Alok Kumar Kanungo
Laure Dussubieux *Editors*

Ancient Glass of South Asia

Archaeology, Ethnography and Global Connections

IITGN

Springer

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Foreword

रमेश पोखरियाल 'निशंक'
Ramesh Pokhriyal 'Nishank'

सत्यमेव जयते

शिक्षा मंत्री
भारत सरकार
MINISTER OF EDUCATION
GOVERNMENT OF INDIA

FOREWORD

In the context of capacity-building in higher education and research for providing high-quality training and exposure to cutting-edge techniques a range of initiatives have been put in place by Government of India. The Ministry of Education has implemented a number of grant-schemes such as SPARC, GYAN, VAJRA, etc. for building international collaborations, providing the resources for hosting leading experts from around the world at Indian institutions for extended periods to foster our own faculty and students. The SPARC scheme also, notably, includes paired provisions for Indian faculty and students to spend time gaining training and research experience at foreign universities.

The core format for intellectual exchange, feedback and the advancement of science remains the focus of International conferences organised around those themes. While conferences undoubtedly advance the development of the focused fields, it is essential that for these events to reap enduring rewards, their products be consolidated in the form of themed publications which can continue to serve as instructive resource materials for Indian and international students and researchers. This volume meets this objective squarely.

Over the last decade, heritage studies and archaeology have emerged fields which require expertise and intervention from a wide range of experts drawn from the humanities, social sciences and scientific and technical fields such as material science, chemical analysis and conservation. Answering this need, several educational institutes of national importance are beginning to create spaces to foster such interdisciplinary expertise. One such example is the establishment of Archaeological Sciences Centre (ASC) by IIT Gandhinagar. Besides a number of interdisciplinary activities, ASC has pursued a program of organising conference cum workshops that focus upon a selected archaeological artifact class or material. The aim of these events has been to expose a selected group of students with an acute sense of the specific problems and opportunities that are involved in the study of that material. The motivation has been to host a conversation between the leading experts in the field, and equally to provide hands on training in the ethno archaeological and experimental prospects of that particular field of archaeological research. Notably, the first of these 'conference cum workshops' was held between the 10th and 14th of August 2015 and focused on stone beads. The proceedings of that conference have subsequently appeared as a volume (Kanungo, A.K. (Ed.) 2017. *Stone Beads of South and Southeast Asia: Archaeology, Ethnography and Global Connections*. Gandhinagar / New Delhi: Indian Institute of Technology Gandhinagar / Aryan Books International) as designedly meant to serve as a resource for both the teaching of stone beads and aid further research into them.

PTO

स्वच्छ भारत

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Continuation Sheet

The book in hand *Ancient Glass of South Asia – Archaeology, Ethnography and Global Connection* edited by SPARC awardee Alok Kumar Kanungo and one of the leading archaeological chemists of the world Dr. Laure Dussubieux of the Field Museum, Chicago interrogates a glass-making technology that is over 3,500 years old. It highlights how innovative ancient Indian artisans were who developed a single-ingredient recipe, unique in premodern glassmaking. Using this glass, craftsmen in preindustrial South Asia mass produced these distinctive beads which were then exported to lands as distant as South-East Asia, Africa and Europe in different periods. The volume considers how the history of South Asian glass is defined by a series of technological innovations and successive adaptations of vitreous materials to social and aesthetic customs of different periods of Indian history. These include the design of innovative tank-furnaces, and the extensive use of expediently constructed furnaces allowing for multiple working ports. Notably, Indian craftsmen developed distinctive blown-drawn glass beads in a period prior to the global invention of blown glass vessels. These glass beads were premier Indian exports in the premodern period, reaching African, European, and South-East Asian consumers.

In 1986, the 14th International Congress on Glass was held in Delhi. Its proceedings were published in a volume titled "The Archaeometry of Glass", edited by H.C. Bhardwaj. In a much needed update for the field, for the first time since that Delhi glass conference a major gathering of glass specialists was organised to discuss several issues related to Indian glass. This five-day conference-cum-workshop on *History, Science and Technology of Ancient Indian Glass*, was held between January 21st and 25th, 2019, at IIT Gandhinagar. The 22 articles in this volume result from this conference and provide a series of state-of-the-art interventions and synthesis of the current state of research into Indian glass. Using various approaches including archaeology, archaeometry and ethnography, the contributors of this volume placed India in the larger context of ancient glass studies. The individual papers provide insights into different topics such as glass conservation, bead typology, traditional glass bead and bangle making in India, archaeological glass in different regions of India and the diffusion of Indian glass beads around the Indian Ocean and beyond. This volume will constitute a solid foundation for further research in Indian glass and will certainly motivate additional investigations to address unresolved issues about the origin of glass in India, the organisation of its production in ancient times, and the identification, distribution, and chronology of the different Indian glasses.

The chapters of this book, written by some of the most eminent national and international experts in the field, bear testimony to the vast amount of research carried out on these artifacts. Rich contributions in the fields of archaeology, craft traditions, ethnography and literature make this book not only a major reference on South Asian glass, but also a model of cross-disciplinary studies. I hope it will go a long way in fulfilling the textual and research needs of Archaeology.

