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THE INSTITUTE OF ARCHAEOMETRY IN FREIBERG

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Mit der Einrichtung des Instituts für Archäometrie an der TU Bergakademie Freiberg ist im deutschsprachigen Raum erstmals die Möglichkeit entstanden, die Verbindung von Archäologie und Naturwissenschaften in Forschung und Lehre zu institutionalisieren und fest in der kulturwissenschaftlichen Forschungslandschaft zu verankern. Hierdurch ergeben sich gute Voraussetzungen, einerseits interdisziplinäres Denken in die archäologische Ausbildung zu integrieren und andererseits archäometrische Forschungsprojekte aus eigener Kraft kontinuierlich über längere Zeiträume zu betreiben. Bei größeren multidisziplinären Vorhaben werden weiterhin Institutionen anderer Wissenschaftszweige zur Zusammenarbeit gewonnen werden müssen. Aber es wird dadurch besser gewährleistet, daß die verschiedenen Sichtweisen unter dem Aspekt der Archäometrie und der archäologischen Fragestellung das wissenschaftliche Vorgehen bestimmen.

Institute of Archaeometry that has been established at the Freiberg University of Mining and Technology creates an opportunity to institutionalize science-based archaeology in the academic world for the first time ever in the German speaking countries. In teaching the aim is to educate scientifically trained archaeologists and in research it is to integrate the results of multidisciplinary studies into the context of cultural history rather than to create isolated specialist's reports.

KEYWORDS: ARCHAEOMETRY, TEACHING, RESEARCH, INTERDISCIPLINARY COOPERATION

INTRODUCTION

In the past it became increasingly apparent that many questions of archaeological research cannot be solved by a mere historical approach. Scientific methods are now routinely employed to determine the location, composition, provenance, and the age of archaeological finds. The study of the development of technology from the beginnins to the Industrial Age is virtually impossible without the application of knowledge derived from the sciences and from engineering. Therefore, scientific methods are nowadays almost routinely applied in archaeological projects.

The increasing tendency of archaeologists to deal with more complex questions that go beyond the scope of traditional methods and to include insights and methodologies from other fields of research requires an open mind for an interdisciplinary approach. A few decades ago one could often observe that archaeological material was given away for analysis but that the results were rarely used in the main text. Thus they used to form an uncommented appendix to a report. On the other hand, well meaning scientists often studied archaeological finds without proper context or archaeological question. Although they often spent much time and effort for the analyses the results were meaningless for any historical interpretation. Such bad examples were common in the early days of archaeological science when it was vagely felt that the application of scientific methods could be useful but the studies remained in a multi-disciplinary stage with several disciplines working in parallel on the same material but with little interaction. Nowadays it is recognized that at each step of a program, from field work to the interpretation of analytical data, it is necessary to involve all partners to arrive at meaningful scientific and hence archaeological interpretations.

Ideally the leader of such a transdisciplinary project should be fully aware of the possibilities and limitations of all applied methods himself. He does not need not to be an expert in all fields involved. But in order to extract historically useful information from the raw data and for decision making at turning points he needs an education that goes beyond traditional teaching of archaeology. In recognition of the need to offer such an integrated curriculum the Volkswagen foundation initiated and funded a chair for archaeometallurgy which was implemented at the University of Mining and Technology (Bergakademie) Freiberg in 1997. Since it was not intended to restrict the academic training only to archaeological metals and metallurgy the Institute of Archaeometry was soon founded. It concentrates on all inorganic archaeological materials in its research while in teaching it is attempted to cover all aspects of scientific analysis in archaeology.

