

Science versus Archaeology? The Case of the Bernstorf Fakes.

Ernst Pernicka

Keywords

Late Bronze Age, Bernstorf, gold, fraud

Abstract

Although scientific methods are frequently applied in archaeology and are often considered as indispensable, their results do not always agree with archaeological expectations. This can usually be resolved by detailed discussions and by acknowledging the potentials and limitations of the different approaches. To do this it is necessary to accept the competence and experience of each other and, foremost, accept and understand the different methodologies. Here a case is presented, in which such a conundrum could in principle be solved but archaeological arguments are given *a priori* more weight and disconcerting scientific results are thus suppressed. The case deals with a number of decorated gold foils and pieces of amber that were found near a Late Bronze Age structure at the hamlet of Bernstorf near the small town of Kranzberg, Lkr. Freising, in Bavaria. They were interpreted as clear evidence for contacts between Mycenae and Bavaria in the Late Bronze Age and it was suggested that the gold derives from Egypt. It was also maintained that this find would corroborate the widely accepted hypothesis of an “amber road” and a link between the Mediterranean cultures and Central Europe. Analyses of the Bernstorf gold showed it to be exceptionally pure which is not only unknown in natural gold but also in all prehistoric gold objects hitherto analyzed. It was therefore concluded that the finds from Bernstorf were made from modern gold foil, which is supported by radiocarbon dates of soil intentionally enveloping an amber “seal” containing gold foil of similar composition. However, this unavoidable conclusion is dismissed by some archaeologist, claiming that “mere chemical analysis” and “a chemist” cannot decide on the authenticity of an object and that archaeological reasoning has to be given priority.

Introduction

The involvement of scientific methods in archaeological research is as old as the two disciplines themselves, e.g. when philologists of the Renaissance translated ancient technical texts like Pliny’s *Historia naturalis* or Vitruvius’s *De architectura*, which contained technical terms and described materials that required scientific knowledge for interpretation (e.g. Durand, 1725). When large-scale archaeological excavations began at Pompei in the middle of the 18th century, the textual information could be tested by chemical analysis (e.g. Klaproth, 1815; Davy, 1815). While these early studies were mainly motivated by the curiosity of scientists with humanistic education, systematic studies with series of quantitative analyses began in the second half of the 19th century, especially in the analysis of metal objects (Pollard, 2015). This period saw major scientific breakthroughs of cultural, biological and geological evolution and it paved the way for a period of systematic data collection and methodological ordering of data in archaeology headed by Oscar Montelius. The founder of prehistoric archaeology in Germany, Rudolf Virchow, actually regarded prehistoric archaeology as a scientific discipline. Accordingly, in Vienna the prehistoric cultures including the finds from Hallstatt are displayed in the Museum of Natural History while Greek and Roman statuary art is found in the opposite building of the Museum of Art History.

Although archaeology as a whole took a turn to become a humanistic discipline after about 1900, the application of scientific methods was dramatically expanded by the introduction of atomic emission spectrometry around 1930 by which an enormous number of data was accomplished until the late 1960s (Pernicka, 2014a). This may be seen as the first science revolution

in archaeology and the fast development of analytical methods means this database is still growing. This was a period when the involvement of scientific methods in archaeology was welcome and, indeed, fashionable but it was also often fraught with too simple and unrealistic expectations concerning the provenance determination of the raw materials. Nevertheless, nowadays such inter- or transdisciplinary approaches to archaeology are the rule rather than the exception and the best results are usually achieved when the evidence and expertise of both humanistic and scientific research are combined and weighted equally.

The second science revolution was certainly the introduction of the radiocarbon dating technique that made it possible to date archaeological objects and contexts independently from contextual and stylistic considerations. This method is nowadays universally applied and the results are usually acknowledged, although it may still happen that archaeological considerations or expectations do not agree with the physical dating result. Usually this can be resolved by a detailed discussion of the material submitted and its treatment as well as its relation to the context that is to be dated. However, it must be remembered that, at least in the German speaking countries, radiocarbon dating initially met with great scepticism and even rejection (e.g. Milošević, 1957), often based only on the notion that each discipline has developed its own methodological toolkit and, therefore, should not rely on methods and their results that are “foreign” and therefore inappropriate. Similarly, the high hopes concerning the provenance of metals in prehistoric periods were not fulfilled, many archaeologists tended to dismiss the application of scientific methods for their own research. This position was untenable in the long run but the course of events seems to be repeated with every stage of the science revolution in archaeology with an enthusiastic phase at the beginning, disillusion when the first results seem to be incompatible with archaeological knowledge and finally acceptance and even appraisal after methodological corrections on both sides.