New Delhi
December, 2020

(Ramesh Pokhriyal 'Nishank')

Preface

The Archaeological Sciences Centre (ASC) at the Indian Institute of Technology Gandhinagar (IITGN) has pursued a programme of organising short-term courses cum workshops/conferences that focus upon a selected archaeological artefact class or material. The aim of these events has been to expose a selected group of students with an acute sense of the specific problems and opportunities that are involved in the study of that material. This has taken shape in hosting a conversation between the leading experts of the field and equally to provide hands-on training in the ethnoarchaeological, experimental and scientific prospects of that particular field of archaeological research.

With these objectives in mind, at these events, the resource persons are invited to speak for 45 min slots and allowing ample time for discussion. In these talks, they are required to address pre-assigned themes and topics that combine their research expertise and knowledge towards the planned content for a volume. These volumes themselves are envisaged not as the collection of papers or conference proceedings; they are intended to be valuable and useful resources on the subject. They are aimed at being useful for both students and researchers and thus to be useful for archaeological syllabi in South Asia and also globally.

The first of these 'conference cum workshops' was held between 10 and 14 August 2015 and focused on stone beads. The proceedings of that conference have subsequently appeared as precisely such a volume meant to serve as a resource for both the teaching of stone beads and to aid further research into them (Kanungo, A.K. 2017. Ed. *Stone Beads of South and Southeast Asia: Archaeology, Ethnography and Global Connections*. Gandhinagar/New Delhi: IIT Gandhinagar/Aryan Books International). The second of such a conference was held from 21 to 25 January 2019 and focused on the History, Science and Technologies of Ancient Indian Glass. The book you are holding is the outcome of this second conference.

The conference brought together a wide range of experts, which included archaeologists who have extensive experience of South Asian proto-glass, glass and archaeological chemists with expertise in the elemental analysis of glass. In addition, it included established ethnohistorians and ethnoarchaeologists of South Asian glass and vitreous materials, alongside craftspeople who brought their lifelong and inherited skill, expertise and knowledge.

These five days of conference cum workshop included four days of academic presentations and two field trips, veritably covering all aspects of the study of glass. These ranged from the origin of glass and faience, to the manufacturing techniques developed at different times in South Asia and the regional distribution of key artefacts both within and as traded far outside the region. Valuably, the talks developed to papers for this book also included detailed introductions and extended examples of the analytical chemistry of ancient glasses. Finally, the field trips gave exposure to the contemporary traditional glass working at Kapadvanj and to the world famous archaeological heritage site of Vadnagar in Gujarat.

The invited craftspeople at this workshop included glass bead-makers from Banaras, stone bead-makers from Khambhat and beading and mirror-stitching craftspeople from the Rabari and Mir communities of north Gujarat. An interesting experimental archaeology workshop on replication of Indus Valley faience technologies was conducted parallelly by Profs. Mark Kenoyer and Massimo Vidale.

These diverse contributions brought together the challenges of studying the history, science and technology of ancient Indian glass in vivid detail. Considered together, they provided the best introduction to the complexities of regional diversity in glass traditions, the archaeometric challenges that stand before the field and the prospects of all we stand to learn from further investigations. The last major collective evaluation of the state of scientific interdisciplinary research on ancient Indian glass had been made in 1987 (*Archaeometry of Glass: Proceedings of the Archaeometry Session of the XIV International Congress on Glass, 1986, New Delhi, India.* Calcutta: Indian Ceramic Society). Similarly, the last monograph that had synthesised the available data on the history of Indian glass was written yet a generation earlier (Dikshit, M.G. 1969. *History of Indian Glass.* [Bombay]: University of Bombay). This book aims at filling precisely this gap. The description above has communicated the efforts made to provide as multifaceted, thorough and valuable an experience to the next generation of researchers, who will hopefully pose research questions and pursue methods of analysis that will build on, extend and exceed those reported here.

The experts and participants at this truly international event were from eleven countries including USA, UK, France, Italy, Denmark, Cyprus, Poland, Malaysia, Thailand, Sri Lanka and India. It was gratifying to see that participants represented 54 universities, research institutes, laboratories, museums and state departments. The sixty student participants had been selected on the basis of prior interest in glass and/or ancient Indian technologies, and the conference-cum-workshop prepared them to embark on diverse research projects of their own.

An ambitious series like this and workshop having a target to publish a time-bound reference manual, covering all related research areas of the topic, are not possible without the vision and support of the head of the Institute, trust of the authorities and tireless team effort of the unit in which we work.

We are indebted to Prof. Sudhir Jain, Director of IITGN, for not only supporting the workshop at every stage but also giving his precious time in meeting the experts, participants and craftsmen who came for the workshop for the welfare of the centre; Prof. Amit Prashant, Dean of Research and Development, Prof. S. P. Mehrotra,

Dean of External Affairs and Co-ordinator of ASC, and Prof. Michel Danino, Co-coordinator of ASC, for all the encouragement; Prof. D. P. Roy for the administrative support without entertaining any excuses yet making no reservations about the required paraphernalia; and Dr. Yadubirsingh Rawat for advocating that we develop a good publication of the outcome. The efforts put by our postdoctoral fellow and nodal officer for the conference, Dr. Oishi Roy, in organizing the event were tremendous. As always, Dr. Trupti More, Librarian of Deccan College Post-Graduate & Research Institute, played her role in promptly providing rare literature and references.

