EMBERS2020

Eurasian Metallurgy from Beginning to End: a Research Symposium

Virtual Conference – 25th & 26th March 2021

Conference Programme

www.arch.flame.ox.ac.uk

Day 1 – 25th of March

Session 1	Prof Mark Pollard	Welcoming Address	8:00 am	8:30 am
	Prof Liangren Zhang, Renjie Ma, A. A. Tishkin & S. P. Grushin	A New Picture of Bronze Age Metallurgy in the Russian Altai	8:30 am	8:50 am
	Prof Wugan Luo	From Elements to Elegance: Microstructure and Provenance Study of Some Ancient Chinese Bronze Artifacts	8:50 am	9:10 am
	Dr Ji Zhang, Chen Jianli, He Hansheng, Wang Kefei & Tian Jianhua	Scientific Research on the mould and bronze objects unearthed from the casting workshop of Sunjiacun Site in Zhenjiang, Jiangsu	9:10 am	9:30 am
		QUESTIONS	9:30 am	10:00 am
BREAK				
Session 2	Dr Anna Fedrigo, Carlo Cazzaniga & Antonella Scherillo	Elemental analysis at the ISIS Neutron and Muon Source – results on a Chinese bimetallic sword fragment from 2nd-1st century BC	11:00 am	11:20 am
	Dr Hongyan Xiao & Cui Jianfeng	Local cementation brass production during 11th-13th Century CE, China	11:20 am	11:40 am
	Prof Thomas Fenn, Amartuvshin Chunag, William Honeychurch & Badma-Oyu Badamkhatan	The Production, Consumption and Movement of Copper-Based Metals in Bronze and Iron Age Mongolia: Results of recent pXRF Analyses	11:40 am	12:00 pm
	Mr Sergey V. Bogdanov	Technologies of metallurgical production of the Bronze Age of the steppes of Northern Eurasia	12:00 pm	12:20 pm
		QUESTIONS	12:20 pm	12:50 pm
BREAK				
Session 3	Dr Ivan Stepanov, Evgeny V. Vodyasov, Timur R. Sadykov, Evgeniya M. Asochakova, Olga V. Zaitceva & Ivan A. Blinov	Iron metallurgy of the Xianbei period in Tuva, Southern Siberia	2:30 pm	2:50 pm
	Miss Ilaria Calgaro, Miljana Radivojević, Umberto Veronesi & Antonina Ermolaeva	Copper smelting at Mid-Late Bronze Age Taldysai (central Kazakhstan): its place in the wider Eurasian metalmaking framework	2:50 pm	3:10 pm
	Ms Saltanat Amir, Marcos Martinón-Torres, Zainolla Samashev, Abdesh Toleubayev.	Saka-Scythian goldsmithing: evidence from Eleke Sazy and Shilikty burial complexes (Kazakhstan)	3:10 pm	3:30 pm
	Dr Mengyi Zhang	The iron industry in Song China: a case study of Dabuzi iron smelting site in Guanzhong Plain	3:30 pm	3:50 pm
		QUESTIONS	3:50 pm	4:20 pm
BREAK				
Session 4	Prof Thomas Oliver Pryce	金継ぎ (kintsugi) as a metaphor for lead isotope archaeology in Southeast Asia	5:00 pm	5:20 pm
	Prof Sariel Shalev, Thitt Nyein, M. & Phoe La Min K.K.	"FOR WHOM THE BELL TOLLS" Bells of Myanmar: Metal Composition and Technology.	5:20 pm	5:40 pm
	Ms Mélissa Cadet	Copper smelting evidence at the Vilabouly Complex, a late prehistoric primary production site in Central Laos	5:40 pm	6:00 pm
		QUESTIONS	6:00 pm	6:30 pm

Day 2 – 26th of March

Session 5	Dr Nathaniel Erb-Satullo	The Golden Fleece Paradox: Big Data Approaches to Technological Loss and the Case of Caucasus Gold Metallurgy	8:30 am	8:50 am
	Dr Vana Orfanou, Caroline Bruyere &Barry Molloy	Metal, form, know-how and ideas: tracing the making and shaping of transcultural object types in the Late Bronze Age Carpathian Basin	8:50 am	9:10 am
	Ms Boglárka Tóth, Béla Török & Péter Langó	Byzantine Swords in the Medieval Carpathian Basin - Reflections on technology interaction regarding an examination of an iron sword with bronze guard	9:10 am	9:30 am
	QUESTIONS		9:30 am	10:00 am
BREAK				
Session 6	Mr Steven Matthews & Peter Bray	Archaeological Systematics and Early Metallurgy: Copper Chemical Space and Artefact Classification in the Study of the European Atlantic Bronze Age	11:00 am	11:20 am
	Dr Marc Gener-Moret	Technology, aesthetics and functionality on Iron Age weapons from the Iberian Peninsula	11:20 am	11:40 am
	Ms Julia Montes-Landa, Enriqueta Pons; Marta Santos; Pere Castanyer; Joaquim Tremoleda & Marcos Martinón-Torres	Mind the gap between the Greeks and their indigenous neighbours: Socioeconomic dynamics affecting tin bronze alloying technology in Iberia	11:40 am	12:00 pm
	QUESTIONS		12:00 pm	12:20 pm
BREAK				
Session 7	Dr Betty Rame, Valentine Martin	Producing metal jewellery during Aegean Prehistory:: a matter of innovation, continuity and discontinuity	2:30 pm	2:50 pm
	Dr Tzilla Eshel, Yigal Erel, Naama Yahalom-Mack, Ofir Tirosh & Ayelet Gilboa	Lead Isotopes in silver reveal developments in the Mediterranean metal trade during the Bronze and Iron Ages	2:50 pm	3:10 pm
	Dr Stephanie Aulsebrook	Forging Society at Mycenae: An Introduction	3:10 pm	3:30 pm
	QUESTIONS		3:30 pm	4:00 pm
BREAK				
Session 8	Plenary Panel with Dr Justine Bayley, Prof. Mark Pollard, Prof Marcos Martinón-Torres and Professor Vasiliki Kassianidou		5:00 pm	6:00 pm