THE INSTITUTE OF ARCHAEOMTRY

The endowed chair of archaeometallurgy and the subsequent foundation of the Institute of Archaeometry is a logical continuation of the research program "Archäometallurgie" funded by the Volkswagen foundation between 1987 and 1996. With the endowment it was intended to institutionalize archaeometry as an academic field with a complete curriculum and with enough research capacity to provide hands-on practice for students and guest scientists. Scientific methods of analysis have always been employed in archaeological research but, at least in the German speaking countries, this was either a short-term collaboration between individuals or was confined to restauration and conservation works. Thus, one of the earliest archaeometric laboratories was established 1888 at the Museum für Völkerkunde in Berlin. Its formemost task was the conservation of salt containing tiles and rocks from Egypt. Its first director, Friedrich Rathgen published the important book *"Die Konservierung von Altertumsfunden"* in 1898 (Rathgen 1898) but there was no systematic training of the following generation and very little interaction with archaeological research as such. Nevertheless, the activity of Rudolf Virchow and the *Berliner Anthropologische Gesellschaft* created a favourable environment for the application of scientific methods in archaeological research. It was, for instance, Virchow who supported Heinrich Schliemann in his excavation at Troia and urged him to have a number of finds analyzed. But prehistoric archaeology was not yet established as an academic discipline and classical archaeology was more oriented towards an art historical approach so that this stimulating intellectual environment in Berlin could not develop into a school of archaeological thought and methodology. When Gustav Kossinna, originally trained as a linguist, was appointed as the first Professor of Prehistoric Archaeology in Berlin in 1902, a radically different approach to archaeology began to prevail and interest in the application if scientific methods in archaeology declined.

With the introduction of physical methods of analysis and the possibility to analyze large series of artefacts in the 1930s archaeometric research experienced yet again a rise in interest as demonstrated by the work of Otto and Witter, a summary of which was published only in 1952 (Otto and Witter, 1952). However, the original aim of this study was embedded in the nationalistic and racist concept of the time. Although it was recognized that trace element analyses could provide new insights into the spread of metallurgy and the trade of metals, this political legacy may have contributed to the failure of the later Stuttgart program of metal analyses (Junghans *et al*. 1960) to win widespread acceptance. Another reason may have been that metal analyses were simply used by archaeologists as a tool like ruler without going into the intricacies of the analytical, geological and metallurgical complexities. Although Edward

Sangmeister, one of the collaborators in this project, was Professor of Prehistoric Archaeology at Freiburg University, there was no attempt to include such knowledge into the curriculum of archaeological teaching in order to educate a new generation of archaeologists who would be able to deal with such multi-disciplinary projects and their results.

With the establishment of the Institut for Archaeometry at the Bergakademie Freiberg this situation has changed. Since 1998 a curriculum has been offered that combines courses in prehistoric archaeology and in basic sciences. Originally it was designated as *"Archäometrie (Ingenieurarchäologie)"* owing to the fact that the chair for archaeometallurgy is in the Department of Materials Science. In 2001 it was expanded and modified and is now called *"Archäometrie/Industriearchäologie"*, i.e. the recent history of technology ("industrial archaeology") now forms an optional branch after two years of joint basic courses. This is the first curriculum of archaeometry in German speaking countries. Academic teaching requires active research that is guaranteed by a varied equipment for elemental and isotope analyses.

The curriculum was partly based on experiences made at various universities in Great Britain and the U.S.A. (e.g. in London, Sheffield, Bradford, Glasgow, Oxford, Cambridge, University of Minnesota, Harvard, University of Illinois, to name only a few) in teaching "archaeological science" or "science-based archaeology". Their existence helped to promote the idea that a similar institution should be established in Germany also.

The author, trained as an analytical chemist and geochemist, is the first chairholder. He coordinates the scientific part of the curriculum and is director of the newly formed Institute of Archaeometry. The prehistorian Martin Bartelheim teaches courses in prehistory and directs archaeological research programs. Teaching support and a well equipped archaeological library are provided by the *Landesamt für Archäologie* in Dresden at a distance of about 40 km. The institute has also two technicians and a secretary as well as several guest scientists and research students.

Since the Institute for Archaeometrie is part of the Department of Materials Science of the TU Bergakademie Freiberg, all modern methods of light and electron microscopy as well as the classical methods for material testing are available. Furthermore there is equipment for elemental and phase analyses like X-ray diffraction, electron microprobe, X-ray fluorescence, atomic absorption analysis, neutron activation analysis available or at least acessible. A multi-collector mass spectrometer with inductively-coupled plasma-ionisation and a laser ablation unit allows almost non-destructive determinations of trace element concentrations and isotope ratios. At the TU Bergakademie Freiberg there are also laboratories for radiocarbon and thermoluminescence dating which collaborate in the training of the students. In summary, a rather wide choice of methods for inorganic archaeometric analysis can be offered for teaching and research.