Mr. Yashwant Chouhan and Mr. Shailesh Patani took care of all local logistical support, safety, local transport, campus accommodation and food. Mrs. Sunita Menon left no stone unturned to facilitate the smooth functioning of the workshop. Mr. Hatim A. Sham was the man behind the attractive posters, banners, brochures, invitations, conference tags and visuals. Mr. Devarsh Barbhaya captured the motions of the events. Ms. Shivangi Bhatt made the coordination with media look effortless. A special word of thanks to Dr. Neeldhara Misra for her professional best in managing the visual and media team.

The field visits to Kapadvanj and Vadnagar were made under the guidance of Ahmed Basir Sisgar, proprietor of the Kapadvanj glass mirror workshop, and Dr. Abhijit Ambekar and his team from the Vadodara Excavation Branch of Archaeological Survey of India, respectively.

Our gratitude to all the leading experts who came to IITGN presented their results, trained the students and made sure that the outcome of the workshop in book form was prepared with rigorous scientific and academic standard. Stone bead craftsmen Mr. Anwarhusain Shaikh and Mr. Pratap Bhai of Khambhat; glass bead craftsmen Nandlalji and Krishan-ji from Banaras Beads Limited; and glass beading craftswomen Meghaben Rabari, Ashaben Rabari, Sakinabe Miri, Madinabed Miri and Zanab Miri of Kutch made the workshop an experimental training reality for the participants. Prof. Sonal Mehta of CEPT University and Mrs. Niyati Kukadia of Eklavya Foundation, Ahmedabad, coordinated the beading works.

Dr. Alok Kumar Kanungo would like to add a special thanks to Mrs. Banabasini Kanungo and Dr. Shahida Ansari that have been the two pillars of strength and inspiration for him while organising this conference leading to this book. He is grateful for the regular discussions and the affectionate waiting until he is done with the daily work during the six-month long preparation for the conference.

We would also like to thank Scott Staszak for his help with some English language-related matter.

If we have omitted anyone, we offer our deepest apologies. We once again express our heartfelt thanks to all who have helped in this huge endeavour.

IITGN acknowledges financial support received from the Indian Council for Historical Research (ICHR), the Indian Council of Social Science Research (ICSSR), the National Science and Engineering Research Board (NSERB-DIA), the Gujarat Council on Science and Technology (GUJCOST) and the Directorate of Archaeology—Gujarat State. Gratitude is also expressed to the International Commission on Glass (ICG) and the Elemental Analysis Facility—Field Museum (FM) for timely

support for a few international travels, and to Banaras Beads Ltd. for logistic support for the live glass bead-making display during the conference.

Delegates during the workshop on ‘History, Science and Technology of Ancient Indian Glass’, twenty-first January 2019 at IIT Gandhinagar

Gandhinagar, India
Chicago, USA

Alok Kumar Kanungo
Laure Dussubieux

Introduction

There has been a growing need for books with an international reach focusing on archaeological artefacts from ancient India and South Asia encompassing scientific applications. Glass objects are part of these artefacts that have been neglected by scholars. Glassmaking and glass working are among the early pyrotechnologies and chemistry processes applied by human. Beads and bangles, being small and easy to wear, carry and trade, have been transported thousands of kilometres, across both land and sea. They have a long history of production and use in the Indian subcontinent and are still produced in the present-day traditional craft centres. Their history is preserved in the archaeological record, epigraphy and ancient literature. They are represented in sculpture and paintings, as well. Bead and bangle production techniques encompass a wide range of technologies ranging from simple to highly complex. These technologies developed and evolved through time based on both the creative inspiration of individual craftspeople and the needs to meet the demands of both local and international consumers. Beginning with the earliest glass beads dating to more than 3400 years ago at Bhagwanpura in India, furnace wound glass beads have been mastered in North India for 3000 years and furnace drawn beads have been produced in South India for 2500 years. Quickly, they became most sought-after glass products in the ancient and modern world. These beads and bangles were used by all levels of society as a way to both integrate communities culturally through the use of important symbolic objects and differentiate people by the designs and complexities of production.

This book on ancient glass is the second in a series of books dealing with various artefacts that started with a book on stone beads and demonstrates important continuities from past to present. Ancient artefacts help us to better understand the importance of the past for developing new technologies in future.

The book is divided into five parts. The first of these parts is 'Glass Origin and Evolution' that included four chapters. Thilo Rehren in his chapter on 'The Origin of Glass and the First Glass Industries' introduces the chemistry of glass as a matter of three different components: the sand/quartz base to which a flux is added alongside the third component—a variety of 'spices' to colour, opacify and lend it special qualities. Professor Rehren's paper provides an overview of the complexity involved in the study of trace element contributions from both the flux and colourants. His