Session One, Talk Two – 8:30 AM

A NEW PICTURE OF BRONZE AGE METALLURGY IN THE RUSSIAN ALTAI

From 2016 to 2019, the Sino-Russian Joint Expedition excavated the middle-late Bronze Age site of Soviet-Put' in Altai Krai, Russia. Located not far from the mineral-rich Rudnyi Altai (southwest of the Altai Mountains), the residents of the settlement were engaged in metal production, that is, smelting, casting, and hammering, as evidenced by the findings of a plethora of ore, slag, and artifacts. Our analytical data exposes a new, complex, picture of Bronze Age metallurgy in Russian Altai. Our compositional analysis of ore, slag, and artifact samples disclose that the ancient metal workers mainly employed the oxide copper ores and, except for one tin bronze, produced pure copper artifacts. This is unexpected because tin bronze had already prevalent in the middle Bronze Age in the surrounding regions, i.e., Western Siberia, Minusinsk, Kazakhstan, and in Russian Altai. We also conducted lead isotope analysis of the samples. Due to the lack of lead isotope data from Russian Altai, we compared the data with those from Xinjiang. It appears the Soviet Put' samples are convergent partly with those from the Ashele Mine in Chinese Altai and partly with those from the Nulasai Mine in the Ili River valley. This is also unexpected. Lead isotope data from copper mines in Russian Altai, however, are required for finally pinning down the source of the copper ores for the Soviet Put' metal workers.

PROFESSOR LIANGREN ZHANG, Nanjing Univeristy China
Co-Authors: Renjie Ma, A. A. Tishkin, S. P. Grushin

Session One, Talk Three – 8:50 AM

FROM ELEMENTS TO ELEGANCE: MICROSTRUCTURE AND PROVENANCE STUDY OF SOME ANCIENT CHINESE BRONZE ARTIFACTS

The metallographic study enables us to reveal the exact manufacture techniques of ancient Chinese bronzes, including casting, quenching, annealing and cold/hot-working process. The recrystallized grain structure featured by straight twin lines is however a matter of intensive debate in archaeometallurgy. Whilst some scholars argue that it is indicative of hot-working process, others think that it is cold-working followed by annealing process that leads to such a pattern. In this talk, I would like to illustrate the difference between these two different manufacturing techniques. Meanwhile, I shall also empathize a rather intriguingand unusual phenomenon. High-tin bronzes with ca. 22% tin, after processing by hot-working and cold-working alternatively, shows metallographic features which are similar to cast bronze alloys. Using lead isotopic analysis and trace elemental data of bronzes dated to the Zhou dynasty (ca. 1045 – 256 BC), the final part of the talk aims to present a broad picture related to some key questions on the provenance study of ancient Chinese bronze.

PROFESSOR WUGAN LUO, Department Of Archaeology And Anthropology, University Of Chinese Academy Of Sciences

Session One, Talk Four – 9:10 AM

SCIENTIFIC RESEARCH ON THE MOULD AND BRONZE OBJECTS UNEARTHED FROM THE CASTING WORKSHOP OF SUNJIACUN SITE IN ZHENJIANG, JIANGSU

Sunjiacun(孙家村) site is located in Dinggang(丁岗) Town, Zhenjiang(镇江) City, Jiangsu Province. It is an important bronzer casting site found in the lower reaches of the Yangtze River between the 9th and the 6th BC. A large number of casting-related relics were unearthed at the site, including casting mould, bronze ingot and slag, and bronze tools. Bronze casting moulds had a high porosity and little sand, which is significantly different from the moulds in the Central Plains. The bronze objects and ingots have a variety of alloying types. During the Western Zhou Dynasty, the bronzes were mainly made of lead-tin bronze with high lead, along with lead-arsenic bronze, lead-tin-arsenic bronze and tin bronze as well. In the early Spring and Autumn period, the content of arsenic continued to decrease, and lead-tin bronze gradually became the main type. Since the mid-spring and autumn period, the tin content of bronzes increased, and the high-tin bronze increased significantly.

The lead isotope ratios of bronzes, ingots and slags in the early stage of the Sunjiacun site are relatively consistent. They are mainly similar to the Tongling(铜陵) and Nanling(南陵) region in the southern Anhui Province, but different from the lead mines in the nearby Ning-zhen(宁镇) region.

There are many categories of bronze object in the Sunjiacun site. Besides the bronze tools such as knives and cones, there are many damaged bronze pieces such as weapons and farming tools. Considering the limited quantity of mould and copper ingot, the diversity of bronzes and the alloy types, the casting workshop in Sunjiacun may keep melting the scrap bronzewares.

As a typical bronze-casting site in the lower reaches of the Yangtze River in the first half of the millennium BC, the Sunjiacun site has many characteristics such as long duration, limited scale, rich bronze casting product categories, and outstanding phenomenon of bronze remelting. The Shigudun(师姑墩) site in Tongling has a strong commonality with Sunjiacun between copper resources and manufacturing technology. The two sites reflects that the lower reaches of the Yangtze River is a relatively independent metallurgical area different from the Central Plains, and has a strong impact on the Central Plains as well as Huai-si(淮泗) area around the 8th BC.

DOCTOR JI ZHANG, Pekin University
Co-Authors: Zhang Ji, Chen Jianli, He Hansheng, Wang Kefei and Tian Jianhua

Session Two, Talk One – 11:00 AM

ELEMENTAL ANALYSIS AT THE ISIS NEUTRON AND MUON SOURCE – RESULTS ON A CHINESE BIMETALLIC SWORD FRAGMENT FROM 2ND-1ST CENTURY BC

In this work we investigate the bulk elemental composition of a bimetallic sword fragment from ancient China, using non-destructive methods.

The sword fragment investigated has an iron blade mounted on a studded bronze grip (probably for a twine binding) and a ricasso with three long spikes protruding on each side. The object resembles a published example with similar form of hilt [1] listed as originating from burials investigated in the mountainous regions of Longpaozhai, in the Min River Valley (Central Sichuan), dating from the 2nd or 1st century BCE. Similar swords are also found further north and may have been introduced from further west.

Neutron Activation Analysis (NAA) and Neutron Resonance Transmission Imaging (NRTI) were applied [2, 3] for the material characterization of a bimetallic sword fragment from ancient China, in order to highlight presence and distribution of elements in the objects.

NRTI was carried out at the INES beam line, a time-of-flight powder diffractometer, and NAA was performed using a newly installed High Purity Germanium gamma ray spectrometer on CHIPIR, after irradiation on INES, both instruments operating at the ISIS neutron and muon source in UK.