The rejection or at least negligence of the knowledge and evidence of another discipline is not restricted to archaeology. An example of a vice versa case is the story of ancient silver mines on the Cycladic island of Siphnos, which according to Herodotus who lived in the fifth century BC was the wealthiest of the islands because of its rich gold and silver mines (Herodotus III, 57). Apparently, this prosperity did not last very long since Pausanias in the second century AD writes that the mines have been flooded and obliterated (Pausanias X, 11,2). In the late 19th century, iron was mined on the island,

but no indication of noble metals was found, which cast some doubts on the ancient reports of rich gold and silver mines on Siphnos. Actually, modern geologists of the Greek Geological Service were convinced that Herodotus was a storyteller and not the “father of history”, a title first conferred by Marcus Tullius Cicero (*De legibus* 1.5). However, archaeological and archaeometallurgical field work on Siphnos between 1975 and 1980 revealed that the ancient miners were not interested in the iron ores that were won in the 19th century but in small inclusions of argentiferous lead-antimony-sulfosalts. Particularly interesting was the site of Ayos Sostis, where numerous ancient galleries are visible near the seashore. The galleries are flooded in their lower parts, thus supporting Pausanias’ statements. In these mines, various materials and objects such as charcoal, pot-sherds, mining implements, and obsidian artefacts were found and dated to a Late Archaic phase, to which Herodotus relates, and an Early Bronze Age phase of mining activity that was an entirely new discovery (Wagner and Weisgerber, 1985). This was the first proof of lead and silver mining in the Cyclades at such an early stage, with the important implication that there was no necessity to import these metals from elsewhere as has been assumed previously.

Especially in the initial phase of enthusiastic acceptance of a new method, it sometimes happens that its possibilities are greatly overestimated and one’s own expertise completely neglected. Although lead isotope analysis was introduced in the 1970s as a new tool for provenance analysis of materials, especially metals, such notions can still be occasionally observed like the claim that the tin for the bronzes of the Chinese Shang dynasty of the second millennium BC derived from South Africa (Sun, et al., 2016; Liu, et al., 2018). On the other hand, one may add that even some scientists are prepared to discard centuries of scientific research and adopt the religious belief that the universe and life originated “from specific acts of divine creation”. Thus they reject various aspects of science in order to maintain a semi-literal interpretation of certain biblical passages.

In the following, a case study is described, where hard scientific evidence of fake archaeological objects is rejected, mainly on the grounds that it disagrees with archaeological reasoning and that this is considered superior to “mere” measurements, thereby repeating the position of German archaeology more than fifty years ago. This notion was most acutely expressed by Jacquetta Hawkes who was concerned with preventing “the scientific and technological servant from usurping the throne of history” (Hawkes, 1968, p.255).

The finds and the controversy

The gold finds from Bernstorf (Figure 1) were first published by Gebhard (1999). They were found by amateur archaeologists on a hill in Bavaria north of Munich near the village of Kranzberg in the district of Freising, allegedly enclosed in lumps of soil between uprooted trees in an area that was cleared for gravel mining. They consist of decorated gold-sheet ornaments (Figure 1). The same two persons also found altogether 56 pieces of amber, most of them unworked but six with a single perforation and two with engravings, one with a bearded man's face, resembling the Mycenaean face masks and another one with four engraved characters that resemble Linear B script and was interpreted as a "seal". None of these finds derives from a secure context. There are no archaeological drawings or photographic records of the undisturbed find situation for any of these amber and gold finds.

A very large fortified enclosure of the Middle Bronze Age (in central European chronological terms) was known there and partly excavated in the 1990s. It consists of a ditch and a wall behind it that was constructed with oak wood and earth filling, similar to the much later *murus Gallicus*. It turned out that this wall was completely burnt, at least in the excavated parts, and radiocarbon and tree ring measurements firmly date the construction and probably also its destruction to around 1340 BC. However, none of the spectacular pieces, including those discovered within the area of the Bronze Age fortifications, can be directly dated or confidently assigned to any archaeological features. This also relates to a small gold foil that was wrapped around a piece of charcoal that was identified as oak wood. Four radiocarbon dates were obtained from this charcoal and all resulted in a date of roughly 1350 BC like the burnt fortification (Gebhard and Krause 2016, p.112). This was considered key evidence for the authenticity but as Weiss (2016) remarked, the date only proves the authenticity of the charred wood fragment and could have easily been planted as there is abundant charred oak wood on the site. The finder even mentioned that he had submitted large pieces for dendrochronological dating.

The composition of the gold finds was first determined by XRF without clear description of the measurement parameters, but it was noted that the silver concentration was "less than 0.2 %" and both copper and tin concentrations were "less than 0.5 %" (Gebhard, 1999). It was further noted that gold of such high purity is virtually non-existent in nature so that it must be assumed that the gold was desilvered by the cementation process and that this was already practiced in the central



Figure 1. The gold finds from Bernstorf (copies) as they are displayed in the *Bronzezeit Bayern* Museum in Kranzberg. Photo: the author.