paper also stresses the need to locate all archaeometric analysis within a sense of the contemporary glass cultures and elite networks of political economy that sustained them. The chapter on 'Glass in the Middle East and Western Europe at the End of the First Millennium CE, Transition from Natron to Plant Ash Soda or Forest Glasses' by Bernard Gratuze, Nadine Schibille and Inès Pacta addresses the issue of the specificities of the transition from natron glasses to plant ash glasses and 'forest' glasses in the connected spheres of the Middle East and Western Europe at the end of the first millennium. Dr. Gratuze's paper shows what chemical analysis can reveal when are combined an innovative sample selection from well dated assemblages with the precision of Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS). Chapter 'Glazed Steatite and Faience Technology at Harappa, Pakistan (> 3700–1900 BCE): Technological and Experimental Studies of Production and Variation' by Jonathan Mark Kenoyer summarizes the results of more than twenty years of the study of Harappan glazed steatite and faience technologies. The paper provides a sense of the pyrotechnical virtuosity and playfulness with which Harappan craftsmen excelled at the manipulation of this material. Prof. Kenoyer summarizes results not only from the use of a range of instrumental techniques [ICP-MS, scanning electron microscope (SEM) and others] but also from his extensive replication studies. The chapter on 'Traditional Bead and Bangle Crafts in India' by Alok Kumar Kanungo summarises key insights from his ethnoarchaeological work at sites like Papanaidupet, Purdilnagar, Jalesar, Akrabad and Hasayan, to ask Indian archaeologists to be more attentive to the skill, expertise and innovations with which South Asian glass crafts developed and diversified. In doing so, the paper highlights the need to be attentive to the 'when and why' of changes in Indian glass craft traditions, especially in the pre-colonial era, a task in which archaeology can contribute but hitherto has not. Turning to the evidence for production, he argued that the problem in Indian archaeology persisted on account of our expectations as far as the forms of evidence and a misunderstanding of the taphonomic processes that are involved. As a result, the distinctive debris of both glass production and glass working is likely often misrecognized.

There are four chapters under the second part, i.e. 'Scientific Study and Care of Glass'. The chapter on 'Elemental Compositions and Glass Recipes' by Laure Dussubieux provides a synoptic overview of the kinds of questions which can be chemically asked of glass artefacts. Dr. Dussubieux very usefully organises these into three kinds of questions. First are questions that can be asked of glass making: (who made glass, where, with what technology, which ingredients, and what was the organisation of primary production). Second are questions that we can ask of trade in glass: (who traded what, what trade in raw glass existed, how networks sustained varied trade) and finally questions of the use of glass. The chapter on 'Isotope Analysis and Its Applications to the Study of Ancient Indian Glass' by Laure Dussubieux, Christophe Cloquet and Thomas Oliver Pryce introduces new scientific approaches to understand glass production and trade. By looking at strontium, neodymium and lead isotope signatures of ancient glass, it is possible to determine the origin of the raw materials and understand the circulation of raw materials as well as finished products. The chapter on 'The Conservation of Glass' by Stephen P. Koob is an introduction

to the kinds of care which are demanded in the handling of glass. It provides a very useful and detailed discussion of the preferred binders (Paraloid B-72) that should be used in the conservation of glass. The chapter on 'Typology of Glass Beads: Techniques, Shapes, Colours and Dimensions' by Joanna Then-Obłuska provides a tour-de-force survey of the issues, challenges and attention to detail which the typological study of ancient glass beads demands. The paper admirably summarises the different methods by which ancient glass beads were made and provides excellent illustrations of their visible traces on artefacts.

The third part, 'Ethnography and Literature', covers four chapters. The chapter on 'Glass in Indian Archaeology, Ancient Literature, Historical Records and Colonial Accounts' by Alok Kumar Kanungo dismantles the unhelpful debates over the origins of glass, glassmaking and widespread use in South Asia. The paper examines a series of otherwise difficult to understand textual references (in the Satapatha Brahmana, the Arthashastra and other texts) and points to how the metaphorical and allusive use of glass and glassmaking must presume at least a few centuries of familiarity with the material. The latter texts and social customs which define the customs related to use of glass bangles are discussed. The colonial accounts that documented the native glass production and glass bangle making in different regions of India are dealt upon. The chapter on 'Situating Harinagar Hoard Finds in Pre-Iron Age Glass Crafts' by Bhuvan Vikrama argues, contrary to the present knowledge, that there existed a possible knowledge of glass crafts in India from at least 2nd millennium BCE on the basis of the evidence revealed by recent finds from that site. The chapter on 'History of Glass Ornaments in Tamil Nadu, South India: Cultural Perspectives' by Veerasamy Selvakumar is a thorough and thought-provoking review of the evidence for the production, use and status of glass in Tamil Nadu. His paper also provides a very rich account of the historical evidence on glassmakers and especially the caste of bangle traders and makers known from Tamil inscriptions. The chapter on 'Traditional Glass Mirror Making in Kapadvanj, Gujarat, India and an Outline of the Use' by Jan Kock and Torben Sode presents a precis of their work over the last several decades on Indian glass crafts—of primary oval shaped hot lead-coated glass mirror-making, mirror work and mirror use.

