be different in different icons. Thus, these defects can serve as authentic fingerprint of an icon. Duplication of these defects is not possible as the probability of the defect occurring in the same location and with the same geometric contours

Radiography is one of the oldest and most widely used non-destructive testing (NDT) methods. In this method, a source of penetrating electromagnetic radiation such as X-rays and gamma rays is used. When such electromagnetic radiations pass through an object, they are differentially absorbed. The amount of X-rays/gamma rays absorbed depend on the nature of the object and its composition. Variations in the beam intensity are detected by a recorder, normally a special photographic film called radiographic film. The image is seen as difference in optical gray levels and the developed film is called a radiograph. For a given exposure, a void would appear darker since more X-rays pass through while a tungsten inclusion will appear to be light since lesser X-rays will pass through it on account of its higher density. The technique of radiography is thus a two dimensional shadow projection of the internal details in an object. The schematic shooting sketch for radiography is given in Figure 5.2 and the setup for radiography of icons is given in Figure 5.3. The method is ideally suited for the detection of volumetric defects such as voids and porosities. With the advances in electronics and software, it is possible today to enhance the radiograph by image processing techniques so that finer details that can be missed by human eye can be revealed and the features in the radiograph quantified.

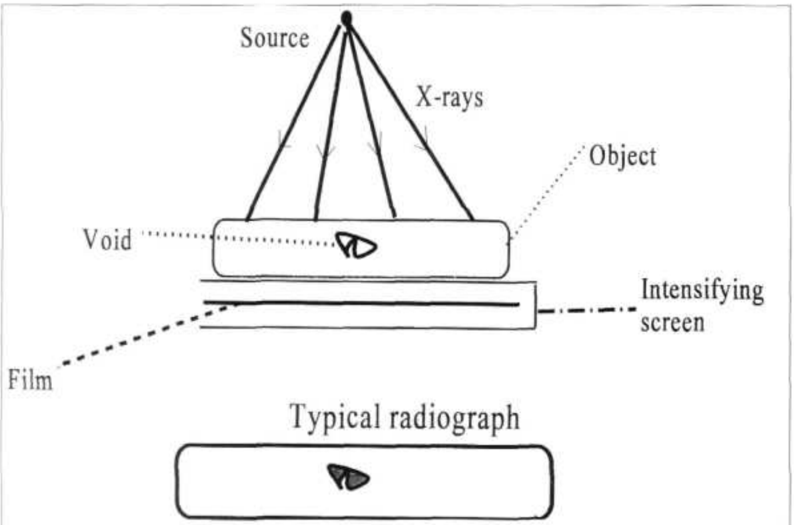


Fig. 5.2 Schematic sketch of radiography technique

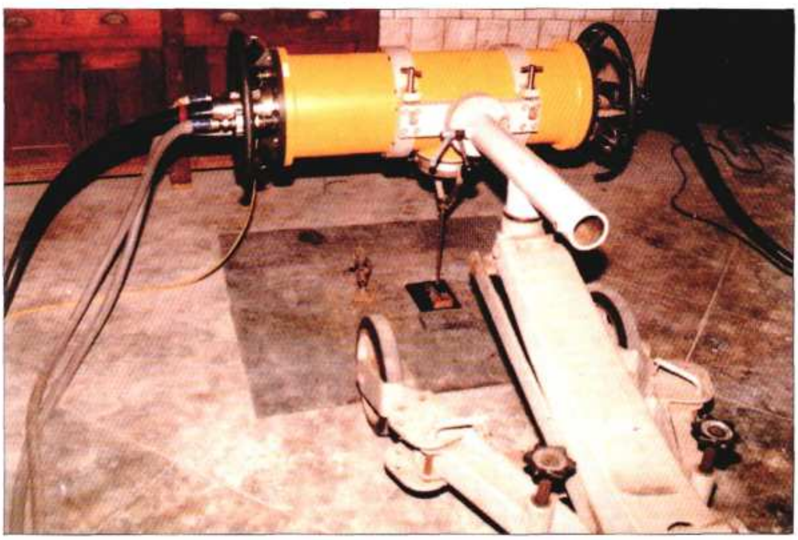


Fig. 5.3 The radiographic set-up

Table 5.3 Thickness of various parts and the radiography parameters

Sl. No.	Part	Thickness (mm)	kV	mA (min)
1.	Crown Top	20	150	25
	Bottom	26	160	30
2.	Chest	30	180	30
3.	Leg-Top	26	160	30
	Bottom	13	130	25
4.	Hand -Top	21	150	28
	Bottom	12	120	40
5.	Dress	5	100	4

and area is remote if not impossible. Apart from serving as fingerprints, the radiographs also serve as an indicator of the quality of the castings. A typical icon has an intricate and complex shape with wide thickness variation and presents an interesting challenge to any radiographer. To give an example, Figure 5.4 is the photograph of a 9th century *Vishnu(S)* icon belonging to the *Pallava* (T) period. Table-5.3 gives the thicknesses of the various parts and the radiography parameters. It can be observed from the Table 5.3 that the radiographic exposures range from 100 kV to 180 kV. Apart from this, each part of the icon to be radiographed has to be appropriately positioned with respect to the radiation beam for best detection of the internal features. Figure 5.5 is the positive print showing the radiographic outline of a 9th century vishnu icon.

Each icon that has been investigated is unique in its own way and necessitates individual standardisation of exposures and techniques. Detailed analysis of the radiographs of all the icons reveal many common and interesting observations

1. Most of the icons radiographed had very little defects in their main body. This is a pointer to the fact that the *sthapathis(T)* of yesteryears had mastered the technology of lost wax process to perfection. This was also passed on by them to their next generation as revealed by the radiographs of the icons right from the 9th century to till date.

2. Defects, if any, in an icon were mainly porosities. Such porosities were observed predominantly in the thinner portions of the icon such as the *Vastra(S)* in between the legs, ear lobes etc. Typical pore sizes range from 0.1 mm to about 10 mm in diameter. Figures 5.6-5.8 are typical porosities detected in the icons.

Fig. 5.4 Photograph of a 9th century *Vishnu*(S) Icon belonging to the *Pallava* period

Fig. 5.5 Positive print of a radiograph

Fig. 5.6 Porosities in the earlobe

Fig. 5.7 Porosities in *Vastra(S)*

Shrinkage cavities were also observed in a few icons. Figure 5.9 (a) is the positive print of one of the radiographs indicating the presence of cavities in the stomach portion. Figure 5.9 (b) is a processed image while Figure 5.9 (c) is an edge enhanced version. Edge enhancement helps in the delineation of edges which are necessary for quantitative estimation. Both porosities and shrinkage cavities can be used as fingerprints for the icons.

3. As observed earlier, the main body of the icon was practically of very good quality. However, the base (pedestal region) and other structures such as the *Prabhavalli(S)* were not of the same quality. Figures 5.10 and 5.11 indicate the typical porosities and cavities observed in the pedestal region and the *Prabhavalli(S)* of the icons belonging to 15th and 13th century respectively. This is also an indirect pointer to the fact that while the *sthapati* took meticulous care and concentrated in casting the main body, he was less concerned in his approach for the fabrication of other ancillary parts/structures. It can also be inferred that while he did the casting of the main body, the other parts such as *Prabhavalli*(*S*), pedestal etc., could have been cast by his students/juniors or those under his guidance.

4. In practically all the bigger icons, it has been observed by radiography that the main body of the deity, the pedestal and associated features like *Prabhavalli(S)* etc. were cast independently and were subsequently forge welded. Joints between the body and the pedestal were revealed in the radiographs. It was observed that reference studs were used to facilitate the alignment of the red hot individual parts of the icon during forge welding. Figure 5.12 is the radiograph in which the stud is clearly revealed in the base of 13th century *Vishnu(S)* icon.

5. While all the icons had solid body, one small size icon was found to be hollow inside. It appears to have been cast in that way intently. Figure 5.13 (a) shows the photograph of the icon and Figure 5.13 (b) gives the positive print of the radiograph.

6. In general it appears that the main body of the icon is cast and subsequently the other features such as conch, *Sudarshanchakra* (in case of *Vishnu*(S) icon), *Prabhavali*(S) etc., are added. This could be made out in all the radiographs by the density difference.

7. Radiography also reveals if the icon has undergone repair at a later stage. Figure 5.14 is the photograph of icon belong-

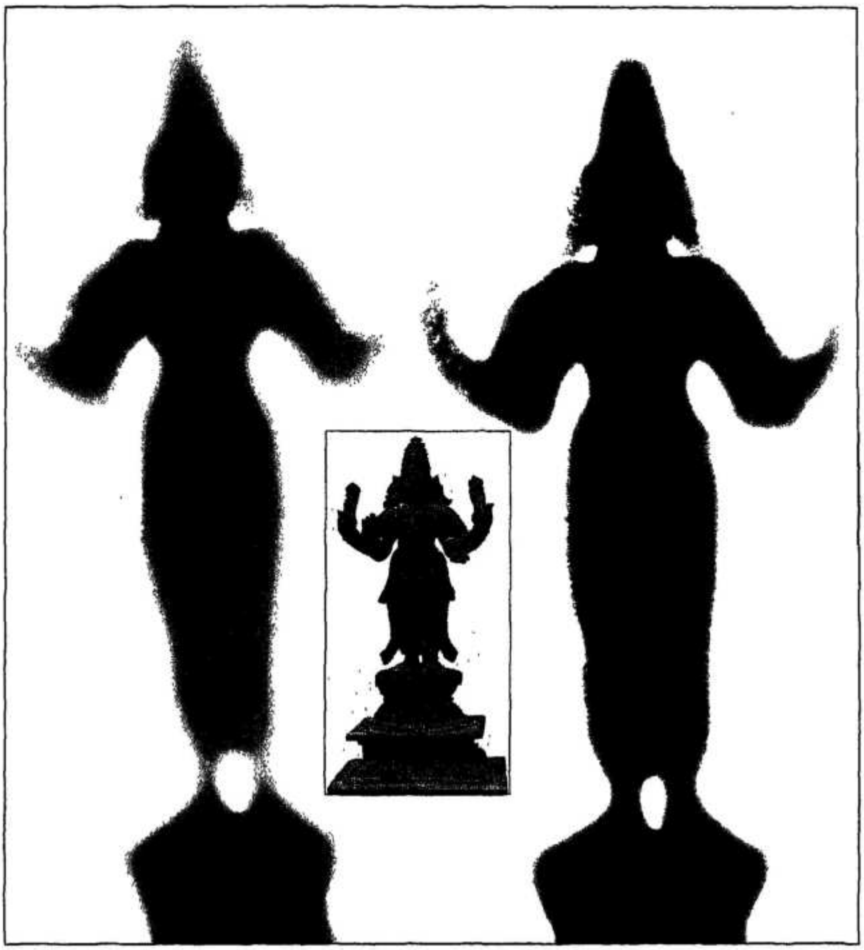


Fig. 5.8 Positive prints of Subrahmanya Icon with porosities throughout its body (photograph of the Icon is in the middle)

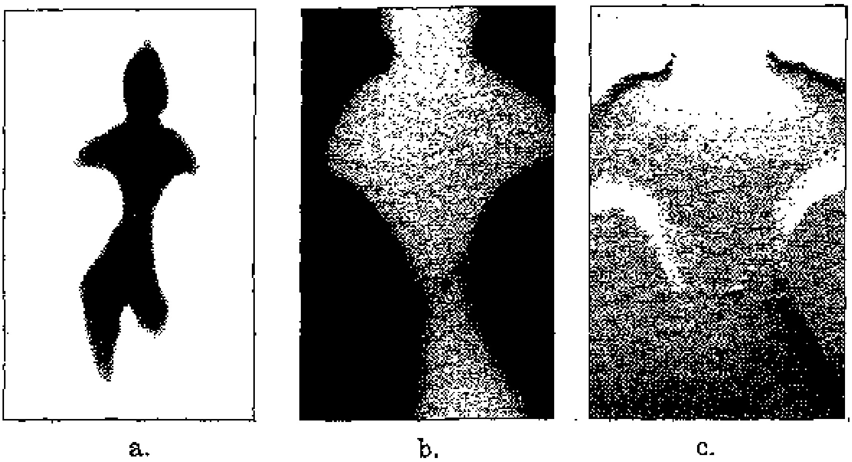
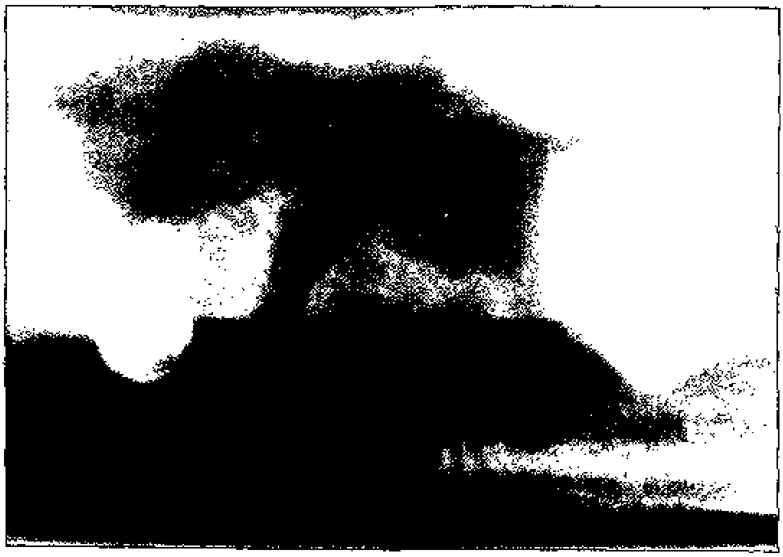


Fig. 5.9 a. Positive print of radiograph indicating cavities
b. Image after averaging and contrast stretching
c. Image after edge enhancement



5.10 Porosities and cavities in the pedestal region of an Icon

Fig : 5.11 Porosities in the *Prabhavalli* of a 13th century Icon

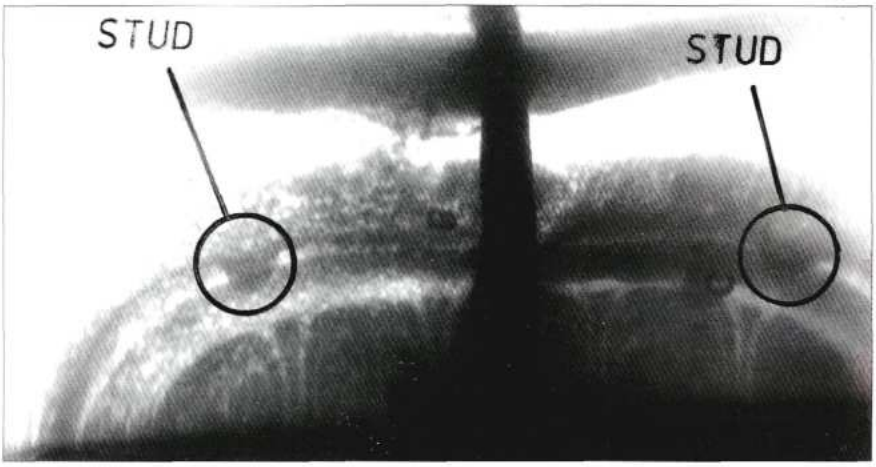
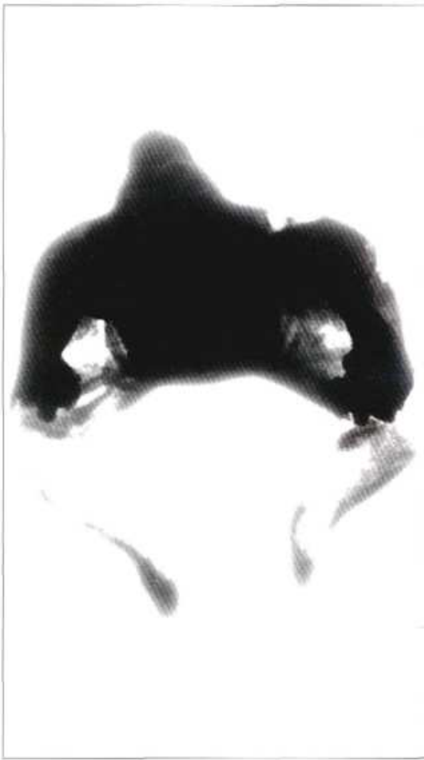


Fig : 5.12 Positive print of the radiograph showing reference studs

(a)



(b)

5.13 (a) Photograph of the hollow Icon
(b) Positive print of the radiograph

Fig 5.14 Photograph of Icon. (Emphasis on the head gear)

Fig 5.15 Positive print of radiograph (note that the head gear appears incomplete due to lower density material used during repair)

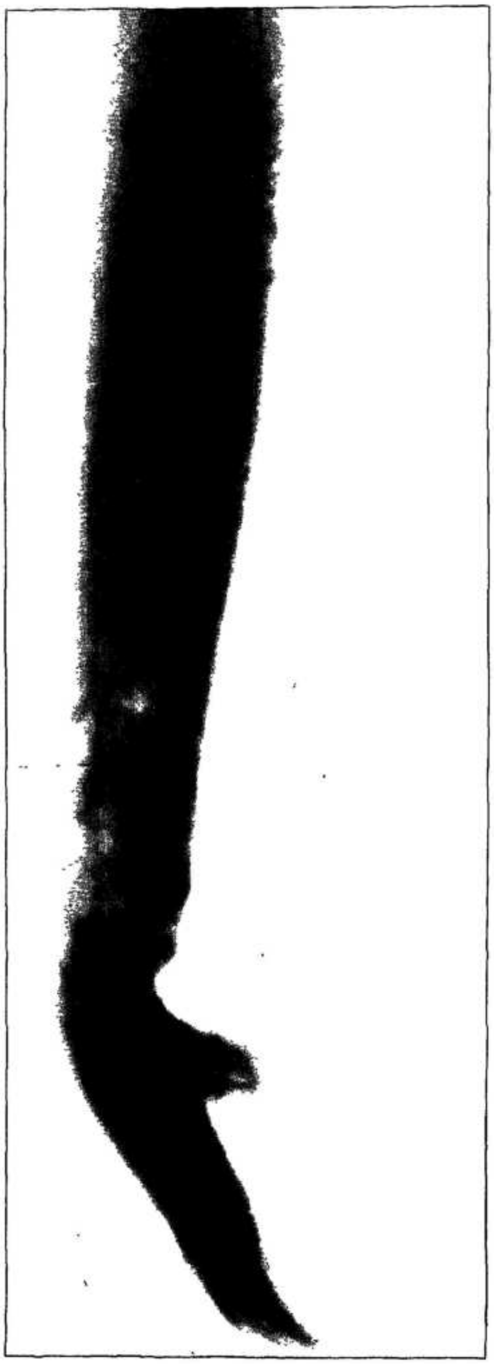


Fig : 5.16 Porosities and cavities in the hands of Nataraja ing to 15th century. While the head gear appears complete, radiography has revealed (Figure 5.15) that a portion of the gear is of very low density indicating that it has been repaired at a later stage. Another typical example is the case of the 9th century icon wherein the leg has been repaired (indicated by an arrow in Figure 5.5).