TEACHING ARCHAEOMETRY

The curriculum in archaeometry is characterized by a tight combination of courses in science and engineering on the one hand and in the humanities on the other with about equal time for both. It is the aim to offer enough courses to make the part of the humanities equivalent to the requirements for a masters degree in prehistoric archaeology in Germany in order to make possible exchange of students between universities that used to be characteristic for the study of prehistory. The complete program extends over nine semesters with altogether at least twelve weeks of excavation practice and several archaeological and archaeometric excursions. The cooperation with the *Landesamt für Archäologie* in Dresden provides intimate knowledge of the actual day to day work of an archaeologist. In this institution seminars with archaeological collections, on cultural heritage management and the design and organisation of museum exhibitions are held.

For the science part of the curriculum basic courses in mathematics, physics and chemistry are offered as well as some introductory courses in materials science. After two years an intermediate examination is intended to provide orientation for both students and teachers which of the two branches would suite the student best in the advanced studies. The final two years in archaeometry are devoted to analytical and dating techniques used in archaeometric studies with hands-on practice. Another emphasis is on applied geosciences like economic geology, applications of geodesy, photogrammetry and geographical information systems. There is also the possibility for the student to choose part of the courses freely from other curricula at Freiberg.

The aim of this curriculum is to train prehistoric archaeologists with detailed knowledge of the principles and methods of scientific research. They should know the sample requirements and the effort in cost and time of a scientific investigation of archaeological material. Only in rare cases they will perform all the analyses themselves. But they will be in a position to understand the advantages and limitations of the most important methods employed in archaeometry and they will be able to formulate the the aims of the investigations in some detail so that a scientist can optimize his instrument accordingly. Thus they will not only be knowledgeable in excavation methods as any archaeologist but will also be competent in planning and coordinating post excavation study programs. Most important of all is the competence to discuss and interpret scientific data and to make them usable for cultural historical studies. Due to the fact that the Bergakademie is nowadays a University of Technology the degree awarded is not a masters degree but a diploma (*"Diplom-Archäologe/Archäologin"*).

Archaeologists from other universities can be integrated into the curriculum provided that they are willing to complete the science and engineering part. It may be somewhat easier for students of a curriculum in science or engineering to switch to archaeometry. In this case they will have to complete the humanities part. There are also postgraduate programs for archaeologists or scientists who want to write a PhD in archaeometry. Again, some parts of the sciences or the humanities must be made up for during the PhD work. It is also planned to offer a one-year compact course in archaeometry and summer schools specifically for students of prehistory from other universities. However, this requires more personnel that is at present not available.

We also encourage our students to have part of their education at other universities not only in Germany. This is most easily accomplished with universities that offer similar curricula like London, Sheffield and Bradford. Support is provided by the SOCRATES program of the European Union. Contracts for exchange of students and teaching personnel have been made with the universities of Vienna, Trento, Warsaw, Sheffield and London.

Since archaeometry does not yet have an established job profile it is expected that most graduates of the curriculum in archaeometry will work in the field of archaeology in its widest sense. Their training in prehistoric archaeology should make them compatible with any job in cultural heritage, in archaeological research and in museums. Moreover they may find job opportunities in archaeometric research or in restauration and conservation. It is thought that the significant increase of the use scientific methods in archaeology will provide enough job openings at least for the first graduates. In addition to opportunities within the wider field of archaeology and archaeometry it is conceivable that the graduates will be welcome in more distant fields where interdisciplinary knowledge and thinking is required such as in journalism, product promotion of scientific equipment and public relations work.

OTHER FACILITIES

One of the major concerns of the Institute of Archaeometry was the assembly of an archaeological and archaeometric library, besides the introduction of a curriculum and the setting up of laboratories and other facilities. The existing library is well equipped with literature in science, especially geosciences, and engineering, the traditional fields of the Bergakademie. Supported by the library staff it was possible to acquire about 4000 volumes of archaeological and archaeometric monographs and journals. This core library is already sufficient for teaching but it is constantly expanded at present. More specialized literature is accessible in the Landesamt für Archäologie in Dresden with a library that comprises about 47 000 volumes.