NRTI provides 2D maps of the elemental composition of the artefact, providing relative abundance and location of several elements (e.g. Fe, Cu, Ag, Sn, Sb, As, Co, Cr, In, Mn) in neutron transmission images, with a spatial resolution of about 1.6 mm. Elemental mapping was performed by selecting some of the most intense neutron resonance up to several keV in the absorption spectra.

NAA is an extremely sensitive technique that provides quantitative results for elements in low concentrations (parts-per-million) that are not easy to obtain by the other techniques.

These techniques combined give the possibility for non-destructive bulk testing of extended artefacts of complex geometry such as, but not only, objects of cultural heritage interest.

[1] Kaogou Xuebao (Acta Archaeologica Sinica) 1977.2. 51

[2] A. Fedrigo, J. Anal. At. Spectrom. 34, 2420 (2019)

[3] C. Cazzaniga, Neutron activation analysis of archaeological artefacts using the ISIS pulsed neutron source, submitted to Review of Scientific Instruments (2021)

DOCTOR ANNA FEDRIGO, UKRI-STFC

Co-Authors: Carlo Cazzaniga, Antonella Scherillo

Session Two, Talk Two – 11:20 AM

LOCAL CEMENTATION BRASS PRODUCTION DURING 11TH-13TH CENTURY CE, CHINA

With recent excavations in Xinli site (a royal sacrificial hall above a mausoleum, 11th -12th century AD), Shenmiao Site (a royal temple, 12th century AD) in Jilin Province, in Liaoning Province and Taizicheng Site (a royal summer palace,12th -13th century AD) in Hebei Province, it is an opportunity to reflect on the "brass issues", particularly the origination, localization, characteristics and social functions of Chinese cementation brass technology in the 11th -14th century AD. Of the copper and copper-alloy objects found on sites, around 40% in Shenmiao Site, 60% in Xinli Site and more than 90% in Taizicheng Site are brass objects. It is a significant change because bronze was the dominant copper-alloy used in society before the 11th century AD. To figure out more information on those brass objects, 21 brass samples including building ornaments and household objects at Taizicheng Site (AD 1189-1217) were analyzed using XRF, SEM-EDS, ICP-AES and MC-ICP-MS to investigate the production technology, chemical compositions and lead isotopes of the brass objects. The results show that these brass objects might have been made roughly at the same time using local cementation technology. The lead isotope results indicate that the copper or zinc used to produce brass most likely originated from local ores in Northeast China. These brass objects represent one of the earliest instances of brass made with cementation technology in China, and are different from imported brassware from the Western countries during 4th -9th century AD. We believe that the diffusion and localization of cementation technology might have been the result of trade along the Silk Road and a crisis of tin shortage in northern China during the 12th -13th century AD.

DOCTOR HONGYAN XIAO, Peking University
Co-Authors: Cui Jianfeng

Session Two, Talk Three – 11:40 AM

LOCAL CEMENTATION BRASS PRODUCTION DURING 11TH-13TH CENTURY CE, CHINA

With recent excavations in Xinli site (a royal sacrificial hall above a mausoleum, 11th -12th century AD), Shenmiao Site (a royal temple, 12th century AD) in Jilin Province, in Liaoning Province and Taizicheng Site (a royal summer palace,12th -13th century AD) in Hebei Province, it is an opportunity to reflect on the "brass issues", particularly the origination, localization, characteristics and social functions of Chinese cementation brass technology in the 11th -14th century AD. Of the copper and copper-alloy objects found on sites, around 40% in Shenmiao Site, 60% in Xinli Site and more than 90% in Taizicheng Site are brass objects. It is a significant change because bronze was the dominant copper-alloy used in society before the 11th century AD. To figure out more information on those brass objects, 21 brass samples including building ornaments and household objects at Taizicheng Site (AD 1189-1217) were analyzed using XRF, SEM-EDS, ICP-AES and MC-ICP-MS to investigate the production technology, chemical compositions and lead isotopes of the brass objects. The results show that these brass objects might have been made roughly at the same time using local cementation technology. The lead isotope results indicate that the copper or zinc used to produce brass most likely originated from local ores in Northeast China. These brass objects represent one of the earliest instances of brass made with cementation technology in China, and are different from imported brassware from the Western countries during 4th -9th century AD. We believe that the diffusion and localization of cementation technology might have been the result of trade along the Silk Road and a crisis of tin shortage in northern China during the 12th -13th century AD.

PROFESSOR THOMAS FENN, Dept. of Anthropology, University of Oklahoma
Co-Authors: Amartuvshin Chunag, William Honeychurch & Badma-Oyu Badamkhatan

Session Two, Talk Four – 12:00 PM

TECHNOLOGIES OF METALLURGICAL PRODUCTION OF THE BRONZE AGE OF THE STEPPES OF NORTHERN EURASIA

The original model of metal production was realized in the steppe of North Eurasia since 4th to 2nd millenium BC. It was characterized by unique features of the natural-climatic, territorial, eco-nomic-cultural (cattle-breeding) production system. Also, it was notable for specifics of ore preparation for melting using the pyrotechnic method (beneficiating and fining fire under temperatures to 1 000°C), and the chemical approach (oxidation by potash), recovery of cooper in reverberatory furnaces with segregation of smelted metals on the pyroxene or olivine slag box above and the whole pancake-shaped ingot of blister recovered cooper (93–98 % Cu; 0,5–2 % Fe; 0,5–1,5 % S and others) on the bottom of an iron mold. Various stages of the mining and smelting industry had a seasonal character and correlated with cattle-breeding cycles. In the steppe of North Eurasia, different variants of the pasturable model had existed for several millennia, combining the two largest metal-production systems of the Old World — Circum-Pontic Metallurgical Country (CPMC) and Eurasian Metallurgical Country (EAMP). The final stages of the metal tools production industry connected with molding and forging processing of items varied substantially in different cultures. Still, basic technological algorithms of cooper production had slightly evolved during the Early Metal epoch. In the steppe of North Eurasia, the metallurgical boom exhausted accessible deposits of resources traditional for 4th–2nd millenium BC, for example, sulfide ore (chalcocite and other minerals) in cooper slates and silica-carbonate metal (chrysocolla and others) in copper sandstones of the Late Permian deposits as well as secondary sulfides of "chalcocite horizons" in zones of secondary concentration of principal deposits. It led to the development of Chalcopyrite raw material of copper-pyrite deposits. The boom was connected with the activity of the Srubnaya and Alakulskaya culture's miners in the Late Bronze Age. Chalcopyrites processing was based on technological algorithms of the pastoral mining model and metallurgical production had been formed before, in the second half of the 2nd millenium BC. Besides the involvement of practically inexhaustible resources of cooper stuff into the metallurgical division, it led to receiving a byproduct — iron and refinery slag. Theoretical points stated in the report have been verified by archaeological materials, data of scientific analysis and a series of successful archaeologicalmetallurgical experiments in 2018–2020.