European Late Bronze Age. From later analyses with an electron microprobe as well as with laser ablation coupled with inductively-coupled plasma mass spectrometry (LA-ICP-MS, Bähr, et al., 2012) it was concluded that the presence of four elements in the range of several hundred mg/kg (sulphur, antimony, mercury, and bismuth) would exclude the possibility of modern, electrolytically purified, gold. It was furthermore suggested that one could also identify the provenance of this gold based on this impurity pattern that was remarkably similar to one object of presumed Egyptian origin, namely the so-called Akhenaten sarcophagus (KV 55, a tomb in the Valley of the Kings in Egypt). The sarcophagus was lost for some time but reappeared later in Paris in bad condition. It was restored and shown in an exhibition in Munich and later returned to Egypt. The similarity of the trace element pattern of the gold from the sarcophagus and the Bernstorf gold seemed to indicate that the latter derived from Egypt. Infrared spectroscopy of 13 samples of amber from Bernstorf, including samples from several unworked pieces and the 'seal', was consistent with Baltic amber. The script and the style of the engraved face seemed to point towards the Mycenaean culture and gold and amber were also found in Egypt in the tomb of Tutankhamun (KV62). Accordingly, a narrative was

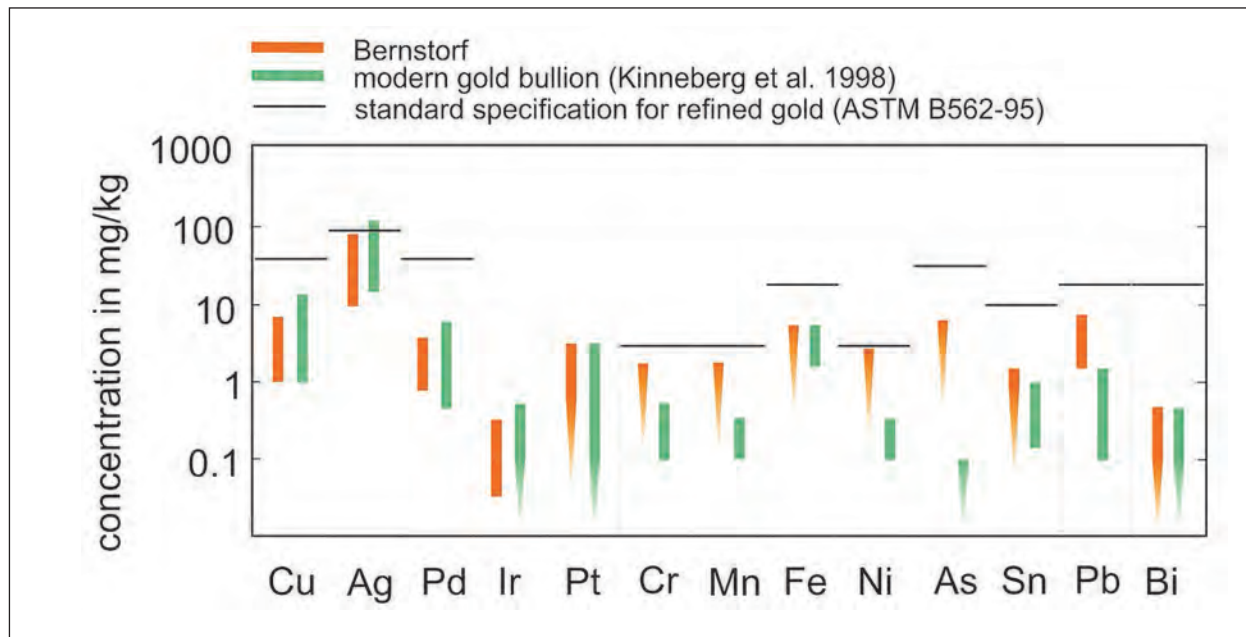


Figure 2. Comparison of the trace element pattern of the Bernstorf gold with gold bullion of 99.95 and 99.99% stated purity from eight different producers (Kinneberg, et al., 1998). Also indicated are the standard specifications for such gold as defined by the American Society for Testing and Materials (ASTM). Reprinted from Pernicka, 2014c (with permission of the Landesdenkmalamt Sachsen-Anhalt).

presented and publicized in TV programs that included an exchange of amber and gold between the Baltic and Egypt with Bernstorf and Mycenae as intermediate stations.