The Institute of Archaeometry has a number of other facilities for teaching and research available besides the analytical equipment. The most important are the collections of various projects and institutions that have been loaned or donated to the institute. Foremost is the collection of samples taken from prehistoric metal objects in the course of the above mentioned program of metal analyses at the *Württembergisches Landesmuseum* in Stuttgart. Thanks to the *Landesdenkmalamt Baden-Württemberg* this collection together with the whole archive (drawings of the objects, laboratory notebooks, original photographic plates with spectra taken with an emission spectrometer, etc.) is now on loan at the Institute of Archaeometry at Freiberg. Together with samples from earlier projects performed at the *Max-Planck-Institut für Kernphysik* in Heidelberg the institute has about 30 000 such samples at its disposal. Furthermore some 10 000 samples of ores and slags and other materials collected during field surveys, mainly by Günther Wagner, Heidelberg, Ulrich Zwicker, Erlangen, and George (Rip) Rapp, Duluth, Minnesota, and the author are stored in the geological magazine. This pool of samples forms the basis of ongoing and future research projects. To this one can add the exceptionally rich mineral collection of the TU Bergakademie Freiberg with rocks and minerals from deposits all over the world. It is one of the oldest and largest such collection in the world, since the Bergakademie is the oldest minig school in the world. In 2002 it will celebrate its 300th anniversary of the foundation of its predecessor school.

In Freiberg there is also the archive of the *Sächsische Oberbergamt* that has complete listings of mining activity and production figures in Saxony since medieval times. This information is invaluable for the research on early mining and metallurgy in the Erzgebirge and in the adjacent regions with many important base metal deposits.

RESEARCH AT THE INSTITUTE OF ARCHAEOMETRY

The Institute of Archaeometry is engaged in a number of research projects in which students are partly integrated during their training. The projects can be grouped into those that employ well-known techniques for specific archaeological questions and those that explore new techniques that may be useful for this purpose.

Pre-Islamic tin production in central Asia is one project of the first group. It is a joint endeavour of the Eurasienabteilung des Deutschen Archäologischen Instituts, Berlin, and the Deutsches Bergbaumuseum, Bochum, and was funded by the Volkswagen foundation. Starting point was the well known observation that in the third millennium BC there is ample evidence for bronze working in the Near East and in the eastern Mediterranean but no known tin deposit. Textual evidence from Mesopotamian cuneiform tablets points to an eastern or northern provenance of tin without specifying any site or region. Only recently it became possible to investigate the tin deposits of central Asia which are located along a belt ranging from the Aral Sea over Samarkand to the Altai mountains. Of special interest was a large stannite deposit in Tadjikistan. Stannite is an ore mineral that contains copper and tin, which on smelting would produce a "natural" bronze. Supporting evidence to search in this region came from lapislazuli finds in Mesoportamia and the Near East, because the only known occurrences of this rare mineral are located in northeast Afghanistan and in the Altai mountains. Two mining regions in Uzbekistan und Tadjikistan were investigated. Extensive Bronze Age mining could be discovered in both (Alimov *et al*. 1998). They were dated by archaeological finds and radiocarbon samples into the first half of the second millennium BC and are thus the earliest well documented tin mines so far discovered (Fig. 1). However, this is not as early as the earliest tin bronzes in Mesopotamia and Anatolia. In addition, the analytical comparison of trace element patterns and lead isotope ratios of the ores with the hitherto analyzed metal artefacts from Anatolia and Mesopotamia do not show agreement. Moreover, even regional metal artefacts of the second millennium BC from Uzbekistan and Tadjikistan cannot be related to these mines. The analyses are still in progress but it seems that we have only touched upon a region with many ore deposits whose relevance for the metal supply of the early civilisations in the Near East remains to be investigated. Thus the enigma of the provenence of the tin in the Early Bronze Age has not been solved but important new insights have resulted nevertheless from this project. The provenance of tin and central Asia therefore remain on the research agenda of the Institute of Archaeometry.