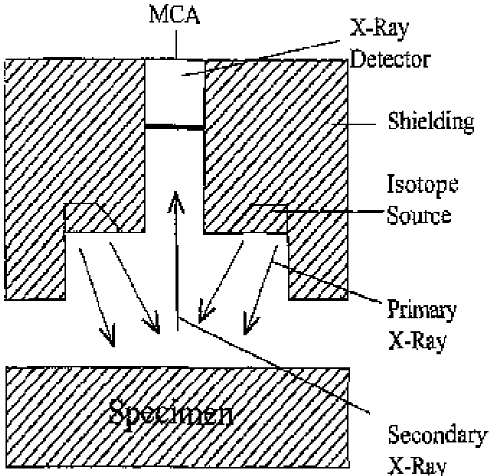


Fig : 5.17 Portable X-ray Energy Spectrometry (XES) system

8. In general a comparison of the icons indicate that smaller size icons have practically very few number of defects while the large ones have a number of defects.

9. In the large ones in case the complexity of the icon increases (such as Nataraja) a large number of porosities and cavities are observed. Figure 5.16 reveals the voids and cavities detected in the hand of a 13th century Nataraja.

5.1.2 X-ray Energy Spectrometry (XES)

It is a well-known fact that medieval south Indian icons are made from a class of alloys known as *"Panchaloha"*. No fixed composition of *panchaloha* can be given since, it evolved over a period of time and depended on the origin of the ores, extent of refining and where the alloy (*panchaloha*) was employed and intentional additions.

> 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 nondestructive 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% pm). With the advent of semiconductor detectors and personal computer-based multichannel analysers, interfacing the system with a computer is straightforward.

Though very small quantities of material samples can be collected from inconspicuous regions of the icons for chemical analysis, it is always desirable to carry out chemical analysis, without scraping out the small pieces. This objective is made possible by portable XES. This possibility enables comprehensive elemental analysis on a large number of locations thus providing better characterisation and sound finger printing.

Contrary to popular belief, no trace of gold was found in these icons. 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.

5.1.3 *In situ* Metallography

In situ metallography was done on selective and inconspicuous regions of the icons due to constraints like retaining the antiquity of the icon. The replica technique was adopted. All the icons showed typical cast structures. Both fine and coarse grain structures were observed indicating that cooling rates in the casting process are different. Photomicrographs of some of the pedestals indicated partially/fully recrystallised grain structure indicating working on the pedestals after casting them. Casting defects were observed in the microstructures of all the pedestals. They range from distributed porosity to interdendritic cavities and blow holes. Compared to these, the microstructure of the main icon indicates better cast structure. A typical micro-

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 microstructures. 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 micro structures. The film is seen in 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.

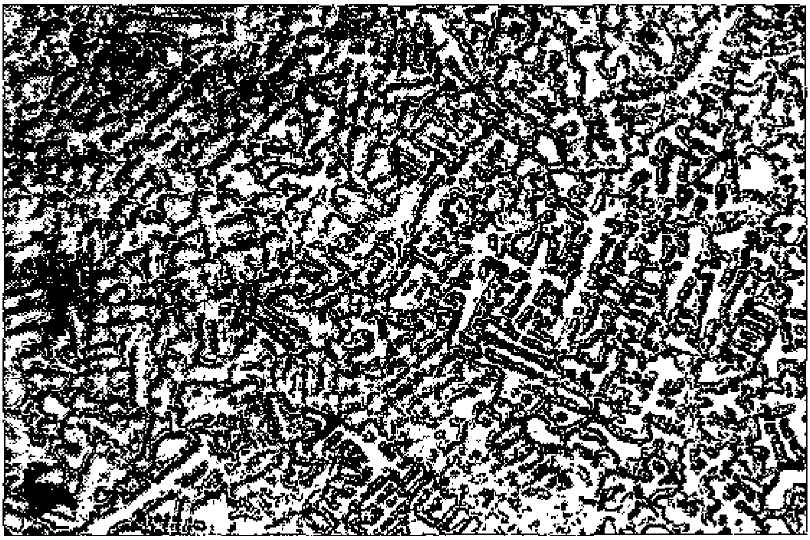


Fig. 5.18 A typical microstructure of a 15th century *Vishnu*(S) Icon

Fig. 5.19 A typical interdendritic cavity observed in the pedestal of the Icon

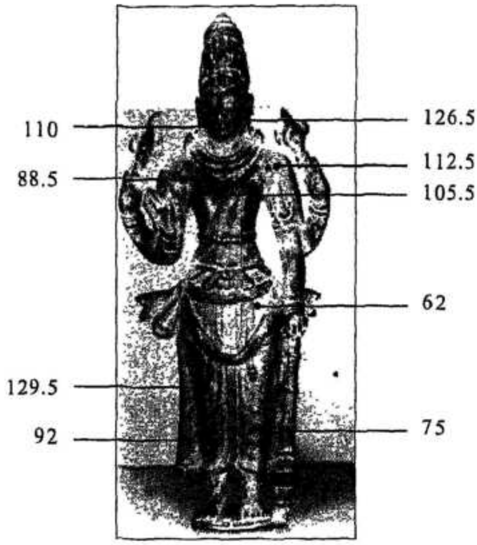


Fig : 5.20 Typical hardness values in a 9th century Icon (measured on the front side)

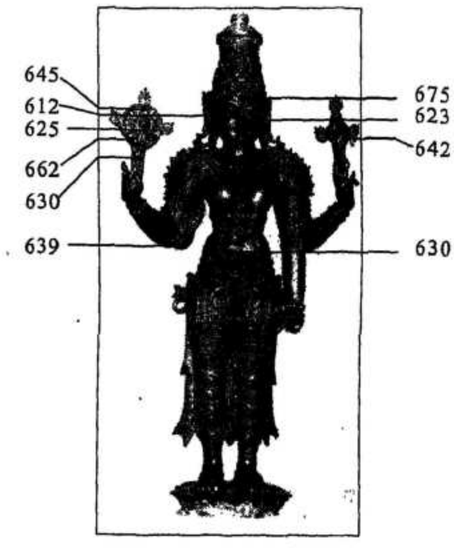


Fig : 5.21 Typical thermo electromotive force (emf) values in a 16th century Icon (measured on the front side)

magnification using a scanning electron microscope. However, these cooling rates vary depending on the addition of trace elements. Thus, from the microstructures obtained from icons belonging to different periods it is possible for us to get an idea of the relative cooling rates of these castings.

5.1.4 Investigations Using Other Technique

Investigations were also carried out using techniques such as hardness measurements and electrical conductivity. An increase in hardness was observed in the icons belonging to the later millennium. Measurements of physical parameters such as hardness, electrical conductivity and electromotive force (emf) indicate that the main body of the icon was treated differently compared to the pedestal or other ancillaries like *Prabhavalli(S)*. Radiography and *in-situ* metallography also corroborate this phenomenon. Figure 5.20 shows the typical hardness values in a 9th century icon (measured on the rear side) while Figure 5.21 shows typical emf measurements on a 16th century icon. It can be observed from Figure 5.20 that the hardness values varies between the main body and the pedestal region. The scatter in these values are also quite high making it difficult for interpretation. However, both emf and hardness are heavily dependent on the material composition and the variation in the values are supportive of the observations made by other techniques. Inspite of the scatter, hardness and emf are valid fingerprinting methods though limited in utility as compared to radiography, *in situ* metallography and XES methods.

It can be concluded from the above investigations that the ancient metallurgical casting practice as practised by the *Sthapathis(S)* was quite sound. The main body of the icon was given maximum importance from quality considerations.

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Chapter 6

Characterisaton

(Baldev Raj, U. Kamachi Mudali* and V. Jeyaraj**)*

It is a wonder that how man has produced many invaluable objects in the past considering the nonavailability of techniques, infrastructures and sophisticated instruments which are widely used today for the production and characterisation of modern materials. How he might have chanced upon the existence of metals, or mastered the technology of producing alloys, and imagined the application for such metals and alloys has only been conjectured especially considering the primitive technology and the methods to produce the required conditions like high temperature, pressure, flow etc. Scientific examination of those antiquities produced in the past with ingenious methods plays an important and essential role in the conservation of those objects today, and for understanding the technological excellence of such objects. Apart from the scientific information from the objects which will be very useful in conservation, the examination would throw light on the technology adopted those days and the associated art and cultural scenario [42].

The result of a scientific examination of an antiquity is a knowledge of its actual condition at the time of examination. From this something can be inferred of its past history from the time of its beginning as raw material and it can lead to an estimate of practicable methods for its conservation against the further passage of time or for its restoration to its original appearance. Further, through the examinations the actual properties of the objects with respect to strength, ductility, chemical stability, corrosion resistance, conductivity etc., can be obtained. This will also lead to revealing the mystery that caused damage or deterioration to the object while it was buried under soil or during storage or display. It can also enlighten the secret of the object's ability to withstand the environment over many centuries with a noncorroding and aesthetic surface appearance. The way in which the object was made, its composition, structure, physical and chemical properties etc., could be obtained through destructive and nondestructive testing methods of examination. Finally, the most important is the possibility to preserve the object for longer time in the present environmental conditions depending on its composition and properties. Thus, characterisation of the bronzes is an important step, and with

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the availability of a variety of sensitive and advanced techniques in chemistry, physics, metallurgy and nuclear science, a lot of useful information can be obtained to achieve all the above objectives.

6.1 Importance and Difficulties of Characterisation

The characterisation of bronze icons is a difficult job in the sense that only nondestructive testing can be effectively adopted for this purpose. Any destructive testing requires sufficient size and number or specimens for which the icons have to be disturbed or damaged while preparing such representative samples out of them. This is not ethical, and also the damage caused while preparing specimens out of them will cause much more problem than arriving at a conservation method out of the study conducted using those specimens. There was also difficulty in preparing specimens representing the icons, that the specimens prepared from any part of the icon or its associated structure need not wholly represent the composition and structure of the icon. This was because each part of the icon could have been made at different periods, or by different technology, or different casting method, or may contain different alloying elements. For example, the face of the so called *panchaloha* icons are supposed to contain predominantly gold and silver, and not the other parts of the body. Also, there was a possibility of variation of composition in different parts because of the possible different flow of the various constituents of an alloy when the molten metal was poured into the mould. In addition, the alloying elements present in various other and not so important structures, like the *iruvachi* or the *peedam* may contain less important and not so crucial alloying elements. Thus, one needs sampling from various parts of the icon to arrive at the alloying elements present and their role in preserving or forming various types of coatings or *patinas* or corrosion products over the surface. The sampling from the surface can give misleading results compared to the sampling form the body or bulk due to various metallurgical processes like diffusion, crystal growth, ageing etc., operating for many years during its storage or use [43-44].

Apart from sampling, the small size of the samples may not be sufficient for conducting various analytical, chemical, metallurgical and physical tests to arrive at a definite picture of various aspects of the icons. Even while applying various analytical techniques at various laboratories, matching results within minimum error levels may not be possible due to the difficulty in reproducing similar measurement conditions, standards and parameters. Another important point was that the forgery or wrong assumption of the object could also give misleading results about the history and science of the period. In many cases the associated soil samples are required for establishing the environmental parameters affecting the corrosion behaviour or *patina* formation since the icons were kept buried in the soil for many centuries. In the case of treasure-trove bronzes this becomes very difficult as the soil may not be available for all of them.

The primary objective of the early investigation in archaeological chemistry seems to be mainly personal curiosity. Of the various disciplines that made an indelible dent in the identification analysis of the antiquities is analytical chemistry, and the studies and procedures evolved this purpose fall into the topic "Archaeological Chemistry". The first significant results of chemical analysis of ancient antiquities were published in 1796 by M.H. Klaproth, a pioneer in the dual fields of archaeological investigations and chemical analyses of ancient materials [45]. It was in 1853, that the possibility of a co-operative collaboration between archaeologists and chemists was first demonstrated by Wocel[46]. Dr. S. Paramasivam[47] pioneered archaeochemical and analytical investigations in India. In recent days [48-50], most of the examinations have been carried out using X-ray diffraction and fluorescence, neutron activation and spectrometries.

6.2 Current Understanding of the Characterisation of Bronzes

Chemical analysis of a number of bronzes have indicated that the main constituents of the bronzes were copper, tin or zinc or lead. According to Otto Werner [48], the chemical analyses of a number of south Indian bronzes by spectrometric investigations indicated the presence of copper, tin or zinc and lead. The older objects contained tin and recent ones contained zinc. A high content of lead was also found in the older objects. Apart from the major elements, many other alloying elements like gold, arsenic, iron, cadmium etc., were found in the alloy which were either impurities or deliberate additions. Most of them contained about 0.001 to 0.003% gold, and a high content of about 0.1 to 0.2% was found in some icons of gods and saints.

6.3 Various Methods of Examination

Examination of the object with the naked eye is an essential preliminary step which, in the case of experienced observer, may provide many of the required data. An experienced observer will have a favourite window at which to make his observations and will turn a particular feature of the object in all directions whilst examining it in order to build up a composite mental picture by the aid of which to make his final pronouncement on the meaning of what he sees.

Qualitative and quantitative analysis by physical, chemical, metallurgical and nondestructive testing methods yield a variety of information from the specimens or live objects of bronze antiquities. Though it was difficult to get sufficient and sizable quantities of the drilling or scrapings, it is fortunate that the advanced analytical and nuclear techniques require very small samples, and the compositions are determined rather quickly. An attempt is made to highlight these techniques, and some of the examinations carried out in the authors' laboratory.

A large number of techniques such as metallography, hardness, optical and electron microscopies, X-ray diffraction, electron microscopy, X-ray analysis, electron microprobe analysis, neutron diffraction, *Auger* electron microscopy etc., are available for the study of the bronze icons to understand the metallurgical nature. In chemical methods, some of the prominent techniques include, wet chemical analysis, thermoanalytical methods, mass spectrometry, electrochemical techniques, spectrophotometric techniques, X-ray fluorescence analysis, electron spectroscopy for chemical analysis, secondary ion mass spectrometry, Mossbauer spectroscopy and neutron activation analysis. Various physical and a range of conventional and modern nondestructive testing methods are also available for the purpose of characterising the bronze icons. However, in this section descriptions are made only for the techniques used by us for analysing the corrosion products/soil collected and the metallic samples collected for the South Indian bronzes of 1200 A.D. and 1300 A.D. A comprehensive article consisting of various chemical, physical, metallurgical, nuclear and nondestructive testing methods is being presented in a separate publication [51]. Before going into the investigations on the south Indian bronzes it is necessary to understand the metallurgy of copper and its alloys, addition of various alloying elements, the casting details and the types of phases formed during the alloy making, which would serve as the base information to understand the results and analysis of the present investigation.