This scenario was called into question by Pernicka (2014b and 2014c), who had already earlier analyzed the gold foils from the sarcophagus from the tomb of Akhenaten (Klemm and Gebhard, 2001). None of the four elements considered so characteristic of the Bernstorf gold were measured at similar concentration levels in KV 55. Indeed, antimony and bismuth were below the mg/kg level. In order to resolve this obvious discrepancy the same samples that were previously analyzed at the University of Frankfurt were re-analyzed with LA-ICP-MS (Pernicka, 2014b) with the result that the assumed similarity of the gold from the Egyptian sarcophagus and the Bernstorf gold could not be confirmed and that the Bernstorf gold is of exceptional purity of 99.99%. This value was later confirmed by XRF with synchrotron radiation (Radtke, et al., 2017) so that there remains no doubt about the chemical composition of the gold. Actually, the concentrations of silver, copper, and several trace elements are suspiciously similar to modern gold (Figure 2) and even comply with the upper limits for impurities set by the American Society for Testing and Materials (ASTM) for these elements. Accordingly, it was concluded that there is a high probability that the gold objects from Bernstorf were made from modern gold foil, which is commercially available in this purity. Fur-

thermore, since two small pieces of gold foil of the same composition were found in the perforation of the “seal”, the amber finds are firmly linked with the gold ones.

While the composition of the gold is a scientific fact, its interpretation is of course open to discussion. Gebhard (1999) suggested that the gold was purified by the cementation process, in which argentiferous gold is heated with common salt and an inert material like fireclay at high temperatures of around 800°C for a few hours. The gold is attacked by chlorine from the dissociated salt and silver is converted to silver chloride and volatilized and partly soaked up by the fireclay. This process was already described in antiquity, e.g. by Plinius in his *Naturalis Historia* (Book 33, Ch. 29).

The earliest archaeological evidence for this process was found at Sardis dating to the 6th century BC (Ramage and Craddock, 2000). It is no coincidence that this technique was only applied with the introduction of coinage for the complete separation of silver and gold, because the embossing guarantees the weight and composition of a piece of metal by an administrative authority. This was not possible with natural gold because of the variable silver content. Pernicka (2014b) discussed the possibility that the cementation process was known and employed already in the Bronze Age and presented both scientific and archaeological arguments to the contrary.

As to the scientific arguments: Experiments were performed to mimic the ancient method for parting gold

with common salt (Wunderlich, et al., 2014) resulting in substantial removal of silver and a gold purity of around 99%. By repeating the process it was possible to achieve similar concentration levels of silver as in the Bernstorf gold but not of copper. However, multiple repetition with multiple loss of a fraction of the gold would serve no obvious purpose. Therefore, even if the process would have been known in the Late Bronze Age, it would not have been possible to produce gold of a composition similar to the Bernstorf finds.

This is corroborated by the analysis of ancient gold from periods when regular parting of gold and silver can safely be assumed as exemplified by Imperial Roman gold coinage. There exist some 600 analyses of such from the Republican era to the end of the Roman Empire (Kraut, 2001). Most of those coins consist of rather pure gold but none exceeds a purity of 99.8%. Interestingly, the roughly 270,000 gold ingots of the Deutsche Bundesbank have the same average composition (Bundesbank, 2017). This can be explained by the modern raffination process where gaseous chlorine is pumped through liquid gold, chemically rather similar to the ancient cementation technique for desilvering gold. Only electrolytically produced gold from gold solution attains higher purity levels of up to 99.999% (Rose and Newman, 1937). This technology was introduced in 1878 but industrially used only since the 1980s, when the Royal Canadian Mint began to issue Maple Leaf gold coins with a purity of 99.99%. A good indicator for the purity of modern gold are the gold ingots of the Deutsche Bundesbank that were mainly accumulated after the Second World War. Insofar the purity of the Bernstorf gold of 99.99% suggests that it was produced after 1980, which can be regarded as **proof** of a fake.

There are also truly archaeological arguments against cementation in the Bronze Age. It is common practice in archaeology to search for comparable finds, in this case not only stylistically and chronologically but also concerning the material properties. This inevitably leads to the largest series of analyses of prehistoric gold objects, performed by Axel Hartmann (1970; 1982) on altogether some 5,000 objects. In Figure 3 the silver concentrations of gold finds roughly contemporary to Bernstorf are plotted. It is obvious that the vast majority of the samples contain between 5 and 25% silver and prehistoric gold with lower silver concentrations is an exception rather than the rule. In the meantime, many more analyses of prehistoric gold from Europe have become available (e.g. Warner and Cahill, 2012; Constantinescu, et al., 2012; Leusch, et al., 2015) that all contain more than 3% silver. The same is true for native gold from various regions (Borg and Pernicka, 2017; Leusch, et al., 2015).