The fourth part, i.e. 'Glass Products in South Asia', deals with five chapters. The chapter on 'Glass Beads of Eastern India (Early Historic Period)' by Sharmi Chakraborty addresses the important issue of how we assess the scenario of glass beads and their use in a regional perspective using new methods such as cluster analysis in the case of early historic Bengal. The chapter on 'A Review of Selected Glass Bead Types from the 2007–2009 Seasons of Excavation at Pattanam, India' by Shinu Anna Abraham concentrates on the non-Indo-Pacific beads of Pattanam in an attempt to understand the complexity of the trade network the site was part of. The chapter on 'Glass Bangles in South Asia: Production, Variability and Historicity' by Mudit Trivedi revisits the questions of chronological change, typological diversity and cultural significance of the glass bangle as an artefact type of a much-neglected point of entry into the study of South Asian glass. The chapter on 'West Asian Glass in Early Medieval India as Seen from the Excavations of Sanjan' by Kurush F. Dalal and Rhea Mitra-Dalal details the range and density of tenth- to twelfth-century

glass tableware that they recovered during excavations including bottles, vials, footed plates, distillation apparatus, goblets and other items such as buttons. The chapter on 'Interrelations in Glass and Glazing Technologies in Mughal Tilework' by Maninder Singh Gill presents the results of his study investigating early Mughal architectural tilework. This paper is a case study of the interaction of indigenous Indian glass tradition in the context of a cosmopolitan court culture, which drew equally in its political and material cultures on Central and South Asian traditions.

The fifth and final part, 'The Diffusion of South Asian Glass', covers five chapters. The chapter on 'Indian Glass Beads in Western and North Europe in Early Middle Age' by Bernard Gratuze, Constantin Pion and Torben Sode summarizes recent discovery and identification of a range of Indian glass beads in early medieval Europe in two distinct clusters. The first group of finds were from Western Europe and France in the period between 500 and 800 CE and as recovered from Merovingian era elite burials. The second and more puzzling group was that as recovered from Northern Germany, Denmark and Sweden in the seventh and eighth centuries. The chapter on 'Early Glass Trade Along the Maritime Silk Route (500 BCE–500 CE): An Archaeological Review' by Sunil Gupta reviews the discovery of glass across most of the Old-World civilizations from mid-second millennium BCE till the BCE–CE transition when the maritime trade in raw and crafted glass becomes widespread, with long-distance networks active from the Red Sea to the South China Sea. This paper also provides the first review of the archaeological evidence of glass trade across the Silk Route in the broad period 500 BCE–500 CE. The chapter on 'Indian Glass in Southeast Asia' by Laure Dussubieux draws on her decade long study of the compositional groups of glass in Southeast Asia (especially sites in Thailand, Vietnam and Myanmar). The paper demonstrates how influential models such as the Arikamedu centric story advanced by Peter Francis Jr. of technology transfer and/or the movement of craftspeople are in need of re-evaluation in the light of the elemental analysis of glass from these sites. The chapter on 'Indian Glass: Chronology and Distribution in Eastern Africa' by Laure Dussubieux and Marilee Wood reports on recent research on Indian glass beads found on the western rim of the Indian Ocean, highlighting the chronological shifts of Indian production centres that fed the African bead market throughout the 2nd millennium CE. The final chapter on 'Indian Glass Beads in Northeast Africa Between the First and Sixth Centuries CE' by Joanna Then-Obłuska presents new evidence to the South Asian audience of Indian beads as traded to Northeast Africa in the period between the first and sixth century CE.

The above-mentioned chapters, written by some of the best known authorities, make the book one of its kinds with holistic approach making it a reference work on the subject.

Alok Kumar Kanungo
Laure Dussubieux

About This Book

This book *Ancient Glass of South Asia—Archaeology, Ethnography and Global Connections* provides a comprehensive research on ancient Indian glass. The contributors include experienced archaeologists of South Asian glass, and archaeological chemists with expertise in the chemical analysis of glass, besides, established ethnohistorians and ethnoarchaeologists. It is comprised of five parts, and each part discusses different aspects of glass study: the origin of glass and its evolution, its scientific study and its care, ancient glass in literature and glass ethnography, glass in South Asia and the diffusion of glass in different parts of the world. The topic covered by different chapters ranges from the development of faience to the techniques developed for the manufacture of glass beads, glass bangles or glass mirrors at different times in South Asia, a major glass-producing region and the regional distribution of key artefacts both within India and outside the region, in Africa, Europe or Southeast Asia. Some chapters also include extended examples of the archaeometry of ancient glasses. It makes an important contribution to archaeological, anthropological and analytical aspects of glass in South Asia. As such, it represents an invaluable resource for students through academic and industry researchers working in archaeological sciences, ancient knowledge system, pyrotechnology, historical archaeology, social archaeology and student of anthropology and history with an interest in glass and the archaeology of South Asia.

Contents

Editors and Contributors

About the Editors

Alok Kumar Kanungo is a faculty at IIT Gandhinagar and an adjunct faculty at Flinders University. He was born in Odisha and grew up in close contact with many indigenous communities of eastern and north-eastern India. His early childhood experiences led him to eventually focus on archaeological and ethnographic studies of indigenous and ancient technology. For the last two decades, Dr. Kanungo has travelled and documented the rich heritage of the Nagas of northeast India, and the Bondos and Juangs of Odisha both in the field and in museums across Europe and the UK. He has worked in many areas where it is difficult to say where anthropology or history stops and archaeology begins. He has studied and published extensively on the subject of glass and glass-bead production and written or edited fifteen books and seventy research articles and book chapters. He has been the recipient of many prestigious awards including SPARC, Humboldt, Fulbright, Rakow and Homi Bhabha Fellowships. He has lectured at many universities and research institutes in Taiwan, England, USA, New Zealand, Bangladesh, Italy, France, Turkey, Malaysia, Germany and Thailand, besides India.