6.4 Copper Alloy Systems

Copper is the parent metal of a large family of alloys which have many interesting properties, however, the discussions are made only with respect to the alloys which are relevant to the present topic. Many alloying elements [30,52,53] are intentionally added to copper or present in the alloy for various purposes as shown below:

Oxygen	-	deleterious, to be removed
Sulphur	-	improved machinability
Tellurium	-	improved machinability, high conductivity
Silver	-	improved creep properties
Cadmium	-	increased strength without affecting conductivity
Arsenic	-	increased strength, lowered electrical conductivity and a deoxidant

Antimony	-	increased strength and lowered electrical conductivity
Bismuth	-	decreased strength, lowered electrical conductivity
Lead	-	increased strength, lowered electrical conductivity
Silicon	-	deoxidant
Phosphorus	-	powerful deoxidant, lowered conductivity, increased strength

In general most of the binary alloy phase diagrams of copper and other elements [30] show a large range of solidification between the liquids and solids. This give rise to a "cored" structure after casting in which the centres of the primary grains consist of almost pure copper, surrounded by grain boundaries showing considerable segregation of other alloying elements. Low-alloyed coppers are basically the high purity metal with additions to improve certain properties without significant reduction in conductivity. Brasses are copper plus zinc (up to 45%) to which many other alloying elements are added for giving improved properties, in particular, iron, manganese and aluminium for improving mechanical properties, and lead and magnesium for improving machinability. Bronzes are copper plus tin (up to 12%) usually combined with other elements like phosphorus, zinc, nickel and lead. There are a varieties of brasses and bronzes that are available depending on the alloying element added for the intended application.

In the tin bronzes, there are a number of intermetallic phases present, significant among them are Cu_3Sn and $Cu_{31}Sn_8$ which significantly affect the corrosion properties. When present in the alloy, lead does not go into solid solution with copper, and hence it is found as interdendritic globules in the cast alloys. The wide freezing range of the brasses and bronzes also generally lead to the formation of pores in the cast structure. Lead appears black in the etched structures but has a characteristic dark grey colour before etching in the as-polished surface. Lead also helps to fill the pores developed in these alloys and by this improves the pressure tightness of castings.

In general, the chemical properties of the copper alloys are not unlike those of the metal itself, though there are important differences, with some alloy groups having superior resistance to corrosion attack. Most of the alloys form protective coatings made of oxides, but some of them like brasses and bronzes undergo dezincification, dealuminification, destannification or selective attack when exposed to corrosive environments. The impurities, inclusions, grain boundaries and their constituents can be selectively attacked due to the differences in their electrochemical potential, and this lead to dezincification, dealuminification, destannification and intergranular corrosion. The general reactions occurring during dezincification are, selective removal of zinc leaving a mass of weak porous copper, and this form of corrosion is accelerated by the presence of chlorides, low oxygen concentration and increasing temperatures. There are two well recognised forms of dezincification, namely "layer" and "plug". In the layer form the areas of metal attacked are covered with a thin red deposit of copper, whereas in the plug form of attack pits or cavities filled with porous copper are present, and removal of this plug is likely to lead to penetration of the alloy. The following (Table 6.1) information gives an idea about the differences in the electrochemical potential of various alloys and metals constituting the copper alloys [30] in dilute chloride medium :

Table 6.1 Electrochemical potential in dilute chloride solution in volts against saturated calomel electrode

Nobel end	
Copper	: 0.29
70/30	: 0.30
Admiralty brass	: 0.29
Phosphor bronze	: 0.31
Aluminium bronze	: 0.22
70/30 Cupro-nickel	: 0.27
Aluminium	: 0.88
Mild Steel	: 0.70
18/8 Stainless Steel	: 0.53
Zinc	: 1.03
Active end	

It can be seen clearly that zinc preferentially corrodes in contact with any of the metal/alloy present in Table 6.1. The tin bronzes are less reactive compared to the brasses and their corrosion resistance increases as the tin content increased in both cast and wrought alloys. However, when inverse segregation was present in cast material the delta phase $Cu_{31} Sn_8$ was preferentially attacked [30]. It is also important for optimum resistance to corrosion; for example, 2% of lead promote sound castings and so enhances their corrosion resistance.

6.5 Analytical Investigations on the South Indian Bronzes

In order to understand the nature, composition, crystal structure, microstructure, surface morphology, hardness etc., of a few South Indian bronzes belonging mainly to 12th century and 13th century A.D., representative specimens of

Table 6.2: Details of ancient Icons and methods of examination

Bronze Icon	Period	Metal	Examination
Pradosha Murthy	1200 A.D.	both	Metal-Optical and SEM EDAX, SIMS, Microhardness, ICPMS, SoilXRD
Bhudevi	1200 A.D.	Soil	Soil-XRD
Bhudevi (Flower in the right hand)	1300 A.D	both	Metal-Optical and SEM/ EDAX,SIMS, Microhardness ICPMS, Soil - XRD
Bhudevi (Pedastal broken)	1200 A.D.	both	Metal-Optical and SEM/ AX, SIMS, Microhardness, ICPMS, Soil-XRD
Somaskandar	1200 A.D.	both	Metal-Optical and SEM / EDAX,SIMS, Microhardness, ICPMS, Soil-XRD
Swamimalai icon	1997 A.D.	metal	Optical and SEM/EDAX, SIMS, Microhardness, ICPMS

Table 6.3 : Metallographic study of bronze Icons

Bronze Icon	Period	Observations As Polished
Pradosha Murthy	1200 A.D.	Large pores, grey phases
Bhudevi (Flower in the right hand)	1300 A.D.	Very large pores, less grey phases
Bhudevi (Pedastal broken)	1200 A.D.	uniformly distributed fine and large pores, round globules with greyphases, pore density is nonuniform
Somaskandar	1200 A.D.	Irregular, very large pores, grey phase in motrix and pores
Swamimalai icon	1997 A.D.	small and medium size pores and particles, homogeneous, uniformly distributed.

the icons, and the associated soil/corrosion product collected from the icons were examined/analysed by using various metallurgical/chemical/surface analytical techniques in the present investigations. Metallography, microhardness, microstructure, composition, surface analysis, phase analysis etc., were carried out using, optical microscopy, SEM/EDAX, SIMS, XRD, ICPM, microhardness tester etc.

Metallography
The ability to fundamentally understand the behavior of a material usually depends on being able to visually examine and quantitatively analyse its microstructural, topographical and chemical characteristics. By metallography, the art of preparing suitable specimens for clearly exposing the microstructure of the material being investigated one can study the fundamental changes in the macro and micro-structural changes (Fig.6.1). The necessary steps involved are, specimen preparation with surface finish up to the required dimensions, mounting in a suitable mould, chemically or electrochemically etching in a prescribed reagent, and examining in an optical or electron-optical system for the observation of the surface topography.

Small samples representing the ancient bronze icons, and the associated soil samples were analysed using the above techniques. The following sections will deal with the basic information about the techniques used in a text box along with a representative figure, and the details about the results obtained in the analysis. Discussions are made wherever necessary. Table 6.2 gives information on the bronze icons employed for the present investigation, and the details of examinations carried out.

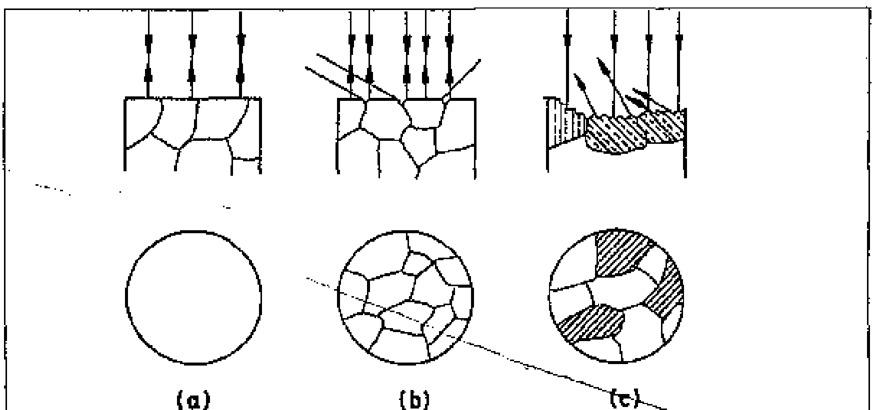

Fig 6.1 a. Polished surface – no detail revealed
b. Etched surface revealing grain boundaries
c. Etched surface revealing grain contrast

Hardness Measurements

The hardness of the material is often referred to its resistance to scratch or flow at the surface, and also related to the bulk strength of the material being investigated. By studying the hardness of the material or a component one can try to understand the strength and toughness of the bulk, or of the surface if it was modified by its interaction with the environment either to produce a coating or intentionally modified to enhance the property of the surface. It is also possible to measure the hardness of the individual phases that are present in the microstructure of the materials. A number of techniques are available to measure the hardness of the materials, and some of them include Vickers hardness tester, Rockwell hardness tester, Brinell Hardness Tester etc. In this test a pointed diamond or a hardened steel ball is pressed into the surface of the material to be examined. The load, divided by the projected area of the "indent". A is defined as hardness (Fig6.4, see page 107)

Microstructural Aspects

Optical Microscopy

The simplest tool available for understanding the structure of the various phases present on the surface is the optical microscope. The reflected light from the specimen surface (Fig.6.5, see page 107) gives preliminary details of the microstructure for understanding the various metallurgical states of the materials. The magnification is small (2000X) compared to the electron-optics microscopes, and also suffers from poor depth of field. The surface texture can be studied only up to a resolution of 0.1µm. compared to the high resolution levels of other tehniques.

The specimens of bronze icons were metallographically prepared in an araldite mould. This was polished carefully up to fine finish using alumina paste, and the as-polished specimens were observed in an optical microscope. After this, the specimens were etched in a chemical solution containing potassium dichromate, saturated sodium chloride (NaCl), sulphuric acid (H_2SO_4) and distilled water, and observed for the micro structure. Gold coating of less than 100 nm was given on the surface to ensure that the microstructural features are finely resolved with a conducting surface.

The results are summarised in Table 6.3. In general, it is noticed that large pores and globular particles are present in the ancient bronzes whereas the Swamimalai icon showed a uniform distribution of fine pores and homogeneously spread particles. Figure 6.2 (a-e) shows the colour metallography of these icon samples in the as-polished condition, showing the features given in the Table 6.3. Similarly, Figure 6.3 (a-e) shows the microstructural features of the samples in the etched condition.

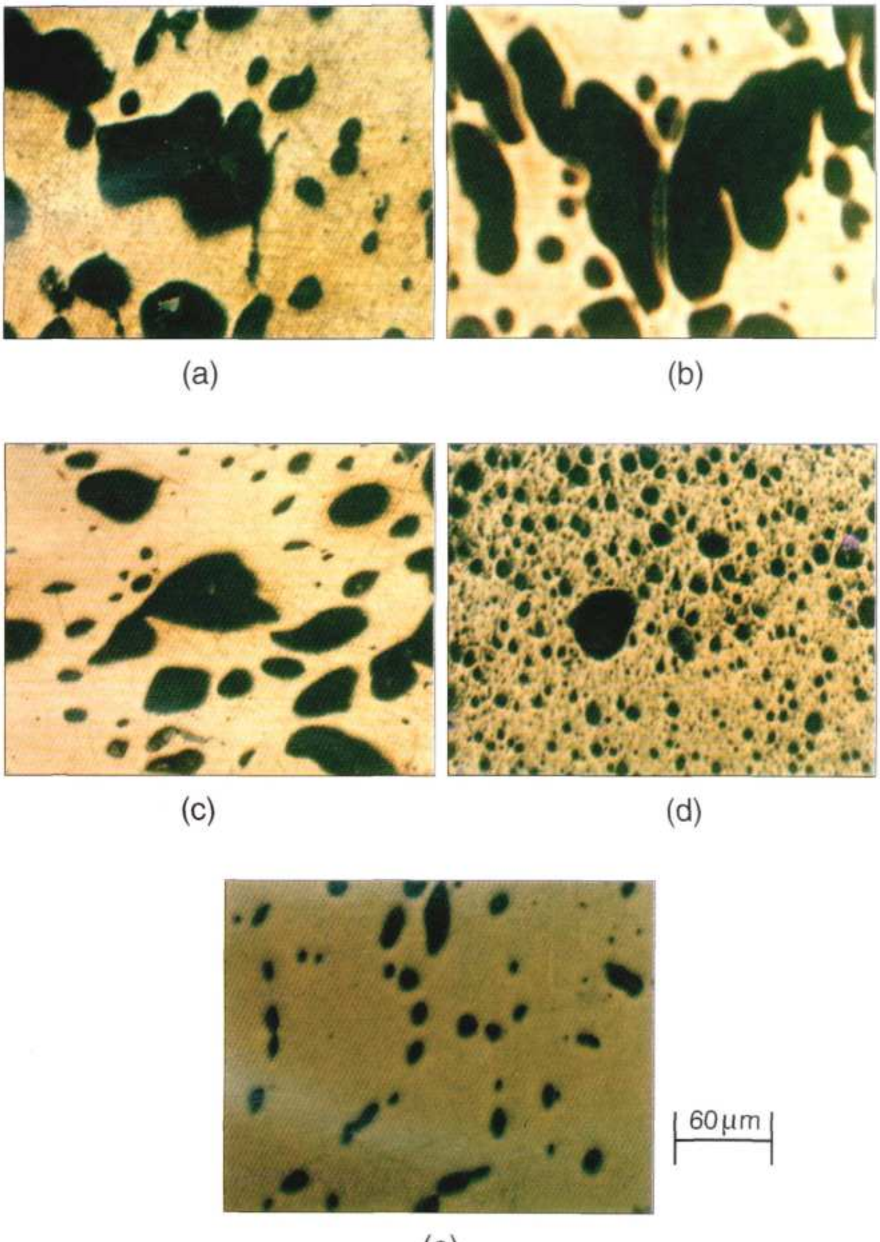

Fig. 6.2 (a-e) : Microstructural features of the samples in the as-polished condition
a. Prodosha Murthy(1200 A.D.);
b. Bhudevi(Flower in the right side)(1200 A.D.);
c. Bhudevi (Pedestal broken)(1300 A.D.);
d. Somaskandar(1200 A.D.) and
e. Swamimalai icon (1997 A.D.)

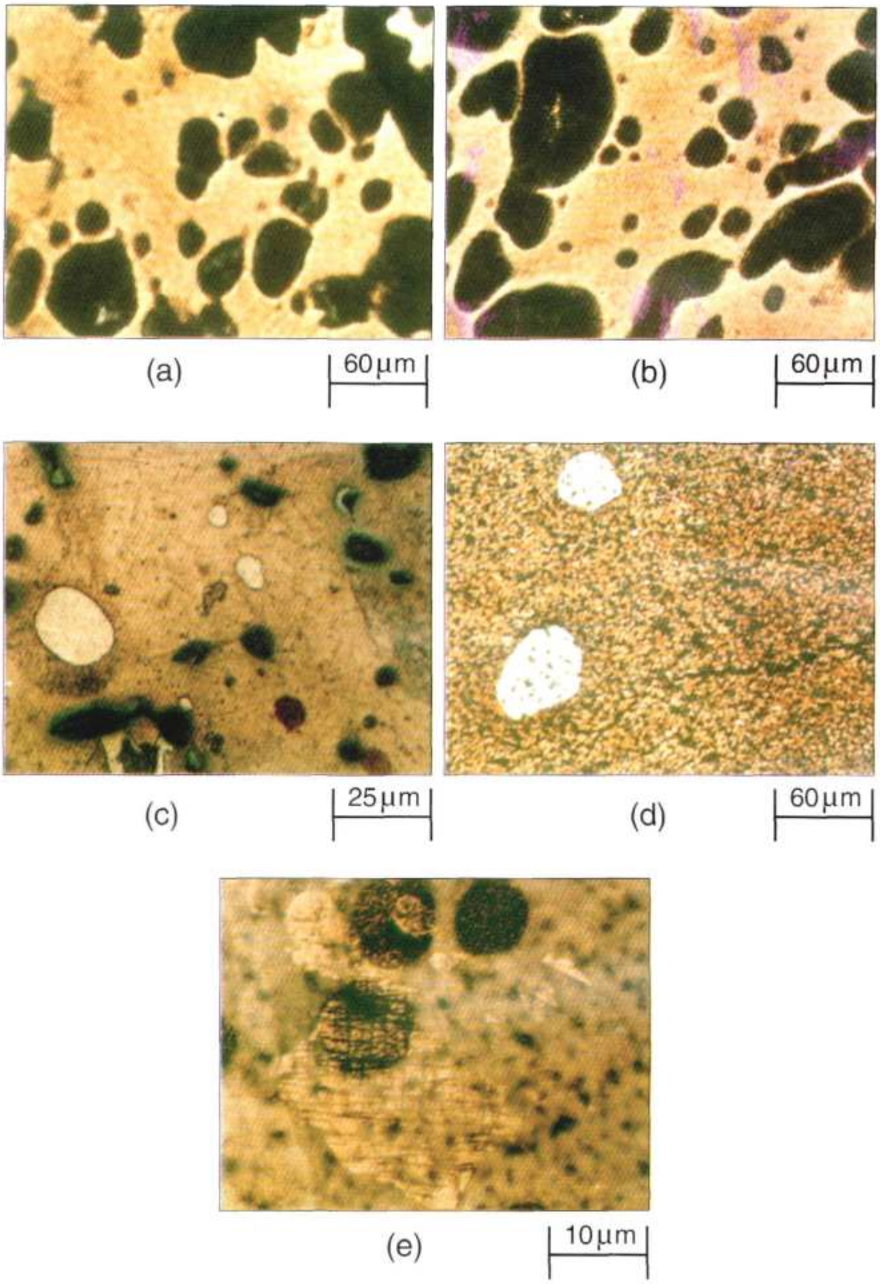

Fig. 6.3(a-e) : Microstructural features of the samples in the etched condition
a. Prodosha Murthy(1200 A.D.);
b. Bhudevi(Flower in the right side)(1200 A.D.);
c. Bhudevi (Pedestal broken)(1300 A.D.);
d. Somaskandar(1200 A.D.) and
e. Swamimalai Icon (1997 A.D.)