MISTER SERGEY V. BOGDANOV, Institute of Steppe, Ural Branch of the RAS (Russia, Orenburg)

Session Three, Talk One – 2:30 PM

IRON METALLURGY OF THE XIANBEI PERIOD IN TUVA, SOUTHERN SIBERIA

We present the results of the complex investigation of large-scale bloomery iron production at the site of Katylyg 5 (Tuva, Southern Siberia). The ongoing excavations have revealed nine smelting furnaces and a tonne of the iron slag. Apart from smelting furnaces, the iron smithing remains were also identified at the site, which was never previously securely attested in Siberia. The iron was smelted in the trapezoid underground furnaces that apart from Tuva are only known from Baikal region where they date within a broad timeframe c. 1st c. BC - 6th c. AD. At Katylyg 5, the smelting activities radiometrically date to 3rd-4th c. AD, which along with the characteristic pottery finds from the site suggests that the metallurgy was performed by the Kokel culture, emerged in Tuva as a result of westward migrations from Trans-Baikal or further east, in the process of Xianbei expansion during the 1st-3rd c AD. The investigation of slag from Katylyg-5 by Optical microscopy, SEM-EDS and ICP-MS confirms that both smelting and smithing operations were performed at the site. The presence of copper-alloy prills in most of the studied smithing slags indicates that copper was worked alongside iron. The smelted iron ore was skarn-hosted magnetite, identified in the slag relicts, and often co-occurring with the copper ores in Tuva. We argue that the distinctive spatial separation of iron smelting and smithing areas at the site indicates a specific organization of nomadic iron production where ironworkers were divided into iron smelters and ironsmiths, with the latter also in charge of the bronze-working. Although the technology of iron smelting using underground furnaces probably emerged in South Siberia during the Xiongnu period, it was subject to local variation as different types of installations were found in different regions of Siberia. Furthermore, the socio-political changes during 1st-3rd c. AD, such as the disintegration of Xiongnu and the westward expansion of Xianbei, were probably responsible for the transfer of new traditions, such as the use of trapezoid furnaces, as evinced by their late appearance in Tuva. Acknowledgements. The research was supported by the Russian Science Foundation (project No. 18-78-10076).

DOCTOR IVAN STEPANOV South Urals Federal Research Center of Mineralogy and Geoecology of the Urals Branch of the Russian Academy of Sciences
Co-Authors: Evgeny V. Vodyasov, Timur R. Sadykov, Evgeniya M. Asochakova, Olga V. Zaitceva, Ivan A. Blinov

Session Three, Talk Two – 2:50 PM

COPPER SMELTING AT MID-LATE BRONZE AGE TALDYSAI (CENTRAL KAZAKHSTAN): ITS PLACE IN THE WIDER EURASIAN METALMAKING FRAMEWORK

It is widely assumed that second millennium BC Eurasian copper extractive metallurgy was large-scale and standardised, and that it reached its highest peak in technological efficiency during the Mid-Late Bronze Age. The areas of present-day Kazakhstan and Southern Urals host among the richest polymetallic ore deposits of Eurasia, which were massively exploited since the Early Bronze Age by the Steppe pastoralist communities. The metallurgical workshop of Taldysai in the steppes of central Kazakhstan was one of these production centres and represents the focus of this study. Extensive evidence of metalmaking has been unearthed at this site, including complex smelting furnaces, production debris, mining and beneficiation tools and finished copper-based artefacts.

Out of these, seven copper smelting slags were chemically and microstructurally analysed by Optical and Energy Dispersive Scanning Electron Microscope and provided a first insight into the multi-step metallurgical chaîne opératoire carried out onsite. In particular, the analysis identified two steps of the smelting process, the use of mixed fuel sources, and the manufacturing of two distinct copper-based alloys at different stages of the production chain, possibly related to the combination of multiple mineral ores. Then, to test the estimated uniformity of Mid-Late Bronze Age copper extractive metallurgy, data collected from Taldysai were integrated with a comparative reference database of thirteen coeval metalmaking sites located between Eastern Alps and Central China. The collected compositional data were analysed through multivariate statistics in form of principal component analysis (PCA) and ternary diagrams, and interpreted paying attention to the function of the comparative metalmaking sites entered in database, i.e. extractive centres, workshops, settlements.

Overall, this study sheds light on the metallurgical process carried out at Taldysai and presents preliminary elements to fit in the wider second millennium BC narrative. Results demonstrate how specific choices dictated by local/regional-scale inventiveness, the exploitation of different mineral ores and the technological solutions adopted by Bronze Age metalsmiths determined variations in smelting steps, technological parameters and efficiency of copper production across Eurasia.

MISS ILARIA CALGARO, University College London

Co-Authors: Miljana Radivojević, Umberto Veronesi, Antonina Ermolaeva

Session Three, Talk Three – 3:10 PM

SAKA-SCYTHIAN GOLDSMITHING: EVIDENCE FROM ELEKE SAZY AND SHILIKTY BURIAL COMPLEXES (KAZAKHSTAN)

Gold is a prominent component in the material culture of the nomadic cultures that inhabited the Eurasian Steppe in the Bronze and Iron Ages. However, the scarcity of studies of contextualised finds from modern archaeological excavations has constrained our ability to discuss the development of technological traditions, the provision and value of raw materials, cross-craft interactions, or the role of gold in funerary rituals. Here we present an initial contribution to these topics through the analysis of gold assemblages recovered from two kurgan complexes, constructed by the Saka-Scythian cultures in Eastern Kazakhstan around 800 - 400 BCE. Recent excavations revealed a few kurgans with rich goldwork assemblages, some left intact or only partially looted. We employed two portable, non-invasive analytical techniques: digital microscopy to identify technological features and usewear, and portable X-ray fluorescence (pXRF) for elemental analysis. The results show remarkably different goldworking techniques, ranging from the application of wrought sheets on organic substrates through to solid casting, granulation and inlaying. Correlations between technology, composition and usewear are suggestive of different modes of sourcing, crafting and using gold. In addition, thousands of gold microbeads, barely visible to the naked eye, highlight the value of skill and labour in addition to that of the material. These initial results give useful pointers for future research, which we plan to pursue as the project expands.