Laure Dussubieux is a chemist specialized in the determination of the compositions of ancient artefacts made from synthesized or natural glass, metals and stones. She obtained her Ph.D. in Chemistry from the University of Orléans (France) in 2001 with a dissertation focused on the use of laser ablation—inductively coupled plasma—mass spectrometry (LA-ICP-MS) to study the provenance and the circulation of ancient glass beads around the Indian Ocean. Prior to her appointment at the Field Museum, she was a post-doctoral fellow at the Smithsonian Institution (Museum Support Center, Maryland, USA) where she developed the application of LA-ICP-MS to the study of ancient gold and the use of portable X-Ray Fluorescence to survey cultural artefacts. Since 2004, she has managed the Elemental Analysis Facility (EAF) at the Field Museum and her current title is a research scientist. At the EAF, in a little more than a decade, in addition to her own research on ancient glass from South and Southeast Asia, she has facilitated more than 150 projects addressing questions related to the archaeology of cultural production, interaction and exchange.

Contributors

Dr. Shinu Anna Abraham is Associate Professor at St. Lawrence University and Archaeologist. She has done fieldwork in Egypt, Israel, India and the USA. She has two ongoing research projects: the systematic survey of iron and glass production in southern Andhra Pradesh, India, and the investigation of South India glass beads to reconstruct both Indian Ocean exchange patterns and ancient South Indian craft production processes. She is interested in the archaeology of craft/technology, state formation and archaeological theory. As Senior Editor, she published Connections and Complexity: New Approaches to the Archaeology of South and Central Asia, by Left Coast Press in 2013.

Dr. Sharmi Chakraborty works as Fellow, Centre for Archaeological Studies and Training, Eastern India. Her main interest is the archaeology of the early historic period of India in West Bengal. Her doctoral dissertation has been on the early historic site of Chandraketugarh (2000). She directed exploration in the Bakreswar River Valley and conducted excavation in Paharpur (historic to early medieval) and Kusumjatra (chalcolithic). Her ethnographic work was published as a monograph (*Ceramic Variability: An Ethnographic Perspective*, 2018). She is Editor of *Pratna Samiksha* (New Series), a peer-reviewed journal of archaeology.

Dr. Christophe Cloquet works as Research Engineer in geochemistry at CRPG and Head Manager of a CNRS National Facility for rocks and mineral analysis (SARM). He did Ph.D. in geosciences at CRPG, University de Lorraine, France, and postdoctoral in Montréal, Canada, at the Geotop (UQAM) and Ghent University, Belgium. He specializes in isotopic geochemistry, developing and using clean room conditions and MC-IC-PMS instrument. He has a strong track record in using isotope ratios to understand sources and processes in the critical zone. He is focused on tracing anthropogenic or natural sources by using metal isotope ratios.

Dr. Kurush F. Dalal received his Ph.D. in the Early Iron Age in Rajasthan from the Department of Archaeology, Deccan College, Pune. Later, his research interest shifted to the Early Medieval Period of the West Coast of India, and since then, he has excavated the sites of Sanjan and Chandore. As Assistant Professor (archaeology) in Centre for Extra Mural Studies, University of Mumbai, he co-directed the Salcette Explorations Project, an Urban Archaeology Project, documenting the Archaeology of Mumbai. His interests in archaeology include memorial stones and ass-curse stones in India, numismatics, defence archaeology and architecture, ethnoarchaeology, culinary anthropology, food archaeology and other related subjects.

Dr. Maninder Singh Gill is Art Conservator and Archaeological Scientist based in Noida, India. He trained for a MA in conservation at the National Museum Institute (NMI) and was later conferred with a Ph.D. in archaeological science by the University College London (UCL). He has been working in the field of conservation in India

since 1999. His interests lie in the application of scientific methods for the analyses of art and archaeological materials. He has conducted research on a wide variety of artefacts and materials from the medieval to early modern period, including architectural glazed tiles, wall paintings, stucco work and painted decorations in historic interiors.

Dr. Bernard Gratuze is Director of research at the French National Center for Scientific Research (CNRS), Institut de Recherche sur les Archéomatériaux, Centre Ernest-Babelon (IRAMAT-CEB), CNRS/Université d'Orléans, France. He received his Ph.D. and the Habilitation for the direction of Ph.D. from the Analytical Sciences Department of Orléans University. His current research interest includes the development of analytical protocols using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) for glass (as well as for lithic materials) to study their production and trade from Protohistory to the Modern Period.

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Glass Origin and Evolution

The Origin of Glass and the First Glass Industries

Thilo Rehren

Abstract Glass is unique among the archaeological materials of the Late Bronze Age, in its production, use and social meaning. Emerging as a regularly produced substance in the mid-second millennium BCE almost simultaneously in both Mesopotamia and Egypt, we still know surprisingly little about its origin and the organization of production and distribution to the elite workshops shaping it into colourful objects. However, over the past two decades, the combination of trace element chemical analyses of glass and a reassessment of earlier excavated production debris enabled us to made massive progress in our understanding of this industry, as is summarized in this paper.