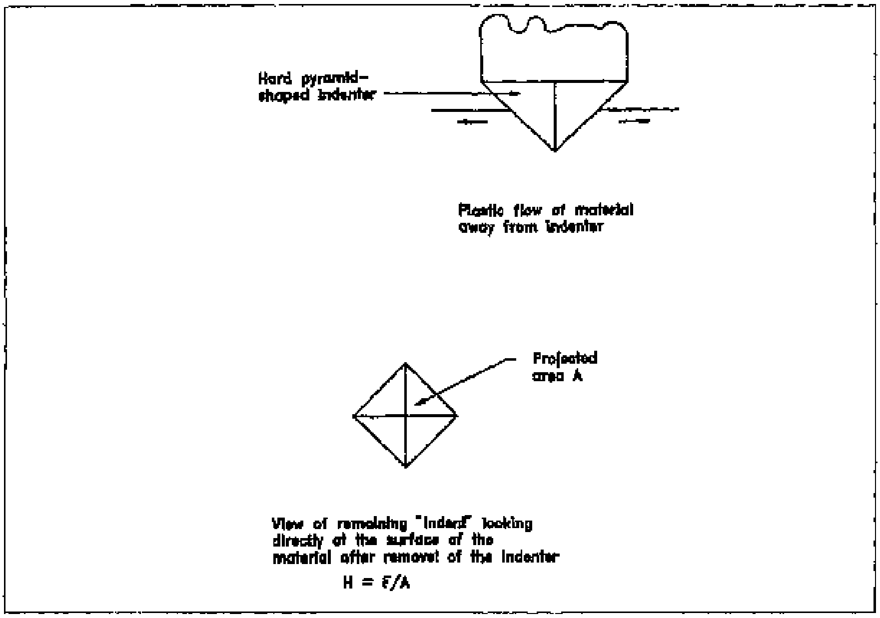

Fig. 6.4. Hardness Measurement

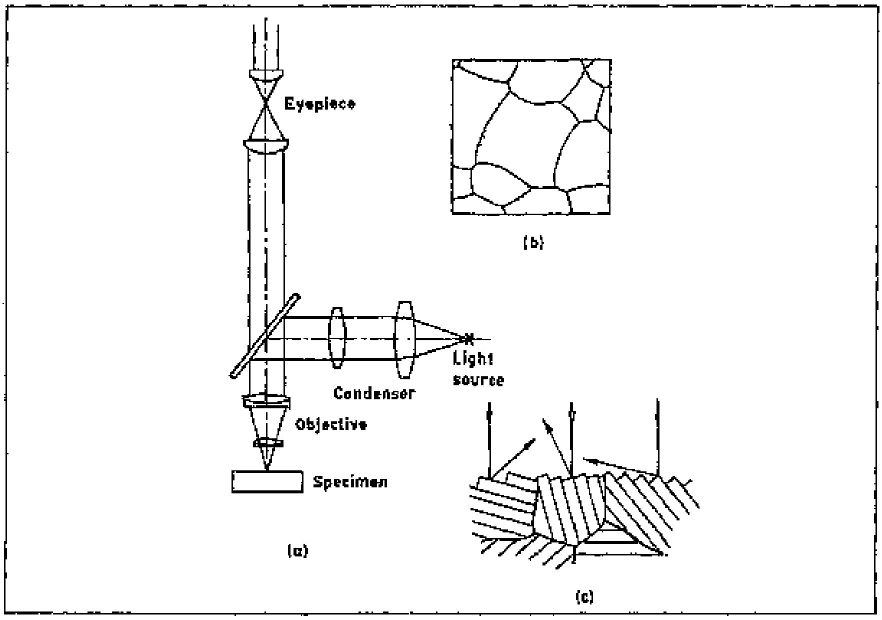

Fig. 6.5 a. Metallurgical microscope
b. Polygonal grain structure
c. Reflection from differently oriented grains

Secondary Ion Mass Spectrometry

Secondary ion mass spectrometry is an ion beam analysis technique useful for characterising the surface to few micrometer depth of materials. Primary ions of energy 0.5-20 KeV, commonly O^-, Cs^+, Xe^+, Ar^+, Ga^+ etc., are used to erode the surface and the secondary elemental or cluster ions formed from the target atoms by the impact are extracted from the surface by an electric field and then energy and mass are analysed (Fig.6.6). The ions are then detected by an electron multiplier and the resulting secondary ion distribution displayed as a function of mass, surface location or depth into the sample. Detection limits up to 10^{13}-10^{16} atoms/cm^3 are achieved for the elements at the surface, and light element analysis with isotopic purity is possible by this technique. Due to its intrinsic properties (low detection limit, and imaging capability of every element, depth resolution in the nanometer range). SIMS constitutes an original method for the characterisation of heterogeneous materials.

Microhardness Measurements

The microhardness measurements were carried out on all the specimens using a microhardness tester at a load of 25g. The results are shown in Figure 6.9. In general the values were close for all the specimens, and the interesting point was that the icon made at Swamimalai today is matching with the values obtained for the ancient 12th century A.D. icons.

Elemental Surface Analysis by SIMS

The mass spectrum was taken for all the specimens in a Cameca IMS-4F Mass Spectrometer, and based on this, the elements present on the surface were identified. Further, depth profiling of the surface was carried out, and the primary beam in all cases were caesium ions. Interesting results are obtained

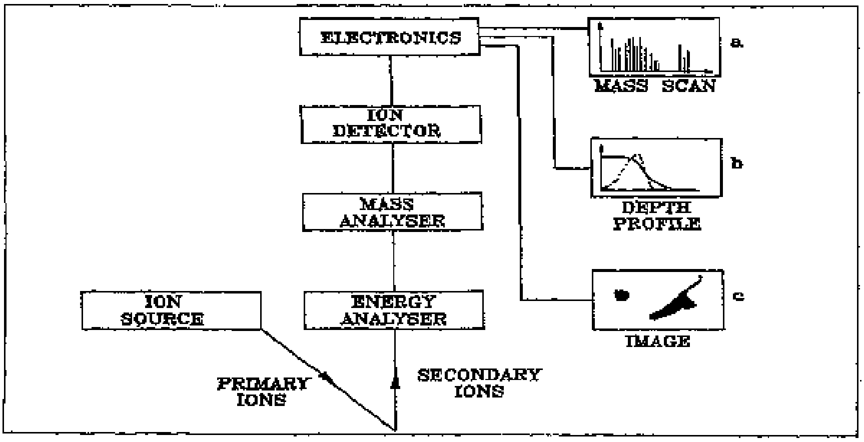

Fig 6.6 . Schematic representation of the main components of a SIMS experiment. The Signal due to the detected seceondary ions may be presented as a function of (a) the ion mass, (b) the duration of ion bombardment or (c) the location of the surface

(Figures 6.10-6.13) with respect to the elemental distribution on the surface. It is noticed that in all the specimens lead and carbon was found enriched at the surface while tin was depleted at the surface. Aluminium was also found in some cases which gets depleted as the depth profiling continued. This could be due to the incorporation of aluminium from the bauxite ore which is present in the earth. Alumina could have segregated to the surface layer while the icons were kept buried for many centuries in the earth.

Scanning Electron Microscopy with Energy Dispersive X-ray Analysis (EDAX)

Scanning electron microscopy is the most useful electron optical system for surface topography and surface imaging. It is essentially a nondestructive testing method. The surface region under study is scanned by an electron beam, and the image of the surface is built up by the signal given by scattered primary electrons, or by secondary electrons from the specimen, or by the current generated in the specimen. The instrument consist of an electron gun, usually fitted with W or Lab6 filament, operates over the range 0.5 -40 kV accelerating voltage. A condenser lens produces a demagnified image of the source, which in turn is imaged by the probe forming lens (often called the objective lens) onto the specimen. The electron path and the chamber will be in the ultra high vacuum. Detectors collect the emitted electron signals, which after suitable application can be used to modulate the intensity of the beam of the display video screen, which is rested in synchronism with the probe (Fig.6.7, see page 110), SEM offers various advantages including little or no specimen preparation is involved, operation over a wide range of magnifications (15Xto 20,000 X), resolution down to about 10mm, large depth of field, and in particular, the ability to use a variety of signals so that information additional to that of surface topography can be obtained.

X-ray analysis is a surface technique in the sense that the X-rays being emitted, and therefore being measured, originate from a surface layer of finite thickness. There are basically two experimental methods of X-ray analysis : wavelength dispersion and energy dispersion (EDA). In both cases an X-ray photon source is used to excite a sample which emits its own characteristic X-rays. The wavelength or energy of the emitted photons is measured to determine what elements are present in the sample (qualitative analysis) and their intensity is a measure of how much of each element makes up the specimen (quantitative analysis). The method is attractive for elements which lack reliable wet chemical methods.

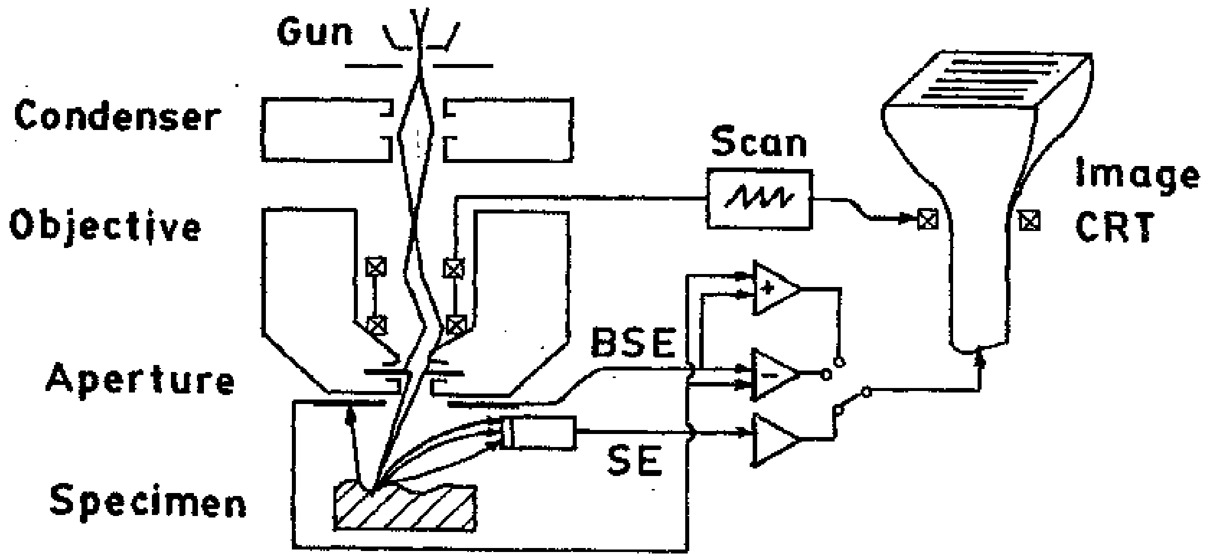

Fig. 6.7. Basic features of the SEM, showing electron gun, condenser and objective (probe-forming) lenses, scanning system, detectors and image display CRT. The diameter of the aperture and the working distance from lens to specimen determine the convergence angle of the probe. The probe at the specimen is the demagnified image of the source, broadened by lens aberrations.
(BSE -back scattered electrons; SE-Secondary electrons)

Mass Spectrometry

Basically mass spectrometer is considered as an apparatus that produces a supply of gaseousions from a sample, separates the ions in either space or time according to their mass-to-charge ratios, and provides an output record or display indicating the intensity of the separated ions (Fig.6.8). From the mass spectrum a wealth of information can be obtained concerning the composition of mixtures of organic compounds and the elemental analysis of solid state samples. The mass spectrometer is an extremently sensitive instrument and can distinguish between particles having very similar weights. Its applications to the study of solid surfaces, adsorption, surface coatings, surface impurities etc., are well established.

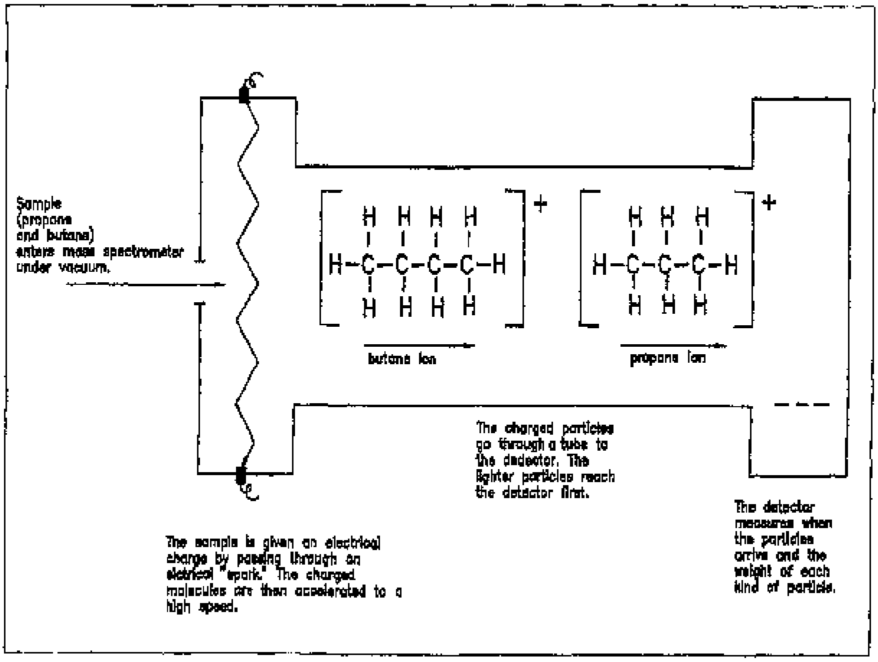

Fig. 6.8. A time of flight mass spectrometer is shown analysing a mixture of propane and butane