Figure 1 *View of the Bronze Age copper and tin mine in Mušiston (Tadjikistan), whose suface has been heavily changed by modern mining.*

Similarly the provenance of tin for the central European Bronze Age is still not resolved. In contrast to Mesopotamia and the eastern Mediterranean there are at least two regions with abundant tin deposits that have always been suspected as sources for this elusive metal. These are the deposits in the Erzgebirge on the border between Saxony and Bohemia (Fig. 2) and those in Cornwall in southwest England. While it is generally held that the deposits of Cornwall may have been exploited in prehistoric times, practically no evidence has come to light for tin or copper mining in the Erzgebirge before the twelfth century AD despite extensive field surveays. The lack of success to find prehistoric mining may be due to the intense mining activity for silver and tin in the last eight hundred years. But other archaeological finds are also missing so that the often postulated role of the Erzgebirge as source of Bronze Age tin in central Europe remained sheer speculation. In the last three years the majority of the known ore deposits in the Erzgebirge were investigated geochemically together with the Institute of Economic Geology at the Bergakadaemie in order to compare their geochemical fingerprints (trace elements and lead isotope ratios) with Bronze Age metal objects from the surrounding regions (northern and northwestern Bohemia, Saxony, Thuringia). The results obtained so far do not support the assumption that the Erzgebirge was a major metal supplier in the Early Bronze Age (Niederschlag *et al.* in print). However, since the geochemical fingerprint of bronze is largely dominated by the copper, not only because there is usually much more copper than tin in bronze but also because prehistoric copper is known to have much higher concentrations of impurities (including lead) than tin.

Figure 2 *Overgrown mining residues of a tin placer in the Erzgebirge (Saxony).*

For such work a dedicated isotope laboratory with a clean room and a mass spectrometer was established. The mass spectrometer is a new type in which the sample solution is evaporated, atomized and largely ionized in an argon plasma in contrast to the conventional thermal ionization mass spectrometer (TIMS). The advantage of this new technique is that the plasma due to its very high temperature is much more efficient in ionizing most elements of the periodic table. More important is the the fact that the samples are introduced as aqueous solutions so that the time consuming sample preparation that involved a thorough chemical separation of the metal to be measured and the transfer of a minute sample volume onto a metal filament is not any more necessary. A major advantage of the plasma excitation is its very high temperature that renders almost irrelevant the sample composition. In contrast to TIMS the element of interest does not need to be highly purified which results in a largely simplified and time-saving sample preparation for many applications.

The other parts of the instrument are more conventional. It is a double-focussing magnetic sector based multi-collector inductively-coupled plasma mass spectrometer (MC-ICP-MS, AXIOM, VG Elemental) equipped with nine independently adjustable Faraday cups as ion detectors which enable simultaneous detection of up to nine different isotopes. Comparison of the results obtained with TIMS and MC-ICP-MS are in very good agreement and it seems that the results obtained by the latter method are even more precise than those from TIMS measurements.

The application of lead isotope ratios and trace element abundances for provenance studies of metals is a well-established methodology and can and will be applied to many other more or less restricted archaeological questions and sample sets. In central Europe the ultimate aim is to learn more about the major production areas of copper in the Bronze Age and their relative importance. For this purpose a number of smaller projects have been implemented to study ore deposits, smelting remains and metal artefacts in the eastern Alps, e.g. late Neolithic copper production at Brixlegg, Tirol (see Bartelheim *et al.* this volume and Fig. 3) (in cooperation with the University of Innsbruck); excavation of a fortified Bronze Age settlement at Bartholomäberg, Vorarlberg (in cooperation with the Freie Universität Berlin and the University of Innsbruck); Late bronze Age copper smelting in the Paltental, Steiermark (in cooperation with the University of Heidelberg). It is intended to extend these studies into the Czech Republic and Slovakia in the near future. Another aspect of metallurgy is covered by the study of the working properties of copper-arsenic-antimony alloys that are typical of the central European Early Bronze Age.