MS SALTANAT AMIR, University of Cambridge

Co-Authors: Marcos Martinón-Torres, Zainolla Samashev, Abdesh Toeubayev.

Session Three, Talk Four – 3:30 PM

THE IRON INDUSTRY IN SONG CHINA: A CASE STUDY OF DABUZI IRON SMELTING SITE IN GUANZHONG PLAIN

During the Northern Song dynasty (10th-13th century AD), progress in iron industry was made on a number of fronts, for example in the use of mineral fuel, in the use of water power, and in methods of steelmaking (Wagner, 2007, 278). However, the surveyed and excavated iron smelting sites provide limited information on the use of mineral fuel, namely coal. Dabuzi iron smelting site which is located in the Guanzhong Plain, central Shaanxi province provides the direct evidence of the use of coal in iron smelting. The site has been excavated by the Northwest University and Shaanxi Academy of Archaeology in 2020, and a total of 800 m2 area has been excavated. Different features including operating surface, furnace, warehouse, kiln, well, and pit have been excavated which show the details of Chaǐne Opératoire. According to the preliminary metallurgical research, cast iron smelting and fining were carried out in the site. Besides, coal was used as fuel, flux was added and the iron ore is probably pyrite which exploited from Beishan mountain nearby. As the only excavated iron smelting site of the Northern Song dynasty in Shaanxi, Dabuzi iron smelting site will provide valuable materials to have a deep understanding of iron smelting technology as well as the social and economic aspect of iron industry in Guanzhong during the Song dynasty, fulfill the gap in the study of archaeometallurgy in this region.

DOCTOR MENGYI ZHANG, Northwest University

Session Four, Talk One – 5:00 PM

金継ぎ (KINTSUGI) AS A METAPHOR FOR LEAD ISOTOPE ARCHAEOLOGY IN SOUTHEAST ASIA

It is now 12 years since the Southeast Asian Lead Isotope Project (SEALIP) was brought to life at the Research Laboratory for Archaeology and the History of Art at the University of Oxford - the first systematic attempt to provenance copper and lead-base metals in protohistoric Southeast Asia, c. 1000 BC to AD 700. Metals provenancing, fascinating in technical complexity, is at its base the anthropological endeavour to link producer and consumer populations, often via one or more intermediary groups. So why allude to **金継ぎ**, the traditional Japanese art of repairing pottery using lacquer mixed with powdered metal? Because now, as in 2009 and decades prior, in Mainland and Island Southeast Asia, we lack reliable ceramic typologies that can be seriated through time and traced across space. That is the fundamental material culture for most post-Neolithic societies, pottery, cannot be convincingly and safely used to reconstruct ancient interaction networks at the critical 2500 year, non-universal and varyingly-staged, transition from hunter-gatherers of the late 3rd millennium BC to the formation of full state societies in the mid 1st millennium AD. This is not to say there are no good ceramic studies in Southeast Asia, not at all, but they are insufficiently dense to provide chrono-spatially contiguous datasets, and the quality and quantity of regional radiometric dating, also improving rapidly, remains insufficient to provide good cultural coverage.

This is where archaeometallurgy can, should and, I argue, has stepped up to the plate. Lead isotope archaeology, honed over six decades from its birthplace in the Eastern Mediterranean, brings a rigorous methodology to bear on a regional-scale problem. Critically, thanks to those years of debate and refinement, we are well aware of the weaknesses and blind spots of copper and lead-base provenance research. In this paper I will outline how SEALIP, and its successor programme 'BROGLASEA', have furnished reliable data to link metal-making and metal-using communities over thousands of kilometres and years. With N now c. 1000, we are reaching critical mass for interpretive power, reaching into China, India, and potentially beyond.

MS SALTANAT AMIR, University of Cambridge
Co-Authors: Marcos Martinón-Torres, Zainolla Samashev, Abdesh Toeubayev.

"FOR WHOM THE BELL TOLLS" BELLS OF MYANMAR: METAL COMPOSITION AND TECHNOLOGY.

Today, throughout Myanmar, hundreds of sacred bells are hanging in the open courtyards and sheltered pagodas of temples, bearing dedicatory inscriptions that include the exact date in which they were donated. These dates reflect more than 450-year-old tradition of metal production that began in 1552 C.E. Thus, these bells represent a high-resolution archaeological source for the history of metal technology in Myanmar. The archaeological potential of the study of these objects is even more significant given the current state of this country's stratified material cultural typology and the dating of archaeological objects and production techniques.

During 2013-2015, an interdisciplinary pilot field study of these bells by an on-site collaboration between local archaeologists and philologists from the Pyay Field School of Archaeology in Myanmar and an archaeometallurgist from Israel.In this preliminary study, we conducted over 300 P-XRF analyzes of 56 selected bells in 7 different pagodas and museums (out of 20 surveyed sites) according to their inscribed donation dates.

Beside relatively small changes in trace elements, we observed one dramatic shift in alloying from tin bronze to zinc brass at the end of the 19th century. Within this distinct transitional period, we found several years when bells were produced from both alloys.

For modelling their possible production method, we studied two traditional bell foundries still operating in the Mandalay region and used ethno-technological observations of modes of productions as a 'ready-made' experimental field lab for industrial archaeology and metal technology.

The study of the still-operating traditional bell foundries enables us also to suggest a possible production protocol for casting the bi-metallic bells at the end of the 19th Century. The historical and archaeological data offer a possible socio-political explanation for this observed change in Myanmar's metal import, trade and use.

PROFESSOR SARIEL SHALEV, Dept. of Archaeology & Maritime Civilisations, University of Haifa & Physics Dept. Weizmann Institute of Science, Israel
Co-Authors: Thitt Nyein, M. and Phoe La Min K.K.

COPPER SMELTING EVIDENCE AT THE VILABOULY COMPLEX, A LATE PREHISTORIC PRIMARY PRODUCTION SITE IN CENTRAL LAOS

Evolving from purely 'origins'-based research, significant advances have been made in our understanding of early Southeast Asian metallurgy in the last decade, partly through new excavations of metal production sites, and partly through the application of established provenance methodologies to assemblages covering almost two millennia. On the fieldwork front, ancient copper mining and smelting sites at the Vilabouly Complex (VC, formerly known as Sepon) in Savannakhet Province, Central Laos, have been excavated since 2008. The VC, with a radiocarbon sequence from the early Bronze Age (c. 1000 BC) to the late Iron Age/beginning of the Historical period (c. 700 AD), is one of only three prehistoric copper production sites physically known in Southeast Asia, the other two being in Thailand.