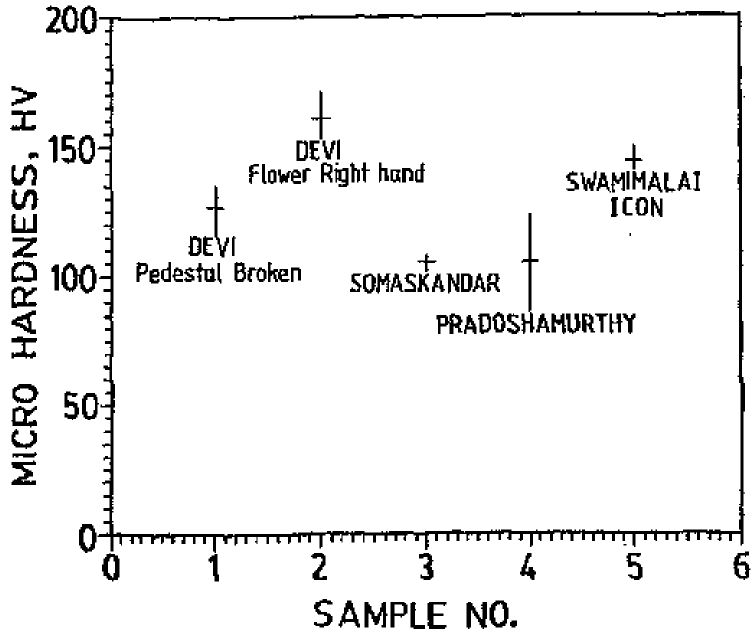

Fig. 6.9 : Microhardness values of the samples

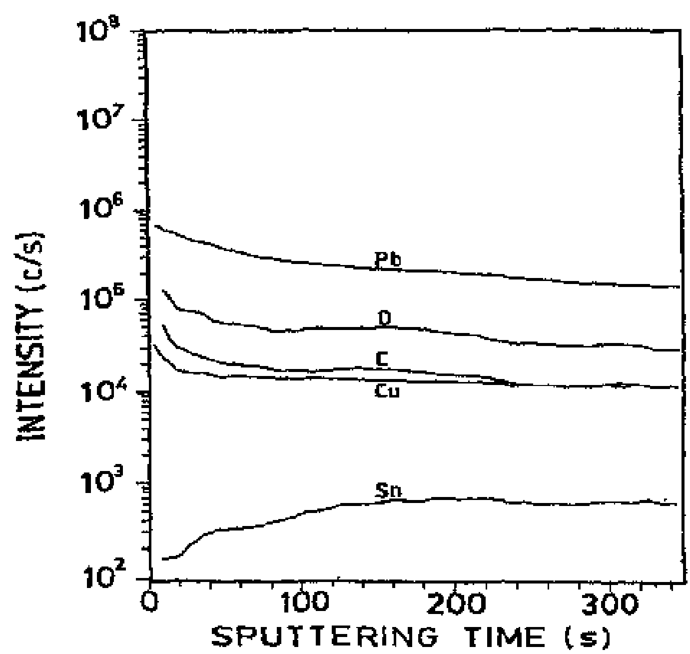

Fig. 6.10 : SIMS depth profile of sample of Pradoshamurthy

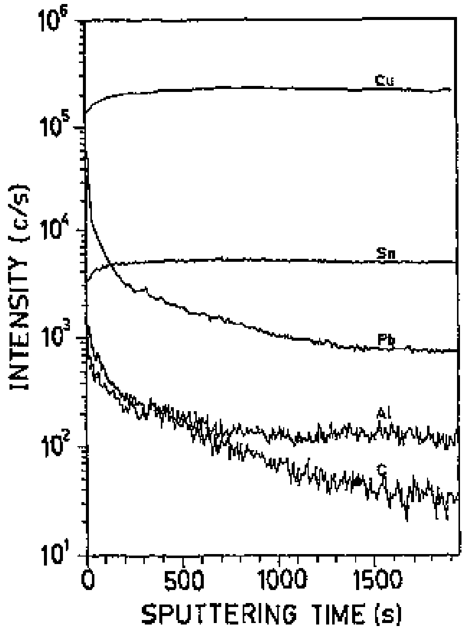

Fig. 6.11 : SIMS depth profile of sample of Bhudevi (flower in right hand)

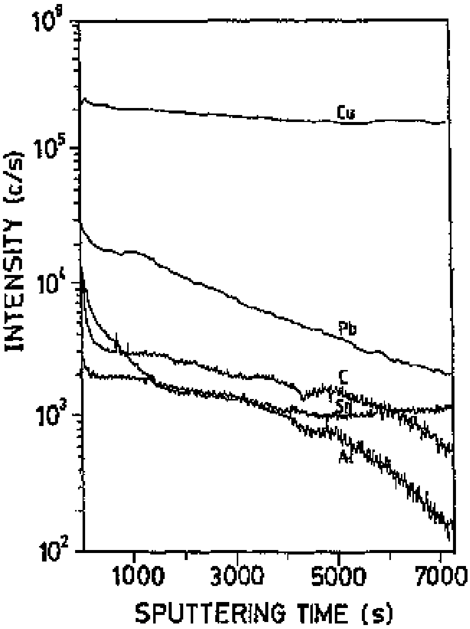

Fig. 6.12 : SIMS depth profile of sample of Pradoshamurthy (pedestal broken)

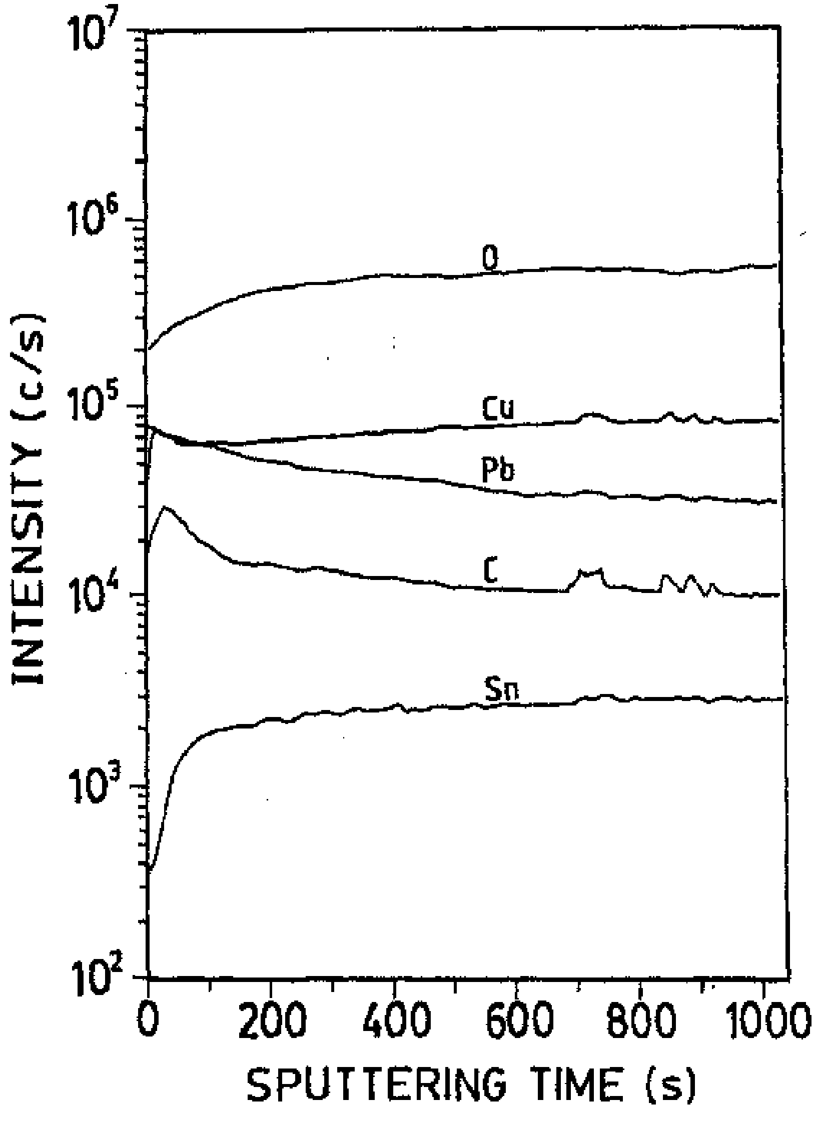

Fig. 6.13 SIMS depth profile of sample of Somaskandar

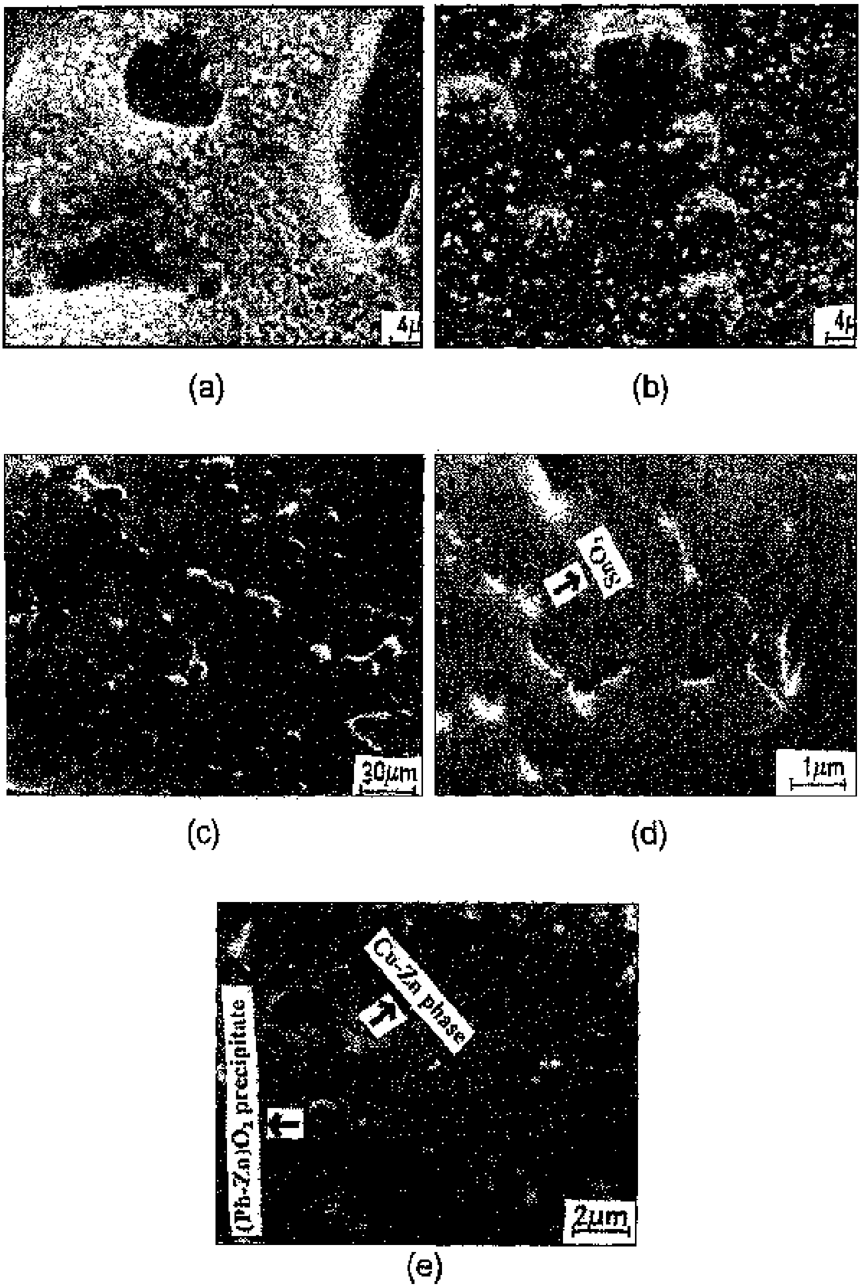

Fig. 6.14 (a-e) Micrograph of samples in etched condition—observation of Scanning Electron Microscope (SEM)

X-ray Diffraction Analysis

Since the wavelength of X-rays is comparable to that of the distance separating the atoms in solids, diffraction effects are produced when a beam of X-rays strikes a material. Diffraction, or constructive interference, occurs only when the difference in the distance travelled by two identical diffracted waves is an integral number of wavelengths, so that the two waves are in phase (Fig6.15). This is explained by the Bragg's law of diffraction, $n\lambda=2d\sin\theta$. This method is extensively used for studying the crystal structure of the solid materials, and also the structural aspects of the coatings or modified surfaces.

X-ray diffraction furnishes a rapid, accurate method for the identification of the crystalline phases present in a material. It can determine the possible polymorphic forms of a substance, for example, carbon in graphite or in diamond. Differentiation among various oxides such as FeO, Fe_2O_3 and Fe_3O_4 or material present as mixtures can be analysed.

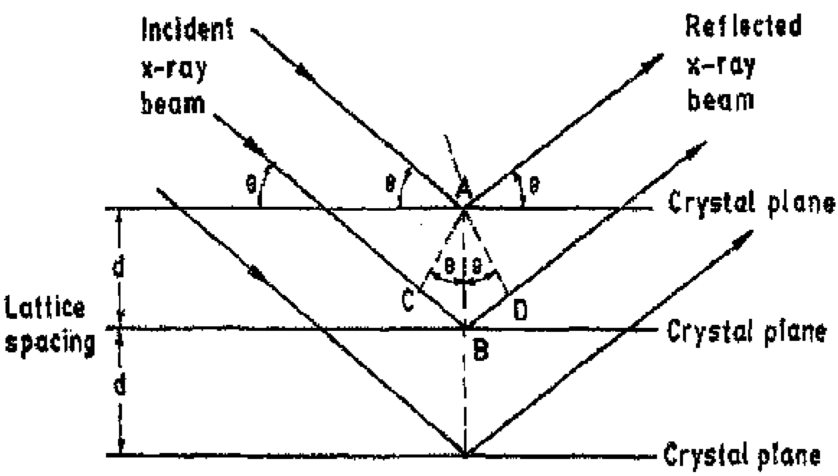

Fig. 6.15 Diffraction of X rays from a set of crystal planes

Surface Topography and Phase Analysis

The metallographically prepared specimens were examined in a SEM for observing the surface features Fig. 6.14 (a-e). In addition, using the EDAX system, the elements present in the inclusions, matrix, and other phases were analysed for studying such phases. The results indicated that in all the specimens a number of phases of (i) Lead and Zinc, (ii) Copper, Zinc, Lead and Iron, (iii) Lead-rich precipitates, iv) Copper-rich phases, (v) Copper-Tin phases, etc., were present. Also many of the specimens indicated the presence of big cavities and blow holes on the surface. They could be either cast defects or those formed due to corrosion of the alloy (dezincification, destannifiation) during its burial in the earth. This was also supported by a large amount of Lead-rich and tin-rich particles found around such cavities.

Elemental Analysis by ICPMS

All the specimens along with a few other ancient bronze icons were analysed for the alloying elements present in the alloy by inductively-coupled plasma mass spectrometry (ICPMS). Table 2.3. shows the results of the analysis in detail. It should be mentioned here that most of the trace elements present in the alloy could not have been added intentionally but would owe their origin from the raw copper metal prepared or used in the icon making. This is an interesting observation from the present investigation. The major alloying elements like tin, zinc and lead could have been added with purpose while the alloys were cast. Probably to control the flow of the molten liquid metal and to improve the castability lead was arbitrarily added to copper. Tin and zinc could have been added in small amounts to have the golden yellowish lustre for aesthetic appearance.

Table 6.4 : XRD analysis of soil samples of bronze icons

Bronze Icon	SiO_2	Cu_2O	$Cu_3(CO_3)_2(OH)_2$	$Cu_2CI(OH)_3$	Cu	Sn	Zn
Bhudevi-PB	✓	✓	✓	✓	X	X	X
Bhudevi-FIRH	✓	✓	X	✓	✓	✓	✓
Somaskandar	✓	✓	X	✓	✓	X	✓
Pradoshamurthy	✓	✓	✓	✓	✓	✓	✓
Bhudevi	✓	X	✓	✓	X	✓	X

Phase Analysis of Soil by X-ray Diffraction

The soil samples of the bronze icons were examined by XRD (Table 6.4) in order to understand the corrosion products present and also the role of the soil adjacent to the icon when it was buried in the earth. Attempts were made to correlate the nature of the soil to the corrosion products formed on the surface. In general the samples contained SiO_2, Cu_2O, $Cu_3(CO_3)_2(OH)_2$, $Cu_2Cl(OH)_3$ and also intense peaks were noticed for tin, lead and copper.

Characterisation of Bronze Casting : Our Investigations

In general the microstructural studies of the icons revealed that very large pores and cavities combined with gray phases and globular particles are present. However, the present day Swamimalai icon showed small and medium size pores and particles which are homogeneously and uniformly distributed. The microhardness measurements indicated that all these icons fall within a range of hardness values indicating insignificant variations in their strength values. The SIMS analysis showed interesting observations with respect to the surface composition and distribution of alloying elements. Lead was found invariably enriched on the surface of all icons irrespective of the changes in their chemical composition as shown in Table 2.4. Such an enrichment of lead was reported by R. Cesareo et. al [49] while analysing several bronze icons by X-ray fluorescence method. Also depletion of tin was noticed for all the samples, and the enrichment of both aluminium and carbon was also observed.

XRD analysis of the soil (Table 6.4) indicated that main constituent of the soil is silica and cuprous oxide, in *addition to copper chloride*. The presence of copper chloride indicated that the soil is corrosive and it contained salt. A large variation is noticed with respect to the presence of elements including copper. For example, one of the soil samples did not show any metallic elements, the other two showed the presence of all elements. The chemical analysis of the icons (Table 2.3) showed the presence of copper, tin, lead and zinc in all icons. However, the zinc content is lesser in comparison with lead and tin. Iron, arsenic and antimony were also present in trace quantities. The other alloying elements could have been due to their coexistence with copper ore. The ancient technologists were not using refined copper as this was invented only in 19th century AD. The crude copper metal will invariably contain these elements in sufficient quantities. Lead is the most important alloying element [30] which can give important contribution to the casting technology of the bronze icons. The deliberate addition was demanded for the flexibility in the casting of the icons. The presence of lead which is not soluble in copper would fill up the cavities and increases the pressure tightness of the castings. In addition, during initial stages of corrosion lead is interacting with the surroundings to form lead dioxide, sulphate and carbonate particles which enrich the surface. In the ancient tin bronzes the presence of tin was attributed to the use of copper ores containing tin stones [52]. Historical evidences show that the Sumerian civilisation was the first to develop high quality bronze articles during 3500 B.C. which contained about 10 to 15% tin. The tin content in the present alloys are about 1 to 5% falling in the solid solubility limit and hence the presence of delta phase compound $Cu_{31}Sn_8$ is ruled out. It has also been reported [52] that the cast bronzes containing more than 5% tin only will precipitate $Cu_{31}Sn_8$ unless it is extremely slowly cooled. In addition the presence of ε-phase is not possible in these alloys as there is no thermal input of the order of 350°C for longer duration beyond 1000h to initiate such precipitation. The absence of above phases will improve the corrosion resistance of these icons. However, when zinc is added in small quantities to the bronze as in the present alloys, it goes into the primary alpha phase which would not significantly affect the corrosion resistance. The microstructure of the present alloys showed the presence of cored alpha-phase of Cu-Sn-Zn due to the long freezing range, with lead present as dark interdendritic globular particles in all alloys.