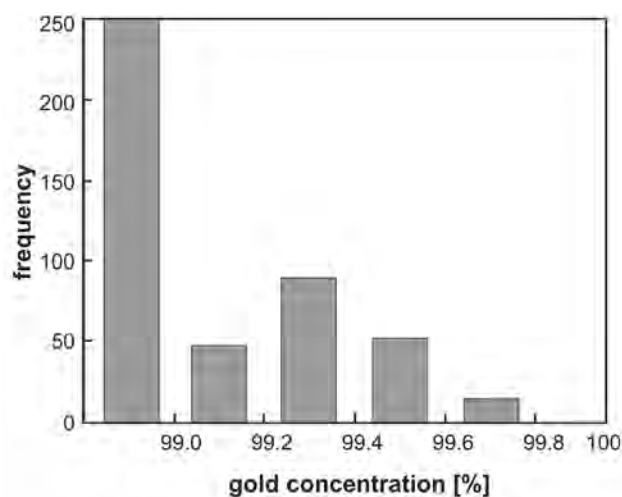


Figure 3. Silver contents of almost 1000 Bronze Age gold finds published by Hartmann (1970; 1982).

Among the analyses published by Hartmann there were very few, actually only seven, that contained less than 1% silver and Hartmann indeed suggested that they may consist of gold desilvered by cementation. All of these can be dismissed either because there were mistakes or because the objects derive from the antiquities market (Pernicka et al. in print). Only two small rings from Susa derive from a reliable but later archaeological context. Two from Dendra in Greece probably belong to a robbed tomb but were acquired through the antiquities market. One from Ireland had a wrong number and, accordingly, a wrong analysis. The object contains 15% silver. Another one from Ireland cannot be dated but most likely belongs to the Viking period. There remains only the disc from Moordorf in northern Germany that was acquired from the antiquities market in the 1920. It contains 0.2% silver and is now considered to be a fake also (Pernicka, et al., in print; Lehmann, et al., 2018).

In summary, all this cannot be considered as hard evidence for parting gold and silver in the central European Late Bronze Age. Even in the eastern Mediterranean there is no evidence for parting in the second millennium BC as indicated by the composition of Mycenaean and Minoan gold seals (Pernicka, 2014b) and gold artefacts from Egypt (Troalen, et al., 2014) and Mesopotamia (Jansen, et al., 2016).

More evidence for a forgery

Some of the gold pieces, and the amber 'seal', were enclosed in an 'envelope' of unconsolidated soil, originally interpreted as some kind of sheathing that could easily

be removed with a paintbrush and water. Unsurprisingly, this sediment is local as several investigations have shown (Gebhard and Krause, 2016). However, there are several pieces of hard evidence that it derives from the upper (i.e. recent) soil levels at the site, such as uncarbonised plant residues, residual radioactivity of ^{137}Cs from the Chernobyl accident, and a mineralised conifer needle that produced a modern radiocarbon date (i.e. after 1950 and most likely around 1995). This soil envelope contained the amber “seal” that also had two small pieces of gold with identical composition as the other gold finds in the perforation. This comes close to a “smoking gun”.

The authenticity of the amber seal has frequently been called into question (e.g. Hughes-Brock, 2011) and new investigations by Verkooijen (2017) and Wunderlich (2017) clearly showed that the engravings are modern. Kristiansen (2016) remarked in a footnote on page 165: “Most recently a conference was held in Munich organized by Rupert Gebhard and Rüdiger Krause to discuss with Bronze Age specialists from around Europe the much debated finds of goldwork of apparent Mycenaean inspiration: a carved face in amber, and an amber seal with Linear B. We all had a chance to study the finds in exemplary detail, and analyses of the gold were presented. Having now studied the amber close up, it is clear to me that the carving of the face and of the Linear B are too fresh to be ancient. This also creates doubt as to the authenticity of the goldwork. Hopefully a full publication of the results of the conference will be published.”

Several reviews of Gebhard and Krause (2016) have appeared (Reichenberger, 2017; Weiss, 2017; Harding and Hughes-Brock, 2017; Ernée, 2017; Jung, 2017; Pernicka and Wunderlich, 2017). All of them criticize the polemic style of the book, highlight weaknesses and contradictions in the argumentation of the authors and come to the conclusion that Bernstorff should be left out from models and discussions of long-distance trade in the Late Bronze Age between the Mediterranean and Europe.

Discussion and conclusion

Gebhard and Krause (2016) correctly state: “... archaeologists should not make themselves uncritically dependent on the statements of natural scientists, as any interpretation and cultural-historical assessment ought to be exclusively based on a dialogue between both sides. Archaeological criteria and methods need to be given at least the same weight as natural historical ones, all the more so if natural scientific analysis gets to the limits of its possibilities and interpretations.” Do we see here an-