The Vilabouly Complex has revealed major copper mining and smelting sites with artefacts linked to the smelting of copper (ores, slags, crucibles and scorched clay) along with copper and copper-alloyed artefacts (ingots, drums, axes etc.). Analyses of the different types of artefacts (OM, SEM-EDS, Raman Spectroscopy, pXRF, lead isotope analyses) permit the reconstitution of the chaîne opératoire of copper production involved at the VC and its wider implication for Southeast Asian metallurgy.

Results seems to show the use of a crucible smelting technology during a one-step co-smelting revealing a mastery of the production process leading to homogenized by-products denoting good metal/impurities separation. Primary and most probably secondary copper production are attested with most of the metal objects 'lead isotope signature' matching VC one with objects composed of copper, bronze and leaded-bronze. The consistent geochemical signature corroborates the extensive on site production and fits with the regional copper-base metal being sated in part by VC supply as the VC lead isotope signature has been identified in the copper exchange networks across Southeast Asia, involving metal consumers from Myanmar, Thailand, Cambodia, and potentially as far as Indonesia. The VC's chaîne operatoire also share some common traits with others Southeast Asian metallurgical sites including the use of a crucible technology and co-smelting such as the primary production site of the Khao Wong Prachan Valley and other secondary production sites.

MS MÉLISSA CADET, Préhistoire et Technologie (UMR 7055), LAPA (UMR 3685)

Session Five, Talk One – 8:30 AM

THE GOLDEN FLEECE PARADOX: BIG DATA APPROACHES TO TECHNOLOGICAL LOSS AND THE CASE OF CAUCASUS GOLD METALLURGY

In archaeological studies of innovation and technological change, technological firsts are the subject of intense research and discussion. Cases of technological loss, abandonment, and rejection, on the other hand, are severely understudied, despite the widespread acknowledgement that technological evolution does not progress in predictable, linear, uniform sequences. The lack of research on cases of technological loss is in part due to methodological challenges in identifying and analyzing potential cases, as changes in archaeological visibility may be misinterpreted as instances of technological loss. A large geospatial analysis of gold metallurgy in the South Caucasus, encompassing more than 4500 objects from 88 sites spanning 4000-500 BC and representing nearly 130 years of archaeological research, directly addresses these methodological issues. The analysis both confirms the decline of gold-working technology in the Middle Kura zone between 1500-800 BC, and provides the analytical tools to explain why this phenomenon occurred.

DOCTOR NATHANIEL ERB-SATULLO, Cranfield University

Session Five, Talk Two – 8:50 AM

METAL, FORM, KNOW-HOW AND IDEAS: TRACING THE MAKING AND SHAPING OF TRANSCULTURAL OBJECT TYPES IN THE LATE BRONZE AGE CARPATHIAN BASIN

During the Late Bronze Age (LBA), c. 1300-1100 BCE, social crises are documented in southeastern European and eastern Mediterranean communities that culminated in the collapse of palatial systems and dramatically transformed prehistoric societies. Different patterns of human and cultural, personal and collective mobility have been proposed for explaining the above period, though without reaching full agreement regarding its causes and effects. During this LBA, a closely similar package of weaponry spread across a wide and culturally diverse region including the Carpathian Basin, as periods of high mobility often coincide with increased social conflict.

In the present study, we aim to shed light on this transformative period of European prehistory by reconstructing the circumstances surrounding ideas of metal procurement, making, shaping and using along major communication routes and the river corridors in the inland Balkans through metallographic, elemental isotopic analysis. Analysis focuses on transcultural forms of metalwork such as swords and spearheads that, at the time, spread over the Balkan and Italian Peninsulas and the Aegean in order to trace a) the transmission of craft practices, b) the changing cultural traditions as they were affected by migrations, c) the changing networks that arose from the LBA crisis and d) the defining characteristics of the emerging long-range travels.

Results from the combined analytical approach show promising avenues for discussions of long-range communication routes, and ideas surrounding the manufacturing and function of the various artefact types (swords, spears, sickles, and axes). In the Carpathian Basin, a region removed from known important primary LBA copper sources, results demonstrate the importance of local mobility in secondary production and long-range connections for sourcing raw material. Metallographic and elemental results reveal trends in the treatment of the various object types, as well as site dependent patterns of alloying and recycling. Overall, our data indicate levels of access to raw material that can create distinct patterns of connection and mobility, alongside local strategies of resource management and alloy making.

DOCTOR VANA ORFANOU, School of Archaeology, University College Dublin
Co-Authors: Caroline Bruyere, Barry Molloy

Session Five, Talk Three – 9:10 AM

BYZANTINE SWORDS IN THE MEDIEVAL CARPATHIAN BASIN - REFLECTIONS ON TECHNOLOGY INTERACTION REGARDING AN EXAMINATION OF AN IRON SWORD WITH BRONZE GUARD

The usage of bronze as a basic material of weapon manufacturing had decreased progressively when ferrous manufacturing technologies spread. However, the application of the copper-based alloy for ornament works was continued in the history of technology of human civilization. Bronze decorations can also be observed on swords, one of the most significant weapons in history.

A few Early Medieval double-edged swords, excavated in the Carpathian Basin, presumably have Byzantine origin. One of most unique piece of this small but significant group ofByzantine originated weapons unearthed at Kunágota, Hungary. The sword, which has a special sword-guard made of bronze, has been examined by the experts of the Archaeometallurgical Research Group of the University of Miskolc with optical microscopy, SEM-EDS, ED-XRF, and microhardness tests. The primary aim was to study the characteristics of the microstructure of the blade and guard. There was also an important objective of the investigations to explore the traces of processing in order to characterize the possible manufacturing technology.

In a wider aspect, other questions had arisen. For instance, is it possible to detect any differences or similarities in morphological or manufacturing technologies between the recently examined swords found in the Carpathian Basin and the Kunágota-sword? What was the extent of popularity of using bronze for guards and hilts throughoutEurope, particularly in the Carpathian Basin in the Early Middle Ages? Is it possible to establish any impact or significance of these Byzantine swords on the culture of people living in Carpathian Basin? The major object of this study is to summarize the possible answers to the above-mentioned questions.