> Characterisation describes those features of the composition and structure including defects of a material that are significant to a particular preparation, study of the properties or use and suffices for the reproduction of the material

***

Chapter 7

Conservation

(Baldev Raj, U. Kamachi Mudali* and V. Jeyaraj**)*

Conservation is an art of preserving the originality of an object without doing any alteration to the features of the object, by applying natural, physical and chemical methods. The term 'conservation' is different from 'repair' or 'restoration' in the sense that the former is used even to protect a repaired or restored object. In better description, conservation is the term now-a-days frequently used for a profession which takes action to determine the nature or properties of materials used in any kind of natural holdings or in their housing, handling or treatment; any action taken to betterment the condition of such holdings [54-56]. Restoration is any action taken to bring the object, as far as possible, to its original state. Therefore, conservation also includes both restoration and preservation.

It is a common practice in the rural areas of India, to apply a soil coating to the outer bottom of brass or any other metallic vessels used for cooking to avoid chemical reaction due to direct heating. Also, similar practice was followed while burying such metallic vessels for longer storage of food and agricultural products. This was the simplest conservation method that a common man of our country adopted to preserve the materials from any deterioration to the metallic objects. Once the cooking or the intended storage was over the coated portion of the vessels were removed by washing with water to bring back the original lusture and metallic brightness. While considering such protection offered to the house-hold utensils of day-to-day use, nature provided a wonderful conservation mechanism to the objects buried with her, either intentionally or for safety, for over many a hundred year. The formation of a soiled coating or a *patina* or a corrosion product covered over the surface protected objects like idols, vessels, coins, jewelleries, weapons, ornaments and many other valuable items from the danger of being destroyed or eaten away by the soil during the burial.

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** *Government Museum, Chennai*

7.1 Why Conservation is Necessary?

Any metal, when exposed to an atmosphere, interacts with the surroundings and form corrosion products, exception being gold and platinum to some extent. When the metal objects were buried under the soil, the objects react with the soil depending on the resistance or conductivity, salinity, basicity, oxidising agents, air, sulphur compounds, organic matters, bacteria, acidity, etc., of the soil. Thermodynamically, the initial reactions were rapid, but kinetically the reactions were slowed down with the time showing that a stability or an equilibrium between the deteriorated metal and its surroundings is maintained. This particular state of equilibrium was maintained for over many hundreds of years until the object was excavated or chance discovered from the site. However, the equilibrium is disturbed once an object is excavated and exposed to an entirely different environment leading to further deterioration of the object. The metallic object that was excavated is not available in its original condition and it had to be brought back to its original state after removing the adherent mud and corrosion products from its surface. Moreover, the damages to the object during the process of recovering the object, should be corrected to restore the object to its original state. After this it is important to keep them in an environmental condition which will not be harmful to the objects. Thus, conservation as a profession plays a major role in preserving the invaluable metallic antiquities considering all the above aspects.

There is a relationship between the composition and fabrication of the object, corrosion and conservation. Conservation of bronze icons of Chola period has a great technological impact. The superiority of the casting methodology adopted by them during 7th to 14th centuries A.D. has been discussed in the previous chapters. The study on metals has multiple benefits, like (1) understanding the science behind the casting technology and use of such technology for modern materials casting, (2) the alloying elements used in such castings and their role in preserving the icons with a well-developed *patina* over many a hundred years, (3) the art and science of various *patinas* developed over the surface, and (4) preserving the icons for posterity without causing damage to the surface. Most important is the preservation of such technologically superior bronze icons in museum's galleries and other places like temples, and it could be possible only by evolving suitable conservation methods that can preserve these icons for posterity.

7.2 History of Conservation

The ancient metallurgists were well aware of corrosion and often protected objects by adding noble metals like gold and silver. For example, a horse object was found with heavy layers of rust, but when restored the object was found to be coated with silver [57]. The application of chemistry to the study of decay and conservation of antiquities is not new. While Michael Faraday studied the deterioration of metals during the middle of 19th century, others were already applying the methods of chemical analysis to determine the composition of objects particularly those made of metal. Friedrich Rathgen, who headed the laboratory in the Royal Museums in the Great Britain from 1888 to 1927 might be the first conservation scientist employed for conservation of metallic antiquities. The study of the history of various traditional conservation methods in India is much interesting. Since the metals are prone to deterioration, various preservation treatments were done traditionally by using naturally available materials like oil, flour, ash, sandal powder etc. In Europe before the second World War natural adhesives such as fish or animal skin glue, natural gums, resins, and waxes, shellac and plaster of Paris were used for the restoration of objects. Conservation was never considered in the past as a nonethical problem as it would either make the object safer from further deterioration, or will enable further handling and observation to appreciate the object. However, what is more important is that the recording of the details of the object while recovered so that it would contribute to the history of conservation. One of the finest examples of conservation in the nineteenth century [58] was the deceptive restoration of a life-size Roman Bronze statue of Apollo in the British Museum. When the object was brought to the museum it appeared to be in a good condition, although a split had appeared in one arm and the feet were thought to be restored. It had false patination and when the paint at the surface was removed it was noticed that the statue was extensively restored by addition of both feet and one hand. In addition it had been restored by inserting a wrought iron support inside one arm and this has caused considerable corrosion of the original bronze to split. Presently, this statue has been displayed with original condition after removing the false patination.

7.3 Conservation of Bronzes

Chemical, physical and mechanical methods, either singly or together, are necessary for the conservation of any object received for the purpose [55]. In chemical methods, electrochemical reduction, intensive washing and drying are adopted extensively. Mechanical means, employing chipping, scraping, grinding, cutting, brushing, sand-blasting, polishing and burnishing. Physical methods include various analytical and nondestructive methods used for studying the nature, composition and other properties of objects, both qualitatively and quantitatively.

There are two types of conservation methods adopted in the museums, namely, preventive conservation and interventive conservation. Planning for preventive conservation in a new museum, a museum expansion or renovation involves the proper co-ordination between the museum staff and proper knowledge about conservation so that the needs of the museum collection are met in brief; and that they continue to be met through the design process in construction, building operation and maintenance. Preventive conservation involves three broad categories : (i) environmental standards (relative humidity, temperature, light levels, air cleanliness etc.), (ii) fire, security and safety factors, and (iii) design specifications.

Interventive conservation is the conservation intervening the natural and physical decay taking place. The three important factors associating with this are, removal of accretion, stabilising and arresting damages and consolidation and protection.

7.4 Corrosion and *Patina* Formation in Bronzes

When metals are buried in the soil, the rate of corrosion is intensified depending on the degree of acidity of the soil, its porosity and the presence of naturally occurring soluble salts, air, organic matter, bacteria, etc., adjacent to them. Metals that have been buried and have already suffered some degree of corrosion would have comparatively a porous surface and are liable to retain traces of such salts. Often these salts are sealed up in what may be a stable *incrustation* or *patina*, but should they be exposed to moisture and oxygen they are likely to cause fresh activity with consequent pitting of the surface and possible disfigurement [59]. Metals behave indifferently to their surroundings, sometimes with a progressive growth of the surface layers, which is stable and permanent, or tend to inhibit further reaction after a preliminary growth. A corrosion product of copper, *patina* that has developed slowly may offer many advantages, including evidence of antiquity, aesthetic value, quality of casting, nature of soil and environ-

Pl. 7.1 Photograph of ancient bronze Icon having well developed *Patina* and a heavily corroded surface

Pl. 7.2 Corroding bronzes with the appearance of characteristic pale green powdery spots referred to as *Bronze Disease*

ment etc. It is necessary therefore to consider also the preservation of the *patina* when these may be taken as evidence of age or add to the aesthetic value of the antiquity. However, the *mineral patina* which is apparently quite stable may become unstable if exposed to normal atmosphere. When corrosion starts on such cases, it becomes very difficult to arrest it without serious loss of surface appearance. Plate 7.1 shows the ancient bronze icon having well-developed *patina* and corroded surface.

When buried in soil, copper and bronze objects soon loose their metallic lusture. The oxide layer developed over the surface keeps increasing the thickness, and cuprous oxide becomes compacted into the purplish-red mineral known as

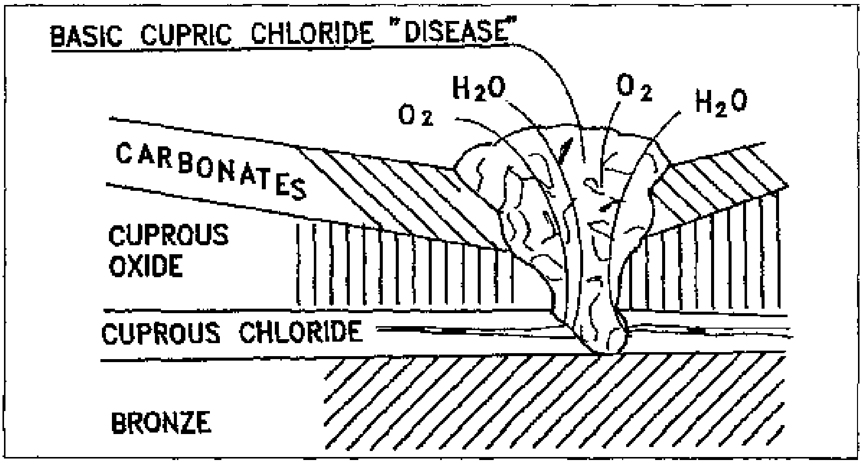

Fig 7.1 Corrosion reactions responsible for *bronze weeping*

cuprite. This in turn becomes encrusted with basic copper carbonate which is green or sometimes blue in colour corresponding to the minerals malachite and azurite. Such incrustations are stable when free from chloride and they protect the underlying metal from further corrosion.

It is not correct that all green incrustations are stable. Appearance has little to do with the stability, even though it is generally true that a thin coherent deposit is more likely to be stable than a heavy porous incrustation that would tend to behave like a sponge and absorb moisture and soluble salts from soil. When more than one metal is present as with tin bronze, it is only to be expected that incrustation will be more complicated both in composition and structure and therefore more liable to contain and retain many salts. In the case of bronzes, the presence of unstable chlorides in the incrustation poses an acute problem from the point of view of conservation. This cuprous chloride continues to react, and therefore corrosion progresses even under museum conditions so that the surface becomes powdery within a short period (Figure 7.1). So common are these features in corroding bronzes that the appearance of characteristic pale green powdery spots was referred to as bronze disease (Plate 7.2).

7.5 Factors Influencing Corrosion of Bronzes

A definition which covers the subject of corrosion as applied to works of art would be the reaction of the metal to its chemical and electrochemical environment, which reaction may result in compounds brought about either by the destruction of the metal or to form a protective film of the most stable compound of the metal. The formation of layered structure on the surface of ancient artefacts of copper and its alloys have been suggested due to chemical and/or electrochemical reaction mechanisms [60]. Some corrosion products on the copper antiquities identified are red cuprous oxide (Cu_2O), black cupric oxide (CuO), greenish blue malachite ($CuCO_3$ $Cu(OH_2)$), blackish green atacamite and paratacamite [$Cu_2(OH)_3Cl$], azurite [$2Cu$ $CO_3Cu(OH)_2$], blackish grey Chalcopyrite ($CuFeS_2$), etc. The corrosion that occurs on the alloys of copper such as bronze, brass etc., is dominated by the chemistry of copper, and the major elements present in the alloy. The main corrosion encountered in bronzes and allied materials has been termed as ***bronze disease***. Bronze disease is a form of pitting corrosion where, the metal constituents present in the alloy being at the lower side of the electromotive series with respect to the major metal copper is actively dissolved by the corrosive agents and the corrosion products get deposited in the pitted points.

One probable mechanism for the underground corrosion of bronze is described in which strata of cuprous chloride, cuprous oxide, and basic copper carbonate are found in succession from the metal to the surface (Figure 7.2a). The cuprous chloride is usually present at the interface between metal and cuprous oxide. Cuprous chloride is known to react in the reversible manner with water to form both cuprous oxide and hydrochloric acid. However, cuprous chloride is again regenerated, and thus copper metal continuously corrodes with the net result that the layer of chloride moves steadily forward into the metal (Figure 7.2b). At areas of loosely covered layers of minerals, air and moisture may enter sufficiently rapidly to convert compact cuprous chloride into bulky basic cupric chloride. This compound easily breaks out at the surface allowing free entry of oxygen. The loose

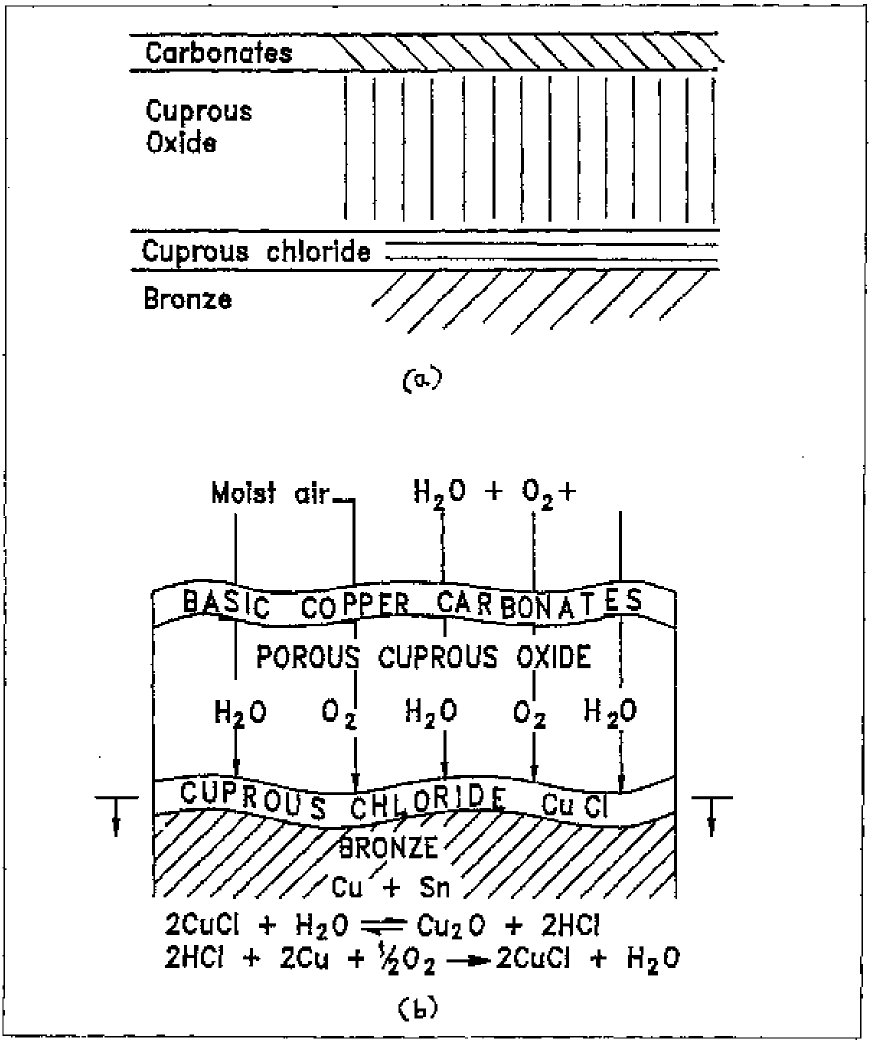

Fig. 7.2 (a&b) Structure of a well-developed *patina* and mechanism for the underground corrosion of bronzes

Pl. 7.3 Photograph showing the bronze Icon with malignant *patina*

Pl. 7.4 Photograph showing the bronze Icon which has undergone *Bronze Weeping*

Pl. 7.5 Photograph showing the bronze Icon with *Brown Patina*

Pl. 7.6 Photograph showing the bronze Icon with ***Edel Patina***

powder that is formed is generally referred as malignant *patina* (Plate 7.3).

It was noticed at the bronze gallery of the Government Museum, Madras [59] that some bronze icons in high humid conditions (up to 96% R.H.) especially during winter, ooze out a liquid that runs out as a streak and leaves bluish white streaky deposits on drying (Plate 7.4). Sometimes bronze icons perspire which when dried becomes white which is due to the leaching of lead to the surface. This liquid on analysis was found to contain chloride, copper, lead and strontium ions, the major constituent being basic copper chloride. This was referred to [55] as *weeping of bronzes*.