Figure 3 *Excavation of a Chalcolithic copper smelting site in Brixlegg (Tyrol, Austria).*

Another field of archaeometallurgical research is the study of the origin and spread of metallurgy in the Old World. In this context already several investigations have been performed in cooperation of the Max-Planck-Institutes for Nuclear Physics in Heidelberg and for Chemistry in Mainz. Especially in the eastern Mediterranean and in southeastern Europe this holistic approach including extensive field surveys and well-dated metal objects from important archaeological sites has produced interesting results (Wagner and Weisgerber 1985, 1988; Pernicka *et al*. 1984, 1993, 1997).

These studies have been extended into central Asia in the search for tin (Alimov *et al*. 1998) and to Iran in the investigation of an important metallurgical center of the fourth and third millennia BC at Arisman (Chegini *et al*. 2000). Both projects are performed in cooperation with archaeological institutions of the respective countries and with the Eurasien-Abteilung des Deutschen Archöologischen Instituts, Berlin, and the German Mining Museum, Bochum (Fig. 4). Also under way is a survey of Early and Middle Bronze Age metallurgy in Armenia (in cooperation with the Academy of Sciences, Yerevan, and the Maison de l'Orient Mediterranée, Lyon). Of more limited scope are a project on the smelting technology and the provenance of the metal of the Early Bronze Age Sintashta culture (in cooperation with the University of Chelyabinsk) and a study of the early metallurgy at Zambujal, Portugal (in cooperation with the Deutsches Archäologisches Institut, Madrid, and the University of Sheffield).

Figure 4 *Remains of an Early Bronze Age copper smelting furnace at Arisman (Iran).*

In contrast to these studies it is also attempted to expand the existing methodologies, especially in the field of isotope archaeology. One such project was the development of a technique to measure osmium isotope ratios in small inclusions consisting of platinum group elements in ancient gold artefacts. This was accomplished with laser ablation by which a very small amount of the sample surface is evaporated and the sample vapour flushed with argon into the mass spectrometer. Only a small crater of about 50 µm diameter is produced so that the damage induced is minimal and not recognaizable with the naked eye. The rationale is the same as with lead isotope ratios. Os has a variable isotope composition in the Earth's crust due to the radioactive decay of ^{187}Re and ^{190}Pt. Therefore it should depend on the Re/Os-ratio in the source rock and the geological age of a deposit, which Os isotope ratio is found. The archaeological question was the provenance of Celtic gold that increases in abundance in central Europe within a very short time in the fourth century BC, largely due to the introduction of gold coinage. Archaeologists disagree on the provenance of this gold, whether it was of regional origin or introduced by Celtic mercenaries of Philipp II and Alexanders of Macedonia. Similarly, the origin of the large amount of gold found in Scythian graves north of the Black Sea is unknown. There is no known gold deposit in the settlement area of the Scythian tribes.

Unfortunately, it turned out that in contrast to lead the variation of the osmium isotope ratios within a single deposit tends to be rather variable. Thus one requirement for provenance determination, namely that the sources are clearly distinguishable from one another, is not satisfactorily fulfilled. Only when a number of platinum group inclusions can be found and analyzed within one gold object attribution to a specific source seems possible (Junk and Pernicka in print). Trace element analysis with very sensitive yet almost non-destructive methods such as laser ablation coupled with ICP-MS may eventually provide information on the provenance of gold.

Further methodological studies include investigations into isotope variations of copper and tin in nature, precise and accurate determination of lead isotope ratios with laser ablation and in ancient iron, strontium isotope ratios in dentine and bone to detect migration of animals and humans, and the application of lead and strontium isotope ratios for the provenance deterimination of pottery. An authenticity test for metal objects has been developed based on the radioactive decay of ^{210}Pb with a half-life of 22.3 years. Freshly prepared metal shows this radioactivity which can be detected, if the metal was produced in the last hundred years or so, depending on the initial radioactivity that varies according to the raw materials and production processes used. Therefore, this method cannot be used for dating. But for authentication, if a metal object is ancient or modern, this test is quite helpful.

There are also projects with an emphasis in archaeology like an investigation into the role of metallurgy in prehistoric societies in the Iberian peninsula in the Late Bronze and Early Iron Age as well as the absolute dating of the late Chalcolithic and Early Bronze Age in Bohemia using radiocarbon and human bone samples from burials (in cooperation with the University of Bamberg, the University of Pilsen, and the dem National Museum in Prague).

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