other critique of post-processual archaeologists against “dehumanization” of the past (Shanks and Tilley, 1987, p.77)? I am afraid that the answer is no. They rather seem to adopt the position of Jacquetta Hawkes (1968): “Are not very strong forces enticing the subject [archaeology] from its allegiance to the humanities and trying to make it look as much as possible like one of the natural sciences? This can never properly be, since, however scientific the methods employed, the final purposes are historical: the reconstruction of individual events in time.” Citing Samida and Eggert (2013) the authors claim that “the Bernstorff case offers detailed insight in the classic theme of verification of finds (“Fundkritik”) and also has proven to be a model example of the limits to possibilities as far as reconstructions with the aid of scientific methods are concerned”. It seems that they merely hold up one of the two mental shields against science-based archaeology (Lidén and Eriksson, 2013), namely “the archaeological scientist by definition does not understand archaeology, so I don’t need to listen.” Accordingly, Pernicka is consistently addressed as “the chemist” in the introduction of Gebhard and Krause (2016). Ironically, they do not use the second shield that “as an archaeologist, I don’t understand these natural science things, so I don’t need to listen”. Quite to the contrary, Gebhard and Krause (2016) tried to disprove the allegation of a forgery mainly with scientific arguments and predictably failed. They merely tried to discredit the scientific results that have been independently confirmed (Radtke, et al., 2017) and instead favoured earlier analyses that have been proven wrong, thereby treating scientific results as “different opinions”. Some results that could not be ignored like the modern date of the soil envelopes were explained by extravagant models of stratigraphic disorder that no archaeologist with excavation experience will follow. Most recently they convincingly showed by neutron diffraction that the Bernstorff gold foils were produced by rolling and annealing (Wagner, et al., 2017), clearly a modern process. On the other hand, they fail to present convincing archaeological evidence for a typological relationship of Bernstorff with the Mycenaean region as Jung (2017) has outlined in detail.

Does this case indicate a tendency in our time to accept only “alternative facts” that one prefers to believe? This may be so in the communication to the public. But the third science revolution in archaeology is under way (Kristiansen, 2014) and will have a decisive effect on future archaeological research and interpretation. However, in the case of Bernstorff it seems that personal reasons are the major impetus for the denial of reality. The silence in the German archaeological community may be explained by the fact that in a small academic discipline

a few opinion leaders may claim the privilege of interpretation for a while, as it happened with radiocarbon dating in the German speaking countries in the 1960s and 1970s. They may impede the scientific progress in a country or even only in a region like Bavaria but their position will not stand the test of time.