Under ambient temperature in the presence of atmospheric air, copper reacts with oxygen, an oxidant, to form a layer of cuprous oxide. The object becomes covered with the familiar brown *patina* (Plate 7.5) of bronzes which constitute a protective layer conforming to the original contours of the object. This copper (I) oxide may subsequently be oxidised to form copper (II) compounds which are characterised by blue-green colour. Basic copper nitrates, sulphates, and carbonates were the end products of the continued combined effects of air, water (moisture), carbonate present in the soil, carbon dioxide and pollutants like oxides of nitrogen and sulphur on copper and its alloys. Once formed, such *patinas* are stable for centuries and is called edel *patina* (Plate 7.6) which imparts an aesthetic beauty to the artefacts.

7.6 Conservation Chemistry of Bronze Objects

Corrosion from the surface to the core of the copper based objects causes considerable destruction to the original surface including its shape, colour, texture, appearance, dimensions and details like inscription—the first three physical properties determine the aesthetic and antique values of the object. Additionally, corrosion products on the objects often become conglomerated with the minerals around them considerably adding to the general grotesque disfiguration of the artefacts.

As a rule, a detailed examination of the corrosion products and siliceous layers is essential prior to removal of anything from the surface. Hurried conservation treatment without careful pretreatment examination can mar intrinsic factors which may reveal history of the period at which they were made. Knowledge of the deposit helps in the choice of right approach to the conservation method.

After the preliminary examination of the whole corroded object, qualitative chemical analyses are to be performed on the corrosion products carefully scraped out of the bronze antiquities. Results often reveal, that they are closely related to some naturally occurring mineral/ore form of the metal constituents present in the alloy. Oxides, halides, sulphides, sulphates and carbonates are some of the less complex commonly encountered corrosion products formed on metallic antiquities. Hanna Jedrzejewska [61] has brought out some new experiments in the conservation of ancient bronzes which includes impermeabilization, using an internal hydrophobic impregnation instead of the conventional surface coatings for the removal of corrosion products and then conserving the bronzes.

An in-depth knowledge of the chemistry and mechanism of the corrosion products and corrosion respectively on different metals/alloys is essential before one selects a particular conservation method. The two main objectives of conservation of metals are: (i) removal of corrosion products and (ii) arresting further corrosion.

7.6.1 Removal of Corrosion Products

The deleterious corrosion products on metallic artefacts should be thoroughly removed in order to prevent further corrosion of the artefacts. The removal of corrosion products can be effected either by (a) physical, (b) chemical, (c) electrochemical/electrolytic methods or (d) by the combination of one or more of the above methods.

(a) Physical Method:

The corrosion products alongwith the siliceous materials can conveniently be removed physically by simple mechanical tools such as pin, scalpel, chisel, hammer, mechanically operated vibro-tool, sand-blasting etc. The areas exposed after the unwanted corrosion products thus removed are given a final rub with fine emery paper to bring out the inner *patina* layer to relief for adding aesthetic beauty to the objects. Mechanical means of removing deposits have the advantage over chemical means in that the former methods do not introduce or leave behind any additional chemical changes on the metal artefacts.

Ultrasonic methods can be used to remove the extraneous silicious matter by immersing the objects in a detergent solution contained in an ultrasonic cleaner. Vibro-tool may also be used to get rid of loose adherent soil and dirt. However, this technique calls for extreme care, for lack of it this may damage the finer workmanship of the artefacts. Air abrasion and laser cleaning can also be of use. Laser cleaning of bronze objects have brought out very good results.

(b) Chemical Method :

Usually chemicals which can dissolve or form soluble complexes with the corrosion products are used to remove the deleterious materials from the objects. Only mild chemicals and very dilute solutions are used to remove the corrosion products without affecting the metal beneath.

If chloride salts are present in bronze antiquities, the antiquities are soaked for a few weeks in an aqueous solution of sodium sesquicarbonate (equal proportions of sodium carbonate and bicarbonate). The complete removal of the corrosion products is indicated by the carbonate solution acquiring the faintest blue tinge. By this procedure the metal chlorides get converted into oxides and/or to other harmless yet protective corrosive products and thereby the metallic artefacts are protected and preserved [62].

Buried bronze antiquities coated with heavy white deposits of calcareous materials such as calcium carbonate and magnesium carbonate are soaked for about a week in 5% aqueous sodium hexametaphosphate in which the calcareous deposits are soluble. The 'bronze diseased' bronze or brass or copper objects may be treated with alkaline Rochelle salt solution (15 gms of Rochelle salt i.e. sodium potassium tartrate, 5 gms of sodium hydroxide and 80 ml of distilled water). This solution completely removes the corrosion products of copper and the oxide layer is exposed. Red copper II oxide is removed by treating the object with a 10% citric acid solution, but the surface is found to be rough because of pitting of the metal by citric acid. 10% ammonia is used to remove the copper corrosion products as ammonia forms a complex with the copper chloride. Also, a 5% EDTA solution is used to remove corrosion products.

(c) Electrochemical/Electrolytic Reduction :

The electrochemical reduction [63] involves the reduction of the corrosion products by nascent hydrogen evolved by the action of 10% sodium hydroxide on zinc granules/powder on the affected spots. Reduction is usually carried out (Figure 7.3) in an electrolytic cell keeping the antiquity as the cathode with two strips of stainless steel gauze suspended on either side of the object or a cylinder of the same material enclosing the object all round as the anode, in a 5% aqueous sodium hydroxide/sodium carbonate/acetic acid or formic acid electrolytic bath. Current was passed at an optimum current density (2 amps per square foot with respect to cathodic

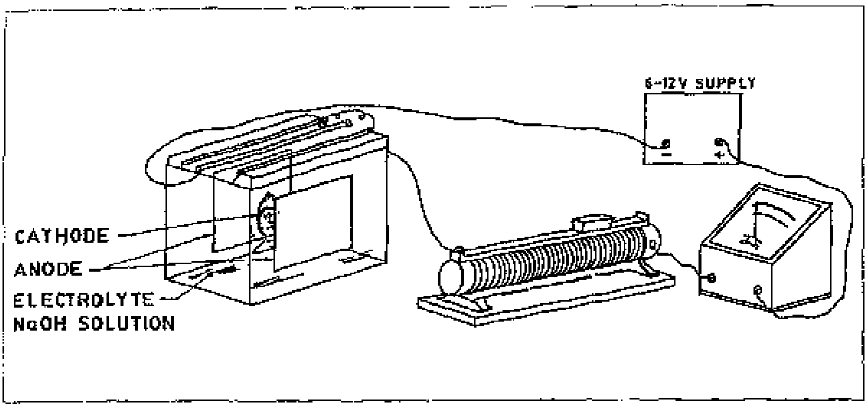

Fig. 7.3 Experimental setup used for electrolytic reduction

object) from a direct current power supply for a few to several hours, depending on the thickness of the encrustation. The corrosion products on the antiquity are reduced and removed by alternate brushing and washing until the hidden details are exposed with all its intrinsic artistic details. Prolonged immersion of the object in the alkaline bath will remove lead from the object. Therefore continuous power supply and less duration of electrolysis is preferred.

(d) Electrolytic Brushing :

In the case of large sized, non-transportable bronze objects (which cannot be easily shifted from the galleries/stores to the laboratory) a localised treatment of a slightly modified electrolytic method is resorted to, with good success. The metal object affected by corrosion is connected to a 12 volt direct current power supply and the electrolyte impregnated sponge is pressed on the affected spot. Electrolytic reduction takes place and the spots get reduced to the corresponding metal. This process has been very successfully used for local treatment and conservation of bronze icons [60].

The bronze icons with areas affected by weeping are locally cleaned by electrolytic brushing. Since the holes found at the weeping spots are just able to take the finest needle of a syringe, the liquid collected in the holes is first syringed out. When numerous holes are present in the icon, the surface of the affected object is poulticed with moist neutral paper pulp and the same is removed when dry. The procedure is repeated till the paper pulp removed give a negative test for chloride.

(e) Intensive Washing :

Intensive washing [63] is the last step but definitely not the least in importance in the conservation of artefacts. Unless the treated objects are washed completely the residual chemicals(s) left behind on the objects will once again react with metal and the corrosion cycle will be repeated again. Therefore, washing should be intensive and though in the final stages especially with methods involving chemical treatment. The last residual salts in the treated objects are eliminated by prolonged repeated soaking of the objects in distilled water to ensure removal of chemicals.

7.7. Arresting Corrosion by Consolidation and Protective Coating

The metallic antiquities which are very fragile and highly mineralised need to be packed up with wax/resin. This process is called localised consolidation [56]. Consolidation can be done with 10% wax dissolved in benzene or by vacuum impregnation. A 2-3% polyvinyl acetate in acetone, toluene or acetone-toluene mixture can either be coated on the object or vacuum impregnated. In the case of fragile bronzes, the missing corroded portion after treatment are filled and modeled with resins like M-seal or Paraloid B 72 mixed with suitable acrylic colours.

In most of the excavated and treasure-trove objects, it is seen that corrosion has proceeded to an extreme stage where very little metal is left intact. In such cases, objects can best be conserved by stabilising the corrosion products formed. Spots of bronze disease formed over protective layer of *patina* may be mechanically removed. The pits found are then filled with a fine paste of silver oxide (in alcohol/water). Insoluble silver chloride thus formed seals off the underlying harmful effect of copper (II) chloride arresting further corrosion. Sodium sesquicarbonate solution dissolves the copper(II) chloride (bronze disease) without affecting the copper(II) carbonate (protective *patina*). Zinc dust in place of silver oxide may also be used effectively. Therefore prolonged immersion of the bronze diseased antiquity in a solution of 10% sodium sesquicarbonate removes the chlorides and stabilizes the carbonate *patina* formed on copper alloy antiquities.

Benzotriazole (BTA) in water or alcohol forms a complex with cupric chloride and oxides. This inhibition procedure can also be adopted to arrest further corrosion. Benzotriazole in water is preferred to benzotriazole in alcohol in the cases of antiquities with thick layer of bronze disease as the former slowly but surely penetrates into the core of the metal-the evaporation of water mixture being slow compared to benzotriazole-alcohol treatment. This is the most effective method for the conservation of copper and bronze archaeological antiquities [56] affected with bronze-disease. One of the methods of preventing "bronze disease" in antiquities is to maintain the antiquity in a dry atmosphere (45-60% R.H.). Under such conditions the spreading of further corrosion is arrested.

7.8 Conservation in the Future

The continuing corrosion of bronzes is often due to the deep-seated chloride, particularly cuprous chloride on the surface. The complete removal of chlorides from the surface is very difficult unless drastic treatments are given to remove all the corrosion products from the surface which might lead to disfigurement of the object. In cases where corrosion is not excessive, removal of corrosion products may be acceptable, but in many cases the result is effectively to destroy the object by 'nibbling' away at its outline and often making holes in areas where the corrosion process is complete. As far as the cleaning of the bronzes without removing the corrosion products is concerned, early treatments attempted to dissolve only the cuprous chloride, while the recent approach has been to isolate the chloride from the effects of the atmosphere by forming an insoluble complex with benzotriazole.

The next problem is that of the conservation of the bronze icons which stands open in the air in the museum, galleries, temples or other places. The rising levels of industrial pollutants have led to serious concern about the safety of some of the objects already kept in open air. Removal of the originals and replacing them with replicas can never be the universal answer for this as there are many valuable icons and the cost of making the replicas are very high. One another possibility is to apply a water-repellent colourless silicon coat, on the top of the icons stored or kept in open atmosphere. The development of artificial *patina* over the surface by chemical and electrochemical methods should also be considered. The possibility of cathodic protection of such icons by connecting to a less noble metal also exists. The utilimate aim of conservation should be to exploit the technological and environmental evidence which may be preserved in the corrosion layers of the bronze icons. Unfortunately, this evidence is often lost between the moment of the excavation and the time the icons go for display or into the storage. During this period, these icons are usually handled by archaeologists and/or conservators, and the cleaning operation of the metal generally leaves an important information related to the icon. One of the most common types of 'fossilized' evidence is traces of textile which have been preserved by being impregnated with corrosion products. All remains of the metal objects are very valuable and should be thoroughly examined for any details. The final important point is the comparison of the technological aspects of the excavated objects with that of the modern metals. If such comparison is made one enormous difference will often be noticed is the lack of corrosion and the superiority of the casting technology and composition.

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Chapter 8

Quo Vadis ?

South Indian bronzes have been the focal point of attraction for many a researcher. A number of excellent treatises are available which dwell on the aesthetic beauty, casting traditions, composition, etc. However, while all these are individual and independent texts, this Monograph combines and highlights the salient aspects of aesthetic beauty, technological excellence of casting, characterisation and conservation of bronze icons. In this Chapter, we attempt to identify new directions and initiate travel in these directions by walking with our distinguished co-traveller (reader) the first few steps.

The tenets prescribed in the *Agamas(S)* and the methods of icon casting are intimately woven and practised since long to the current date. This tradition raises a valid question as to whether the *Agamas(S)* recommend the practising methodologies based on the knowledge of properties of the metals/alloys and casting technology or these merely acted as guidelines and formed a strong link in the long chain of experiences in a tradition that is based on fuzzy concepts and practised based on enlightened wisdom gathered through heuristic approaches by a few enlightened ancient metal workers. A detailed study into this aspect would definitely help depict a new perspective on the origin of the *Agamas(S)* and the practice of icon casting. Surely, knowing about the evolution of these antique marvels would continue to attract the attention of interested investigators.

The second aspect of bronze icon casting has to do with the choice of the alloy. The developments in the field of science and technology are such that current artisans and the *sthapatis(T)* must be in a position, to choose a certain copper alloy, whose properties are better than that of a developed composition in ancient times, in terms of castability, polishing, casting without defects, lower melting point, etc. However, the scriptural commands of the *Agamas(S)* would definitely prohibit the choice of these new alloys and the use of these icons (cast with an alloy other than the traditional bronze) for religious purposes. Yet, this is one direction which can lead to professional making of icons par excellence in the modern times.

The third important aspect relates to the identification, analysis and retrieval of bronze icons that are outside India. One of the prime objectives of the investigations done on the icons, as reported in this monograph, is to fingerprint each of the valuable icons, so that we characterise these wonderful antiquities without any ambiguity so that in case these are stolen, we can prove our absolute right in international courts of law to retrieve the same. We should also focus on the retrieval of Indian bronze icons from abroad. It must be mentioned that the results of scientific investigation and characterisation mentioned in this monograph are exclusively from icons/samples that are avilable in India. These however, represent only a fraction of the total Indian Bronze Icon Treasure. A logical extension of this study would be to fingerprint and characterise those icons which are outside India. Such a study would also fill in the missing gaps in our understanding of the art and technology of South Indian bronzes right from its inception to the advanced stage of evolution.

We must spread the message of using the most modern methods of characterisation of these icons, culminating in cataloguing these priceless treasures, physically and chemically, for posterity. Cataloguing from stylistic points of view has been attempted earlier. Yet, there is no catalogue of these objects of priceless value in museums and places of worship from a scientific and technological point of view. At this juncture, it should also be mentioned that about 300 priceless icons that are presently preserved at the Thanjavur Art Gallery, have not yet been subjected to even simple scientific nondestructive investigations. Such a catalogue, which would describe the physical, chemical and metallurgical aspects of each of the icons, both in India and abroad, would serve as an authentic library of fingerprints of these ancient treasures made by our ancestors for us.

Conservation of priceless south Indian bronze icons is the most important issue requiring our immediate action plan with clear strategy. With the aid of modern scientific tools, it is indeed possible to prevent the deleterious effects of environment and a variety of other related factors responsible for deterioration in the beauty and aesthetic quality of these icons. The valued treasures must be restored, conserved and preserved so that the same can be cherished by our great grand children and future generations too.

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Glossary

Aayathi Kanitham (T) : The science of the calculation of the size of the icon, which is regulated through the match-parameters. A maximum of sixteen match-parameters are usually calculated and studied.

Adavallan (T) : Nataraja idol, cast during the construction of the Brihadeeshwara temple in Thanjavur, by the great Chola (T) emperor, Rajaraja Chola. This idol is still under worship in the temple. Also, a general name given to such Nataraja idols during the Chola(T) reign.

Agni Purana(S) : An ancient text, that describes the process of bronze casting.

Angaratnanyasa(S) : A procedure in which different precious stones and gems are placed over various parts of an icon (head, forehead, neck, chest, stomach, feet and hands), prior to the opening of its eyes.

Ashtabhandhana(S) : Procedure for securing a stone idol onto its pedestal. It involves the grinding of certain well known domestic chemicals, which when crushed in combination becomes a paste. This paste is applied between the icon and the pedestal. When dried, this paste becomes as hard as metal.