The investigation was carried out within the frames of the currently ongoing project. The primary objective is the archaeological and archaeometrical examination of as many double-edged swords found in the 10-11th century Carpathian Basin as possible.

MS BOGLÁRKA TÓTH
Co-Authors: Béla Török & Péter Langó

Session Six, Talk One – 11:00 AM

ARCHAEOLOGICAL SYSTEMATICS AND EARLY METALLURGY: COPPER CHEMICAL SPACE AND ARTEFACT CLASSIFICATION IN THE STUDY OF THE EUROPEAN ATLANTIC BRONZE AGE

Archaeology suffers from what the evolutionary biologist Ernst Mayr called ‘essentialist’ thinking, where analytical units – types, groups, etc. – are treated as if they are real, historical categories. This has a number of consequences for archaeological practice, in particular early metallurgy. If units are real, then it appears we discover rather than create them. Unit construction, which should be an active field of theoretical practice, is reduced to methodology. Most significantly, if units are real then they are immutable and static, profoundly affecting how we approach the study of change, emphasising space over time. Temporal change is modelled only as abrupt transformation between internally homogenous entities, occurring at the boundary of chronological divisions.

In contrast, Mayr’s populationist or ‘materialist’ approach has been demonstrated to have positive consequences for archaeology, where change is envisioned as a continuum of variation across both space and time. Archaeological units are slices of material coalescence, carved artificially from the braided-stream of variation, providing vital scientific devices for measuring change. Consequently, artefacts gain individuality and historical contingency, rather than being used as repeated, idealised examples of homogenous types.

Essentialism typifies traditional metallurgical studies, where archaeological chemists have often sought to recover the prime signal linking artefact assemblages to a point source, as exemplified by the provenance hypothesis. The development of the Copper Chemical Space system, by Bray and colleagues, however, has at its heart a materialist metaphysic. Here, the emphasis is upon the study of variation rather than identifying ideal groups of data. This opens the possibility of identifying socio-technological layers and processes, rather than relying on a reductive, static appeal to provenance.

The full potential of data situated in a continuous Chemical Space for studying metallurgical flow will only be realised within a framework that also includes a materialist approach to artefact classification, with a similar emphasis upon the temporal and spatial flow of trait variation rather than ‘type’ homogeneity. This paper will outline the benefits of such a framework for the study of metallurgical and technological choices in bronze sword design and manufacture in Atlantic Western Europe during the Later Bronze Age (c. 1200-950 BC).

MR STEVEN MATTHEWS, Deutsches Archäologisches Institut (DAI), Berlin
Co-Authors: Peter Bray

Session Six, Talk Two – 11:20 AM

TECHNOLOGY, AESTHETICS AND FUNCTIONALITY ON IRON AGE WEAPONS FROM THE IBERIAN PENINSULA

The research field of early iron technology is strongly focused on the production and circulation of the metal, leaving as a comparatively less explored area the study of the objects made of ferrous alloys. How iron and steel are used in the manufacture of these objects according to their function constitutes a technological corpus of knowledge in itself, with its own patterns of acquisition, development, transmission and exchange, from which conclusions about social change, contacts, and cultural practises can be extracted.

For this to be feasible, the analyses must be approached from an archaeological, technological and functional/anthropological point of view, always interpreting "function" beyond the strictly utilitarian sense. From the study of the objects we seek to understand the relationship of manufacturers and users with their technological tradition and with interpersonal violence in different cultural contexts. This is the basis of the project I present here (IBERIRON), which focuses in the technology of manufacture of weapons and other ferrous objects in the context of the Iberian Peninsula in the Iron Age.

We will present some results of the analytical study and functional analysis of weapons from the sites of Mianes (Tarragona, Spain. Iberian culture, 6th- 5th c. b.c.e.),La Osera (Ávila, Spain. Vettonian Culture, 4th – 3rd c. b.c.e) and La Bastida de les Alcusses (Valencia, Spain, Iberian Culture, 4th c. b.c.e). Samples have been obtained from various specimens (spearheads, soliferrea, atrophied antennae swords, falcata swords, shield furniture and armour) and studied by optical metallography and SEM-EDS. They feature complex manufacturing procedures, including uneven use of selective carburization and fire-welding. The use of different materials and techniques open the possibility of identifying technological differences between different cultural areas, whereas the purpose and use of the weapons seems to follow similar patterns.

The results also highlight some of the systemic methodological problems encountered in this kind of research, such is the distorting effect of the cremation rituals on the study of original heat-treatment and carbon distribution, or the difficulties encountered because of corrosion. These problems are addressed with the techniques used, and some additional innovative techniques are proposed.

DOCTOR MARC GENER-MORET, McDonald Institute for Archaeological Research, University of Cambridge

Session Six, Talk Three – 11:40 AM

MIND THE GAP BETWEEN THE GREEKS AND THEIR INDIGENOUS NEIGHBOURS: SOCIO-ECONOMIC DYNAMICS AFFECTING TIN BRONZE ALLOYING TECHNOLOGY IN IBERIA

From co-smelting through cementation to scrap recycling, there are at least five different ways to make tin-bronze, which can be told apart through the analysis of production residues. Interestingly, the evidence indicates that the oldest techniques are not always replaced by the most modern and 'advanced' ones, and that several techniques often co-exist at the same production contexts. This trend seems counterintuitive and demands to be explained.

The selection of a technique or a range of them is influenced by the socio-economic dynamics related to bronze production. It is necessary to link these contextual factors to the choices observed in the archaeological record to explain the appearance of the different alloying techniques, their acceptance, development, rejection and/or co-existence over time.

We present a case study from two adjacent, contemporaneous sites in Iron Age NE Iberia: the indigenous settlement of Mas Castellar (Pontós), and Emporion (L'Escala), the first Greek Iberian colony. Slags and technical ceramics were analysed (pXRF, OM, SEM-EDS) to relate their microstructures and compositions to specific alloying techniques, and characterise the bronze production strategies.

Our results show absence of technological knowledge transmission between sites. While Emporion shows innovative use of co-melting with metallic tin, favoured by its Mediterranean connections, Mas Castellar followed a diversified raw material acquisition strategy that suggests a solid integration within the indigenous exchange networks. Thus, both manufacturing strategies may be explained by their contextualisation within the on-going socio-economic dynamics (indigenous vs. Mediterranean). Contrary to later phases, the Emporitan influence in the indigenous communities seems limited to Mediterranean goods exchange.