References

- Bähr, V., Krause, R., and Gebhard, R., 2012. Neue Forschungen zu den Befestigungen auf dem Bernstorfer Berg bei Kranzberg im Landkreis Freising (Oberbayern). *Bayerische Vorgeschichtsblätter*, 77, pp.5-41.
- Borg, G. and Pernicka, E., 2017. Goldene Zeiten? – Europäische Goldvorkommen und ihr Bezug zur Himmelscheibe von Nebra. *Jahresschrift für mitteldeutsche Vorgeschichte*, 96, pp.111-138.
- Bundesbank 2017. *Goldbestand der Deutschen Bundesbank Stand: 31.12.2017. Überblick über die Lagerstellenverteilung des Goldbestandes der Deutschen Bundesbank.*
- Constantinescu, B., Vasilescu, A., Stan, D., Radtke, M., Reinholz, U., Buzanich, G., Ceccato, D. and Oberländer-Tärnoveanu, E., 2012. Studies on archaeological gold items found in Romanian territory using X-Ray-based analytical spectrometry. *Journal of Analytical Atomic Spectrometry*, 27, pp.2076-2081.
- Durand, D., 1725. *Histoire de la peinture ancienne extraite de l'Histoire naturelle de Pline, livre XXXV, avec le texte latin.* London: Bowyer.
- Davy, H., 1815. Some Experiments and Observations on the Colours Used in Painting by the Ancients. *Phil. Trans. R. Soc. Lond.*, 105, pp.97-124.
- Ernée, M., 2017. Review of Rupert Gebhard – Rüdiger Krause, Bernstorf Archäologisch-naturwissenschaftliche Analysen der Gold- und Bernsteinfunde vom Bernstorfer Berg bei Kranzberg, Oberbayern Bernstorf-Forschungen 1. *Památky Archeologické*, CVIII, pp.291-336.
- Gebhard, R., 1999. Der Goldfund von Bernstorf. Mit einem Beitrag von Manfred Moosauer. *Bayerische Vorgeschichtsblätter*, 64, pp.1-18.
- Gebhard, R. and Krause, R., 2017. *Bernstorf. Archäologisch-naturwissenschaftliche Analysen der Gold- und Bernsteinfunde vom Bernstorfer Berg bei Kranzberg, Oberbayern. Mit Beiträgen von B. Armbruster, V. Bähr, U. Baumer, P. Dietemann, K.T. Fehr (†), P. Freiburger, J. Haberstroh, W. Häusler, R. Hochleitner, H. Hoffmann, B. Kromer, A. Lazzaro, P. Paoletti, M. Pietsch, M. Radtke, Ch. Rewitzer, A. Röpke, C. Rohde, H. Schulze, C.S. Sommer, F.E. Wagner, U. Wagner, S. Winghart.* Abhandlungen und Bestandskataloge der Archäologischen Staatssammlung, Band 3 (München 2016). Gebhard, R. ed., 2017. Zugleich Frankfurter Archäologische Schriften, Band 31. von Kaenel, H.M., Krause, R., Meyer, J.W. and Raack, W. eds., 2017. Bonn: Habelt.
- Harding, A. and Hughes-Brock, H., 2017. Mycenaean in Bavaria? Amber and gold from the Bronze Age site of Bernstorf. *Antiquity*, 91, pp.1382-1385.
- Hartmann, A., 1970. *Prähistorische Goldfunde aus Europa. Studien zu den Anfängen der Metallurgie*, Band, 3. Berlin: Gebrüder Mann.
- Hartmann, A., 1982. *Prähistorische Goldfunde aus Europa II. Spektralanalytische Untersuchungen und deren Auswertung.* Berlin: Gebrüder Mann.
- Hawkes, J., 1968. The proper study of mankind. *Antiquity*, 42, pp.255-62.
- Hughes-Brock, H., 2011. Exotic Materials and Objects Sent to – and from? – the Bronze Age Aegean. Some recent work and some observations. In: A. Vianello, ed. 2011. *Exotica in the Prehistoric Mediterranean.* Oxford: Oxbow Books. pp.99-114.
- Jansen, M., Klein, S. and Hauptmann, A., 2016. Where does the gold from Ur come from? Provenancing gold sources using analytical methods. *Metalla*, 22(1), pp.98-106.
- Jung, R., 2017. Rezension von Gebhard und Krause (2016). *Archaeologia Austriaca*, 101, pp. 333-348.
- Kinneberg, D.J., Williams, S.R. and Agarwal D.P., 1998. Origin and Effects of Impurities in High Purity Gold. *Gold Bulletin*, 31(2), pp.58-67.
- Klaproth, M.H., 1815. *Chemische Abhandlungen gemischten Inhalts (vol. 6 of Beiträge zur Chemischen Kenntnis der Mineralkörper).* Berlin and Stettin: In der Nicolaischen Buchhandlung.
- Klemm, D.D. and Gebhard, R., 2001. Anhang II, Analyse des Goldes; R. Gebhard, Anhang III, Analyse der Vergoldung. In: A. Grimm and S. Schoske, eds. 2001. *Das Geheimnis des goldenen Sarges – Echnaton und das Ende der Amarnazeit.* München, Staatl. Museum Ägyptischer Kunst. pp.80-86.
- Kraut, J., 2001. *Zerstörungsfreie Analyse römischer und byzantinischer Goldmünzen des ersten bis elften Jahrhunderts.* PhD, Universität Basel.
- Kristiansen, K., 2014. Towards a new paradigm? The Third Science Revolution and its Possible Consequences in Archaeology. *Current Swedish Archaeology*, 22, pp.11-34.
- Kristiansen, K., 2016. Interpreting Bronze Age trade and migration. In: E. Kiriati and C. Knappett, eds. 2016. *Human mobility and technological transfer in the prehistoric Mediterranean.* Cambridge: Cambridge University Press. pp.154-80.
- Lehmann, R., Avraam, G., Merkle, M., Kummerfeldt, J. and Fellenger, D., 2018. Bronzezeitliche Goldscheiben in Nds. – Fälschungserkennung mit Hilfe römischer Aurei. In: R. Lehmann, K. Hagemann and H. Haßmann, eds. 2018. *Von Drusus bis Maximinus Thrax – Römer in Norddeutschland. FAN Schriftenreihe*, Band, 1. pp.248-271.
- Leusch, V., Armbruster, B., Pernicka, E. and Slavčev, V., 2015. On the Invention of Gold Metallurgy: The Gold Objects from the Varna I Cemetery (Bulgaria)—Technological Consequence and Inventive Creativity. *Cambridge Archaeological Journal*, 25(1), pp.353-376.
- Lidén, K. and Eriksson, G., 2013. Archaeology vs. Archaeological Science. Do we have a case? *Current Swedish Archaeology*, 21, pp.11-20.