Ashtaloha(S) : Eight components, namely gold, silver, copper, iron, lead, mercury, zinc and tin, that were used in North India for casting icons.

Bhava(S) : Expression on the face of an icon/idol.

Bijanyasa(S) : The procedure in which nine types of seeds/cereals are placed on the sides of the pits in the pedestal, before fixing the idol onto the pedestal.

Brihadeeshwara Temple : The temple built by the great Chola (T) emperor, Rajaraja chola

Chera(T) Dynasty : A dynasty of Tamil rulers belonging to the Sangam period, who ruled parts of South India, with Karur Vanci as their capital.

Chola(T) Dynasty : A dynasty of Tamil rulers who ruled large parts of South India. Nearly 23 Chola(T) rulers reigned for over 400 years i.e., from about 850 A.D. to 1275 A.D.

Cire Perdue Casting : French term for the casting procedure by which the model is made initially in wax, over which a coating of clay is given. The clay coating is dried and heated to remove the wax. Liquid metal / alloy is pured into the mould to take the place and shape of the wax.

Dasha Aayathi(S) : Refer Aayathi Kanitham, above; if ten parameters match, it is then called Dasa Aayathi.

Dhaanyadhivasam(S) : To lay the Icon on a bed of cereals, covered on all the four sides by screens, before opening the eyes of the icon.

Dhatunyasa(S) : The procedure in which nine types of minerals/ chemicals are placed on the sides of the pits in the pedestal, before fixing the idol onto the pedestal.

Dyanaslokas(S) : Sacred chantings invoking the God, before starting the process of wax modelling / icon casting.

Hastas(S) : Expressions made with single or both the hands; also known as Mudras.

Iconography : Accurate shapes (as described in the Shilpasasthras) of the icons.

Iconometry : Accurate measurements (as described in the Shilpasasthras) of the icons.

Jalathivasam(S) : The procedure in which the icon is taken, three days (five or even seven days, sometimes) before the consecration, placed in either a tank or a river, and to offer prayers. If the icon is placed in a tank, then it is filled with clean water mixed with a variety of perfumes and sandal paste.

Jatibhandhana(S) : A procedure for securing of the (metallic) icon with the pedestal by pouring liquid gold (or silver) around the crevices of the icon-pedestal joint. This is later polished and finished in manner that the icon-pedestal joint is invisible.

Kungilyam(T) : Dammar; used in making the wax for the initial model of the icon.

Lakshanas(S) : The accepted ways of depicting each of the body parts of an icon.

Madhuchchishtavidhana(S) : Sanskrit word for Cire perdue casting; Madhu is wax.

Manasara : An ancient text that describes the procedure of icon casting using the Cire perdue process; compiled during the Gupta period.

Manasollosa(S) : An important work, belonging to the later period of twelfth century, also called Abilas hitarthachin tamani. This work, authored by the Western Chalukyan King Somesvara Bhulokamalla (A.D. 1127-1138) presents a clear picture of metal casting.

Mayan : The mythological, divine sthapati who builds the castles of Gods and the heavens.

Moolavar : The idol (usually made of stone) that is fixed to its place in the sancturm sanctorum of a temple. Never moved from its place.

Mudras : See Hasthas.

Muzhakkol : The basic measuring scale used for modelling stone icons/idols. Usually made of wood with metal rings on both the sides.

Nayakas Dynasty : The rulers who rose to power during 1600 A.D. to 1700 A.D. in south India. They were the last dynasty to have consciously patronised the art of icon casting.

Odiolai : The basic measuring scale used for modelling bronze icons/idols. Made of coconut leaf strip. It is folded in multiples of two, and the fold markings are used for measurement.

Padi Munn : A type of clay taken from the paddy fields; mixed with coarse sand and water and applied for the second and third thick coatings over the wax model.

Pallava(T) Dynasty : A dynasty of Tamil rulers who ruled from Kanchi as their capital. From about 300 A.D. till 900 A.D. the Pallavas (T) ruled the northern part of Tamilnadu.

Panchaloha : An alloy of five metals (zinc, copper, silver, gold and tin), normally used for making idols.

Pandya Dynasty : A dynasty of Tamil rulers who ruled the southern parts of Tamilnadu, during the Sangam period.

Perunthatchan : A titular name given to the chief architect/*sthapati* in ancient days.

Poojas : Prayers and offerings, performed at pre-determined times and with procedures.

Poorna Aayathi : See Aayathi Kanitham above; if all the sixteen parameters match, the match is called Poorna Aayathi.

Prabhava : The semi-circular or oval shaped metal piece usually placed above an idol.

Prabhavalli : See *Prabhava* above

Rajaraja Chola (T) : The greatest Chola (T) emperor, under whose reign, arts and culture flourished. One who built the Brahadeeswara Temple at Thanjavur.

Ratnanyasa : The procedure in which nine types of gems/precious stones are placed on the sides of the pits in the pedestal, before fixing the idol onto the pedestal.

Rig Veda : The oldest of all *Vedas* (Hindu holy scriptures).

Shaivaite Philosophy : A hindu school of thought centred around Lord Shiva as the focal point of worship.

Sangam Period : The period in the Tamil history dating back to 3rd century B.C. to 2nd century A.D., when arts, culture and Tamil language flourished in south India.

Sayanathivasam : To lay the icon on a bed with pillow, before opening the eyes.

Sembiyan Mahadevi : The wife of Gandaraditya Chola (T), who widowed at an young age, was instrumental in starting her own school of bronze casting; several of the wonderful bronze masterpieces of the Chola (T) reign were cast under her personal supervision. Sembiyan Mahadevi, lived through the periods of Arinjayan, Sundara Chola (T), Uthama Chola (T) and RajaRaja Chola (T), and died in 1001 A.D. Eighteen temples (and the icons in them) were consecrated, under her direct supervision.

Shatayathi : See Aayathi Kanitham above; if six parameters match, the match is called Shatayathi.

Shilpashastras : Religious and scriptural texts that detail the process of icon casting and stone carving.

Silparatna : A medieval period text that describes icon casting.

Sthapati : A Tamil name given to the person who masters the art of either icon casting with metal/alloy or carving with stone.

Tala(S) : The system of measurements used in icon casting or carving. The icons are divided into ten categories according to the ranges of their length, measured in terms of the tala units.

Uttama Dasa Tala : The largest icons belong to the category of *dasa tala* (dasa means ten) and the smallest ones being to the category of Eka tala (Eka means one). Within each of the tala category there are three classes or measures which are termed Uthama (superior), Madhyama (intermediate) and Adhama (inferior). The icons of Brahma, Vishnu (S) and Shiva, the high Gods of Hindu Trinity, are always made to the dimensions of Uthama Dasa Tala; Goddesses Durga, Lakshmi and Saraswathi are made to the dimensions of Madhyama Dasa Tala; and other Gods like the Ayyanars, Shanmugha and the *Nava Grahas* (the nine planets) are made to Adhama Dasa Tala.

Utsavar : The idol that is taken out in procession from a temple; also see Moolavar.

Vaishnavaite Philosophy : A Hindu school of thought centred around Lord Vishnu (S) as the focal point of worship.

Vandal Munn : The clayey sand obtained from the banks of the river Cauvery; this is mixed with fine paddy husk and applied in the first thin coating over the wax model.

Vijayanagara Dynasty : A dynasty of rulers who ruled parts of south India after the Cholas(T), with Vijayanagar as their capital.

Visvakarma : See Mayan.

Yajur Veda : One of the four holy scriptures of Hinduism.

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Bibliography

1. *Cire perdue Casting in Swamimalai* Monograph Series of the Census of India Vol. I. Published by the Office of the Registrar General, India (1961).
2. Douglas Barre : *Early Cola Bronzes*, Bhulabhai Memorial Institute, Bombay India (1965)
3. P.R. Srinivasan, *Bronzes of South India*, Bulletin of the Madras Government Museum (Vol. VIII), (1963)
4. *Indian Bronze Masterpieces*, Festival of India Publication (Ed.) Karl J.Khandalavala, Brijbasi Printers Pvt. Ltd., (1988).
5. R.Nagaswamy,"South Indian Bronzes", in *Indian Bronze Masterpieces*, Festival of India Publication (Ed.) Karl J. Khandalavala, Brijbasi Printers Pvt. Ltd., (1988), pp. 142-179.
6. Antonio Monroy, India, pp. 285-286
7. A. Alagiriswamy,"Sembian Mahadevi - Temples' Constructions", Proc. of the 13th Symposium of Tamil Teachers Society, 1981, pp. 36-41.
8. S.Ganesan *(Kamban Adipodi)* in his foreword in the book,"Chirpa Chennool", by V.Ganapathi Sthapati, published by the Directorate of Technical Education, Government of Tamilnadu, Madras, 1994, p.xi.
9. R. Rajaraman "Role of symmetries in the sciences versus the arts - A contrast", *Current Science*, Vol.73, No.7, 10 October 1997, pp. 570-575.
10. Tustam J. Mehta (Introduction by), *Masterpieces of Indian Bronzes and Metal Sculpture*, D.B. Taraporewala Sons & Co. Pvt. Ltd., Bombay, 1981, p.31.
11. D.R. Thapar, *Icon in Bronze*, Asia Publishing House, Bombay, 1961, p.11.
12. A.K. Coomaraswamy, *History of Indian and Indonesian Art*, London, 1927, P.9.
13. *Ibid.*, p.9.
14. Prithvi K. Agravala, *Some Literary Evidence in the Casting of* Metal Images, *in Early Indian Bronzes*, Prithvi Prakashan, Varanasi, 1977, p. 134, - reference to Ramayana, Baroda Critical Edn., *Balakaanda*, IV, 10.
15. Op. Cit. - reference to Mahabharatha, Poona Critical Edn., *Asvamedhikaparva*, XIV, 18.8.
16. Bimal Bandyopadhyaa, "Some Literacy Texts on Metal Casting", Chapter 4, pp. 59 - 77, in *Metal Sculptures of Eastern India*, published by Sundeep Prakashan, New Delhi, 1981.

17. Op. Cit. - reference to Ratnagothravibhaha, 1.124, E.H. Johnston (Ed.), Patna, 1950, pp. 65-66.

18. Chintamani Kar, *Indian Metal Sculpture*, London, 1952, pp.1.

19. Sir John Marshall, *Taxila*, Cambridge University Press, 1961.

20. Sarpotdhar, Mrinalini,"Copper Bronze Technology", in *History of Science and Technology in India*, (Eds) G.Kuppuram, K. Kumudamani and Sandeep Prakash, Vol VI, 1990, p.209.

21. M.N.Dutt,'*Agnipurana*', (Translation), Calcutta 1903-1904.

22. D.R. Thapar, *Icon in Bronze*, Asia Publishing House, 1961, p. 139.

23. Chintamani Kar, *Op. Cit.*.

24. K.S.Subramaniya Sastry, *Kasyapa Silpa Sastram*, Thanjavur Saraswati Mahal Series No. 89, 1960.

25. S.K. Sarasvati,"An ancient text on the casting of metal images", *JISOA*, Vol. IV, No. 2, Dec. 1936, pp. 141-144.

26. Ruth Reeves, *Cire perdue Casting in India*, 1962, pp. 31-32.

27. K. de B. Codrington, 'Sculpture' in *The Art of India and Pakistan*, The Royal Academy of Arts, London, 1949, p.67.

28. A.Veluchami Sudanthiran, "Patti Mandapam", in *Chinthanai-kinia Chirpakkalai*, Eighth World Tamil Conf. Tamil Univ., Thanjavur, pp. 67 - 104.

29. W.S. Hadaway E.Thurston and Velayuda Asari, *Illustrations of Metal Work in Brass and Copper, mostly in South India*, Madras Government Press, 1913, p.9.

30 E.G. West, *Copper and Its Alloys*, John Wiley & Sons, New York, (1982).

31. Subbarayappa, B.V.:'Chemical Practices and Alchemy' in A *Concise History of Science in India*, New Delhi, 1971 (reprint 1991), p.280.

32. For the following account, see B.V. Subbarayappa : Op. cit. pp. 274-348.

33. Bimal Bandyopadhyay, Op. Cit. p. 64. (Chapter 38 verses 32 - 33 of *Agnipurana* as translated by M.N. Dutt in 1903 - 1904).

34. Baldev Raj, C.Babu Rao and D.K. Bhattacharya, Fingerprinting of South Indian Bronze Idols, *Current Science*, Vol. 62, No. 6, Mar.'92 pp.445-450.

35. In a personal discussion with Mr. Devasenapathi Sthapathi, Swamimalai.

36. V. Ganapathi Sthapati, *Chirpa Chennool*, published by the Directorate of Technical Education, Government of Tamilnadu, Madras, 1994.

37. N.Murugesan, *The Thanjavur Brahadeeswara Temple Built by Emperor Raja Raja Chola* (T), (brought out on the occasion of the consecration of the Temple, in June 1997), published by Srimanth C. Bhabhaji Raja Bhonsle Chatrapati, Senior Prince and Hereditary Trustee of the Brahadeesawara Temple,

Palace, Thanjavur, June 1997.

38. R. Cesareo et. al, NDT Techniques applied to the preservation of Italy's Cultural Heritage, *Insight*, Vol. 39, No. 6, June 1997, pp. 382 - 385.

39. B. Illerhaus, The Principle of Computerised Tomography and its Applications in the Reconstruction of Objects of Art, *Proc. Of College on Advanced Techniques in Archeometry and conservation of Works of Art*, Oct. 17-28, 1994, Italy.

40. British J. of NDT, News desk, Vol. 32, April 1990, p.219.

41. Anon, *Computed Tomography of Ancient Chinese Urns*. Materials Evaluation, Vol. 48, No. 5, May 1990, pp. 599-602.

42. S. Paramasivan, Investigations on Ancient Indian Metallurgy, *Proceedings of the Indian Academy of Sciences*, Vol. XII, No. 2, Section A, (1941).

43. N. Harinarayana, Scientific Examination of Metal Artefacts and Art Objects, *Proc. of Seminar on Ancient Metal Industries of South India*, Tanjore, (1983).

44. V. Jeyaraj, *Correlation Between Composition, Metallographic Structure and Corrosion Products of Metallic Antiquities*, Ph.D Thesis, University of Madras, (1990).

45. Earle R. Caley, Early History and Literature of Archaeological Chemistry, *Journal of Chemical Education*, 28 (1951), pp. 64-66.

46. J. Wocel, *Philosophisch Historiche Classe*, 11 (1853), p. 716; 16 (1855), p. 169.

47. Dr. S. Paramasivan, *Chemical Investigation of Ancient Indian Materials and Industries*, Doctoral Thesis, Madras University (1940).

48. Otto Werner, *Spectrochemical Analysis of Antiques and Modern Indian Bronzes*, Berlin, (1968).

49. R. Cesareo, S. Sciuti and M. Marabelli, Nondestructive Analysis of Ancient Bronzes, *Studies in Conservation*, 18 (1973).

50. F. Garbassi and E. Mello, Surface Spectroscopic Studies on Patinas of Ancient Metal Objects, *Studies in Conservation*, 29 (1984), pp. 172-180.

51. Baldev Raj, U. Kamachi Mudali and C. Rajagopalan, to be published.

52. R.H. Greaves and H. Wrighton, *Practical Microscopical Metallography*, Chapman and Hall Ltd., London (1950), pp. 200-238.

53. *Tin and Its Alloys*, ed., E.S. Hedges, Edward Arnold Publishers Ltd., London (1960).

54. *The Art of Conservation*, Andrew Oddy (ed.), Published by the Trustees of the British Museum, London, UK, (1992).

55. *Conservation in the Tropics*, O.P. Agrawal (ed.), Published by International Centre for Conservation, Rome, Italy, (1972).

56. *Hand Book on Conservation in Museums*, V. Jeyaraj, Government Museum, Chennai, (1995).

57. *Principles of Corrosion Applicable to Ancient Metals and Methods of Identifying Corrosion Products*, Daniel Cushing, in Application of Science in Examination of Works of Art, Boston, 1965.

58. *The Corrosion of Metals on Display*, Andrew Oddy, IIC, London, UK, (1978), pp.235-237.

59. *Archaeological Chemistry*, Zvigoffer, John Wiley & Sons, New York, USA, (1980), pp. 270-274.

60. Some New Experiments in the Conservation of Ancient Bronzes, Hanna Jedrzewska, *Proceedings of Recent Advances in Conservation*, IIC Rome Conference, Butterworths Publishing, London, UK, (1963), pp.135-139.

61. *Conservation of Antiquities and Works of Art*, H.J. Plenderlerth and A.E.A. Werner, Oxford University Press, 1988.

62. Electrolytic Restoration of Bronze Statues and Inscribed Copper Plates, *The Proceedings of the Indian Academy of Sciences*, Vol. XII, No. 2, Section A, (1941).

63. R.M. Organ, *Museum Journal*, 55 (1955), p.112.

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