Our results prove the potential of our methodology to reconstruct the bronze making systems of past societies and serves as the basis for future work. Our on-going project will expand the chronology and geographic scope of this study to understand the development and evolution of the bronze making system in NE Iberia from the Chalcolithic to the Iron Age.

MS JULIA MONTES-LANDA, University of Cambridge

Co-Authors: Enriqueta Pons; Marta Santos; Pere Castanyer; Joaquim Tremoleda; Marcos Martinón-Torres

Session Seven, Talk One – 2:30 AM

PRODUCING METAL JEWELLERY DURING AEGEAN PREHISTORY : A MATTER OF INNOVATION, CONTINUITY AND DISCONTINUITY

Between the end of the Neolithic and the beginning of the European Bronze Age, metallurgy emerged in the Aegean area. At first considered as an innovative technical process at the end of the 5th millennium B.C., the metalworking diversifies itself during the Minoan and the Mycenaean periods, and is subject to various influences. The technological and morphostylitic studies of ornaments such as the "ring-idols" and headbands enable to better understand those phenomenons and their modalities.

The "ring-idols" display a concave ring-shaped form, surmounted by an extension with one or several perforations. Typical of the 5th and the 4th millennia B.C., they are mainly produced with metal (gold, silver, copper). The techniques identified for their production are innovating : hot or cold hammering, stamping or cutting. The "ring-idols" attest of the primary work of silver, in the Peloponnese and the northern islands. If the Aegean world maintains a local method of production at the end of the Neolithic period, regional innovations are also identified. It testifies of a high disparity between the regions in the north of Greece, in the south, and in the Aegean islands.

Similar techniques are used in the production of headbands. These head ornaments are revealing of a metalworking that extends from the 3rd millennium to the 2nd millennium B.C. The technological analysis of these artefacts has shown that their conception varies depending on the Aegean regions (continental Greece, Crete, and Cyclades) and on the period (Minoan or Mycenaean). These variations can be perceived at different scales : materials (gold, silver, copper), morphology (atypical, rectangular, biconvex), and ornamental techniques (repoussé, chasing, openwork, stamping).

A cross-approach of these two case studies demonstrate the usefulness of diachronic and supra-regional work for this kind of subject. This research allows to claim that metalworking knows a continuity during the Aegean Protohistory, while local particularisms are developing.

DOCTOR BETTY RAMÉ, Archéologies et Sciences de l'Antiquité (7041), University Paris 1 Pantheon-Sorbonne

Co-Authors: Valentin Martin

LEAD ISOTOPES IN SILVER REVEAL DEVELOPMENTS IN THE MEDITERRANEAN METAL TRADE DURING THE BRONZE AND IRON AGES

Silver, before the invention of coins, was the dominant means of value and exchange in the southern Levant. Silver hoards assert that silver served as currency throughout the Bronze and Iron Ages. However, in each sub-period within this long timespan, silver was provided from specific ores. Each change in ore source reveals valuable information on the regional trade systems, which are often invisible in ceramics. Ores are identified using Lead Isotope Analysis, which is often contested for its credibility. Therefore, we developed several methods that extend the limits of Lead Isotope Analysis and enabled us to discover the changing silver sources to the Levant. Based on these methods, we were able to trace significant developments in the Mediterranean metal trade during the Bronze and Iron Ages.

DOCTOR TZILLA ESHEL, Institute of Archaeology, Ariel University, Israel; Zinman Institute of Archaeology, University of Haifa, Israel
Co-Authors: Yigal Erel, Naama Yahalom-Mack, Ofir Tirosh & Ayelet Gilboa

Session Seven, Talk Three – 3:10 PM

FORGING SOCIETY AT MYCENAE: AN INTRODUCTION

Famously described by Homer as 'Mycenae, rich in gold', archaeologists have, since the late nineteenth century, been astounded by the treasure trove of metalwork discovered in the palace, the cemeteries, and the domestic, industrial and religious quarters of this Late Bronze Age (1700-1050 BC) settlement on the Greek mainland. Indeed it has been argued by many scholars that metals played a crucial role in the development of Mycenae, the pre-eminent centre of Mycenaean culture. Despite this, there has been no comprehensive study of metalwork from this site and the nature of prior research into metals within Aegean Prehistory as a discipline has meant that questions concerning its potential social significance within the community have received comparatively little attention. This paper is intended to offer a brief introduction to a new research project that applies a practice-orientated approach to the aforementioned corpus of material and thus enable a better understanding of the way in which metals were embedded in the daily lives of the inhabitants of Late Bronze Age Mycenae. The three main aims are to 1) demonstrate which social practices metalwork was and was not involved in; 2) investigate the culturally defined criteria which governed access to metals at Mycenae and any associated processes of adaptation, exclusion and resistance in the community; 3) establish the typical object biographies for metalwork and explore the reasons why artefacts may have deviated from such standard paths. The methodology combines the results from a full contextual analysis and an intra-site distribution analysis of metalwork from Mycenae and cross-references them against an extensive range of variables such as quantity, object type, crafting technologies, treatment during deposition and evidence for recycling. The ultimate objective for this project is to bring the study of Mycenaean metalwork up-to-date with research in other material fields, especially ceramics, where previous simplistic modelling centred around the role of elites, still very much the dominant paradigm through which Mycenaean metalwork is viewed, has been successfully challenged and replaced with a more nuanced and complex understanding of Mycenaean communities.

DOCTOR STEPHANIE AULSEBROOK, University of Warsaw

Session Eight– 5:00 PM

PLENARY PANEL

A conversation between:

Professor Mark Pollard, Edward Hall Professor in Archaeological Science at the Research Laboratory for Archaeology and the History of Art, Oxford

Doctor Justine Bayley, Honorary Senior Research Associate at the Institute of Archaeology, UCL and Editor and council member of Historical Metallurgy

Professor Marcos Martinón-Torres, Pitt-Rivers Professor of Archaeological Science, Cambridge

Professor Vasiliki Kassianidou, Professor, University of Cypress

CONFERENCE HELP

The Conference team is Dr Victoria Sainsbury, Dr Ray Liu, Dr Philly Howarth and Ms Samantha Bowring. During the conference they can be reached on:

By email: embers2021@gmail.com

Or twitter: @oxfordflame

UNIVERSITY OF
OXFORD

FLAME

erc