- Liu, S., Chen, K.L., Rehren, Th., Mei, J.J., Chen, J.L., Liu, Y. and Killick, D., 2018. Did China import metals from Africa in the Late Bronze Age? *Archaeometry*, 60, pp.105-117.
- Milojčić, V., 1957. Zur Anwendbarkeit der C 14-Datierung in der Vorgeschichtsforschung. *Germania*, 35, pp.102-110.
- Pernicka, E., 2014a. Provenance Determination of Archaeological Metal Objects. In: B.W. Roberts and C. Thornton, eds. 2014. *Archaeometallurgy in Global Perspective. Methods and Syntheses*. New York: Springer, pp.239-268.
- Pernicka, E., 2014b. Zur Frage der Echtheit der Bernstorfer Goldfunde. In: H. Meller, R. Risch and E. Pernicka, eds. 2014. *Metals of power – Early gold and silver*. Halle [Saale]: Landesmuseum für Vor- und Frühgeschichte, pp.247-256.
- Pernicka, E., 2014c. On the authenticity of the gold finds from Bernstorf, community of Kranzberg, Freising district, Bavaria. *Jahresschrift für mitteldeutsche Vorgeschichte*, 94, pp. 517-526.
- Pernicka, E. and Wunderlich, C.H., 2017. Rezension von Gebhard und Krause (2016). *Prähistorische Zeitschrift*, 92(2), pp.428-444.
- Pernicka, E., Leusch, V. and Lockhoff, N. in print. Die Goldscheibe von Moordorf und die Goldfunde der europäischen Bronzezeit – eine archäometallurgische Perspektive. *Die Kunde*, 67 (in print).
- Pollard, A.M., 2015. The first hundred years of archaeometallurgical chemistry: Pownall (1775) to von Bibra (1869). *Historical Metallurgy*, 49(1), pp.37-49.
- Radtko, M., Reinholz, U. and Gebhard, R., 2017. Synchrotron radiation-induced X-ray fluorescence (SRXRF) analyses of the Bernstorf gold. *Archaeometry*, 59, pp.891-899.
- Ramage, A. and Craddock, P., 2000. *King Croesus' Gold. Excavations at Sardis and the History of Gold Refining*. Cambridge, MA: Harvard University Art Museums, in association with British Museum Press.
- Reichenberger, A., 2017: Rezension von Gebhard und Krause (2017). *Jahresschrift für Mitteldeutsche Vorgeschichte*, 96, pp.543-550.
- Samida, S. and Eggert, M.K.H., 2013. *Archäologie als Naturwissenschaft? Eine Streitschrift*. Reihe Pamphletliteratur 5. Berlin: Vergangenheitsverlag.
- Shanks, M. and Tilley, C., 1987. *Social Theory and Archaeology*. Albuquerque: University of New Mexico Press.
- Sun, W.D., Zhang, L.P., Guo, J., Li, C.Y., Jiang, Y.H., Zartman, R.E., and Zhang, Z.F., 2016. Origin of the mysterious Yin-Shang bronzes in China indicated by lead isotopes. *Scientific Reports*, 6, p.23304. <https://doi.org/10.1038/srep23304>.
- Troalen, L.G., Tate, J. and Guerra, M.F., 2014. Goldwork in Ancient Egypt: workshop practices at Qurneh in the 2nd Intermediate Period. *Journal of Archaeological Science*, 50, pp.219-226.
- Verkooijen, K., 2017. Report and catalogue of the amber found at Bernstorf, Gmd. Kranzberg, Kr. Freising, Bavaria, Germany. *Jahresschrift für Mitteldeutsche Vorgeschichte*, 96, pp.139-230.
- Wagner, G.A. and Weisgerber, G. eds., 1985. *Silber, Blei und Gold auf Sifnos, prähistorische und antike Metallproduktion. Der Anschnitt, Beiheft, 3*. Bochum: Deutsches Bergbau-Museum.
- Wagner, F.E., Gebhard, R., Gan, W.M. and Hofmann, M., 2017. The Metallurgical Texture of gold artefacts from the Bronze Age Rampart of Bernstorf (Bavaria) Studied by Neutron Diffraction. Book of Abstracts, *NINMACH 2017 – 2nd International Conference on Neutron Imaging and Neutron Methods in Archaeology and Cultural Heritage Research*. p.46.
- Warner, R. and Cahill, M., 2012. The Downpatrick Hoards: an Analytical Reconsideration. In: J.R. Trigg, ed. 2012. *Of Things Gone but not Forgotten. Essays in archaeology for Joan Taylor*. Oxford: Archaeopress. pp.95-108.
- Weiss, R.M., 2017. Review of Gebhard and Krause (2016). *Hammaburg NE*, 17, pp.I-XIV.
- Wunderlich, C.H., Lockhoff, N. and Pernicka, E., 2014. De Cementatione oder: Von der Kunst, das Gold nach Art der Alten zu reinigen. In: H. Meller, R. Risch and E. Pernicka, eds. 2014. *Metals of power – Early gold and silver*. Halle [Saale]: Landesmuseum für Vor- und Frühgeschichte. pp.353-370.
- Wunderlich, C.-H., 2017. Studien zur Verwitterung von Baltischem Bernstein (Succinit). *Jahresschrift für Mitteldeutsche Vorgeschichte*, 96, pp.231-246.

Author

Ernst Pernicka
 Curt-Engelhorn-Zentrum Archäometrie
 D6, 3
 68159 Mannheim
 and
 Institut für Geowissenschaften
 Universität Heidelberg
 Im Neuenheimer Feld 234-236
 69120 Heidelberg