1 Introduction

Glass is unique among the artificial pre-modern materials. Ceramics and plasters, which first appear more than 10,000 years ago, are earth-based substances which have more or less the same chemical composition as their raw materials, clay and gypsum or limestone, respectively. Metals are a mono- or oligo-elemental material extracted from more complex ores, fundamentally different in appearance and properties of the raw material; first emerging as a man-made material some 7000 years ago (Radivojević et al., 2010), from at least 4000 years ago, metal production leaves vast amounts of waste such as slag and furnace remains in the archaeological record. Glass, in contrast, only appears in regular quantities from c 3500 years ago (Nicholson & Henderson, 2000). Significantly, as an 'additive' material made from the fusion of several compositionally relatively simple raw materials into a single final product of more complex composition, it leaves almost no production waste. Despite being an artificial material with its own unique working properties, during the Late Bronze Age at least glass was still seen much more as a substitute of precious stone, on a

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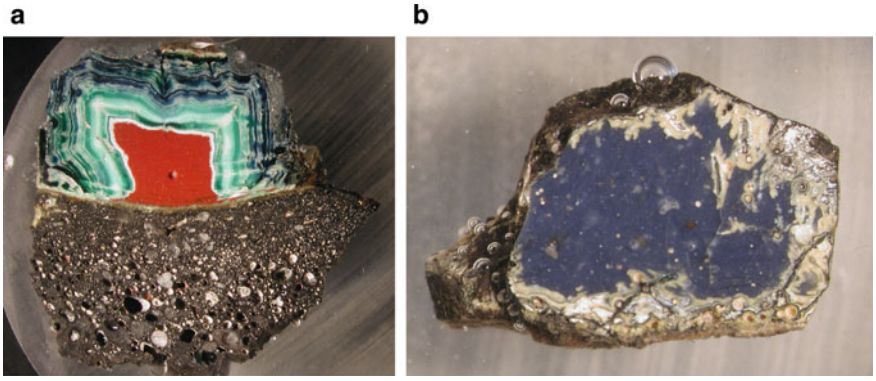

Fig. 1 **a–b** Two samples of intensely coloured glass from the glass workshops in Qantir/Pi-Ramesse in the eastern Nile Delta. The glass is imitating red carnelian and dark blue lapis lazuli. Photos B. Schoer

par with lapis lazuli, turquoise, amethyst, jasper, obsidian, amber and such like, and like those natural precious stones it was used mostly to make decorative items such as inlays or beads and small vessels. Thus, Late Bronze Age glass was typically intensely coloured (Fig. 1a–b), and while it was often worked into polychrome artefacts exploiting the unique working properties that glass afforded, it still maintained in the final product the impression of a natural precious stone.

Glass has several major advantages compared to the precious stones mentioned above which it is meant to emulate; as an artificial material, it can be relatively easily produced in significant quantities, independent of access to a possibly obscure or remote mining area, and the range and shades of coloration can be actively manipulated rather than being limited to what is available in the geological deposits. However, producing large quantities of glass requires sufficient organization to procure the necessary raw materials, while creating different colours depends on the access to and knowledge of specific metal compounds or minerals. Evidently, both conditions were sufficiently fulfilled during much of the Late Bronze Age both in Egypt and in Mesopotamia, not least through the interregional connectivity which the elite exchange network of that period provided.

The term ‘glass’ is about as specific as the word ‘metal’, with several chemically very distinct types of glass now being known (for an overview, see Rehren & Freestone, 2015, and literature therein). When describing an object, it is not really sufficient to state that it is made from ‘metal’; instead, for a proper understanding of its role it is well established to state whether this object is made from iron, or copper, or bronze, or silver, tin, gold, lead, etc. The same is true for glass, although the significance of different chemical glass types is different from the recognition of different types of metal and alloy. When a new metal or alloy emerges in the history of mankind, it is added to the list of previously known metals. In contrast, in most cases, different glass compositions are used in different geographical regions, and often, a new compositional glass type tends to replace the earlier used composition, and the

coexistence of different compositional groups is often restricted to relatively short transitional periods of a few generations. In the context of Near Eastern archaeology, three main glass types dominate the spectrum, namely the Late Bronze Age plant ash glass; the Iron Age to Byzantine mineral natron glass; and the Islamic plant ash glass. Other types include mixed-alkali glass, known particularly from the end of the Late Bronze Age and Early Iron Age of Italy; various types of aluminium-rich glass found occasionally in Byzantine and Islamic western Turkey as well as abundantly in India (Dussubieux et al., 2010); the Han Chinese lead-barium glass mimicking jade; lead glass, in use at least since the Roman period; and the various potash-based forest glass types of medieval Europe. Despite their distinct composition, and in contrast to the various metals, the three main Near Eastern glass types are visually almost indistinguishable; their appearance is not determined by the base glass chemistry, which almost inevitably produces a near-colourless transparent material, but by the range of minor impurities or additives that provide distinct colours and opacity. Instead, the distinct chemical signatures that identify one or the other compositional glass type are contained in the minor and trace elements and require appropriate chemical analysis to positively identify them.

2 The Origin of Glass

There are different types of 'origin' of glass that need to be distinguished. The idea of producing a glassy substance has been around for several millennia before proper glassmaking emerged. The clearest evidence for this is the production of faience, consisting of a body of clean-crushed quartz coated by a thin layer of glass which formed during the firing of the object. Solid glass objects appear much later, around 1600 to 1500 BCE both in Mesopotamia and in Egypt, using the same basic raw materials. These are crushed quartz as the main material, plant ash to help make it melt during firing, and typically copper oxide to make it blue-green in colour. Also the type of objects made from glass is very similar to that made from faience. Does this mean that the idea of glassmaking has its origin in the earlier faience industry? This is quite possible, given the similarity of raw materials, but there does not seem to be a transitional stage where faience became more and more 'glassy' until it became glass proper. However, already Peltenburg (1987: 20) points out that the way how faience was worked, namely being shaped while cold before being fired to become rigid, is fundamentally different from the way how glass was worked while hot and states that '*faience working may have played no more than a minor role in the establishment of glass-working*' (Peltenburg, 1987: 19). To this can be added that glass is made in a two-stage process where glassmaking and glass working are well separated, while faience has more in common with pottery production, where also a previously plastic raw material is shaped while cold and then fired into a rigid form. Others have explored potential cross-craft inspirations from metallurgy to glassmaking (most forcefully but unfounded Dayton (1978) who suggests that the LBA cobalt-blue glass of Egypt is in fact the waste of silver smelting in central

Europe; for more likely interactions, see also Peltenburg, 1987: 20, 22; Mass et al., 2002 and Rehren, 2003), but these are more related to shared use of specific materials than to the inception of glass as a new material more generally.

While for the last half century or more it had been generally understood that glass-making was invented in Mesopotamia, a recent reassessment of the dating evidence puts this into question (Shortland et al., 2018). In any case, it is noteworthy that physical evidence for the making of glass during the Late Bronze Age is only known from several sites in Egypt (see below), but not Mesopotamia. However, Shortland and co-workers have convincingly shown that the chemical signature of glass found in Mesopotamia is systematically different from that of glass found in Egypt, on the basis of several diagnostic trace elements such as zirconium, chromium, titanium and lanthanum (Shortland, 2005; Shortland et al., 2007), and that there were likely several separate production sites in the Near East, too (Shortland et al., 2018). Thus, it is reasonable to assume that there were indeed several sites in Mesopotamia making glass from its raw materials, which just have not yet been found in the archaeological record.

The making of glass from its raw materials is quite different from the making of glass objects. It involves the collection and processing of the raw materials, usually silica either as finely crushed quartz pebbles or sand, a flux such as plant ash or mineral natron and specific additives to provide colour and/or opacity to the raw glass. Glassmaking fuses these very clean raw materials with little if any waste left behind, making it far less archaeologically visible than metal smelting, which generates large amounts of durable slag. Glass working or manufacturing, in contrast, is done by artists shaping the existing glass by heating it to a state of sufficient softness for drawing, moulding or other mechanical manipulation. This leaves slightly more archaeologically visible waste, typically fragments of coloured glass rods (Fig. 2), mis-shaped or broken fragments and discarded drips and blobs of glass not fit for recycling. The best example of this sort of material from a Late Bronze Age context has been excavated over a century ago by Flinders Petrie at Amarna (Petrie, 1894) and underpins to this day much of our understanding of LBA glass-working techniques (e.g. Lilyquist & Brill, 1993).

Both unworked glass ingots and finished glass objects are known to have been transported long distances, as part of the Late Bronze Age network of elite gift exchange; the c. 175 glass ingots weighing around 2 kg each and several amphorae holding tens of thousands of glass beads from the Uluburun shipwreck (which sank c. 1300 BCE off the southern coast of Turkey) are the best archaeological example of this (e.g. Pulak, 2008), but iconographic and textual evidence also demonstrates long-distance movement of glass (Shortland, 2012). Thus, archaeological glass has at least four points of origin or provenance, beyond the still open question of the conceptual origin of glass as an artificial material mimicking precious stones: the geological origins of the various raw materials which can be traced by geochemical methods; the production origin, that is the furnace in which these raw materials were fused into glass; the stylistic origin reflecting the artisans working in the studio in which the raw glass was shaped into its desired form, typically involving glass of different colours and potentially different geological or furnace origins; and then

Fig. 2 Small selection of the countless glass rods excavated by Petrie at Tell el-Amarna in Egypt, indicating the former presence of a glass workshop there producing polychrome objects such as beads and core-formed vessels. UCL Petrie Museum of Egyptian Archaeology, London

the archaeological origin, that is the site where the object was finally discarded or deposited, and later retrieved by archaeologists or other individuals. Unfortunately, this latter origin is sometimes obscured by a further 'provenance', namely that of the arts market with its often missing, incomplete or outright false documentation of find spot.

Historically, most science-based glass research focused on finished artefacts, taken from consumption sites such as tombs or elite buildings. While this produced a good understanding of the chemical compositions of this finished glass (e.g. Brill, 1999; Lilyquist & Brill, 1993), and the art historical trends and developments in its manufacturing (e.g. Schlick-Nolte, 1968; Stern & Schlick-Nolte, 1994; Tait, 2012, to mention just a few key works), it did little to reveal the ways of making glass, or to distinguish the original production sites of the raw glass. In this text, the focus will therefore be on the production and manufacturing evidence of glass in the Late Bronze Age of the Eastern Mediterranean, and what we now know—and do not know yet—about the organization of this industry.

3 The First Glass Industries

The term 'industry' here is used relatively loosely to refer to a wider system of production and distribution of a specific commodity that follows certain planned,