

How to put archaeological geometric data into context? Representing mining history research with CIDOC CRM and extensions

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Abstract:

A wealth of information on cultural heritage coming from archaeological investigations exists in the form of geometric information. Here we want to question how this geometric information relates back to the reality it was intended to document. Building upon the CIDOC CRM - an ontology to represent data for cultural heritage - we apply CRMgeo, an extension to the CIDOC CRM that treats space always in combination with time which is essential to archaeological investigations. Interdisciplinary research on mining sites in Austria within the project HIMAT serves as the field of application for showing our proposal how to put geometries into context. From the various research conducted in the course of HIMAT we selected prospection activities, archaeological excavations, survey and dendrochronological analysis for a prototypical modelling. We want to show how such a modelling may help to answer practical research questions like reconstructing the spatial organisation of the metallurgical production chain.

1. INTRODUCTION

A wealth of information on cultural heritage coming from archaeological investigations exists in the form of geometric information. One kind of geometric information relates to the boundaries of cultural heritage objects and may be recorded as 2D or 3D models in various forms. Examples are footprints of excavations or buildings recorded with tachymetry or 3D

representations of archaeological objects or surfaces within an excavation recorded with 3D laserscanning or photogrammetry. Positioning immobile objects or mobile objects at a specific time on the surface of the earth creates geoinformation, e.g. through georeferencing 2D or 3D datasets or acquiring positions through GPS devices. Here we want to question how this geometric information relates back to the reality it was intended to document. Building upon the CIDOC CRM [1] - an ontology to represent data for cultural heritage - we apply CRMgeo [2] as an extension to CIDOC CRM that treats space always in combination with time which is essential to archaeological investigations. Through establishing a model of real world objects of cultural importance with their geometric and temporal relations we can achieve information integration including geometric and temporal data.

Information integration in Cultural Heritage using ontologies is targeted in a variety of projects and initiatives from those on a national scale within a specific domain like archaeology in the United Kingdom (<http://archaeologydataservice.ac.uk/>) or Germany (<http://www.ianus-fdz.de/>), to those on an European scale featuring an abundance of topics like Europeana, the digital library for Europe (<http://www.europeana.eu/>). Europeana uses the EDM (Europeana Data Model) ontology [15] to harmonize the concepts of different sources to tackle the challenges arising in the Cultural Heritage domain. Geographical content was targeted in the Carare project (<http://pro.europeana.eu/web/carare/home>) which was aimed at making digital content for Europe's cultural heritage monuments and buildings interoperable with Europeana and accessible alongside items from national libraries, archives, museums and other content providers. A Europeana Gazetteer prototype was built within the Carare project, including coordinates for monuments and architecture [16] which means that coordinate information on a site level is provided. The approach presented in this paper takes a further step to include intra-site geometries and as the place concept of the CIDOC CRM corresponds to the place concept of EDM and EDM can model activities the approach would be applicable to Europeana data.

Interdisciplinary research on mining sites in Austria within the project HIMAT [3] serves as the field of application for showing our proposal how to put geometries into context. From the various research conducted in the course of HIMAT we selected prospections activities, archaeological excavations, survey and dendrochronological analysis for a prototypical modelling. The methodological approach consists of using the CIDOC CRM ontology [1] with the CRMgeo extension [2] and specific classes of other CIDOC CRM extensions to represent the objects present in the example. We want to show how such a modelling may help to answer two practical research questions within

the project HIMAT. One of them concerns the periods and locations of mining and the other reconstructing the spatial organisation of the metallurgical production chain.

2 MINING HISTORY RESEARCH AND SELECTED RESEARCH QUESTIONS

The multidisciplinary research center HiMAT (History of Mining Activities in the Tyrol and Adjacent Areas – Impact on Environment and Human Societies) was established at the University of Innsbruck, Austria, in 2007 and is dedicated to the research of mining in the Eastern Alps.

Prehistoric Europe changed extensively since the beginning of the extraction of ore and metal. By the second or early first Millennium BC, there was already an expert-based communication and economy between the Alpine valleys. This involved not only trading in commodities and goods but also an exchange of technologies and specialists. The impact of mining is also included and visible in the settlement history and the resulting economic development of these areas up to Modern Times. Together with internationally renowned partners from the universities of Basel, Frankfurt, Tübingen and the German Mining Museum in Bochum a special research program was initiated by a team of natural and social scientists and technicians from the University of Innsbruck. The research center is supported by an interdisciplinary team of post-graduate students investigating the area around Kitzbühel (Tyrol) dealing with similar data, research questions and problems [12]. The goal of these projects is the investigation of the impact of mining activities on the environment and human society from prehistoric to Modern Times at the highest scientific level [3].

In the traditional mining area of Schwaz/Brixlegg in North Tyrol, Austria, an extensive prehistoric copper mining based on fahl ores is already known since the 1990s. Many still preserved pits whose prehistoric age was unrecognized can now be assigned to Late Bronze Age and Early Iron Age mining. In addition to numerous mining traces above and below ground treatment facilities and so far two smelting places were found. In the synopsis of the results of mining-archaeological prospection and archaeological excavations, another important center of prehistoric copper production in the Alps can be seen here. For investigations in the framework of the research center HiMAT the small and relatively insignificant mining area "Mauken" was selected, which is part of the municipalities of Radfeld and Brixlegg in the lower Inn valley.

There we find in a confined space but spectacular preservation a variety of archaeological findings that provide insightful information on the entire range of the metallurgical production chain on the way from ore extraction over processing and smelting to the raw metal [4]. Dendrochronological as well as archaeological and geometric data

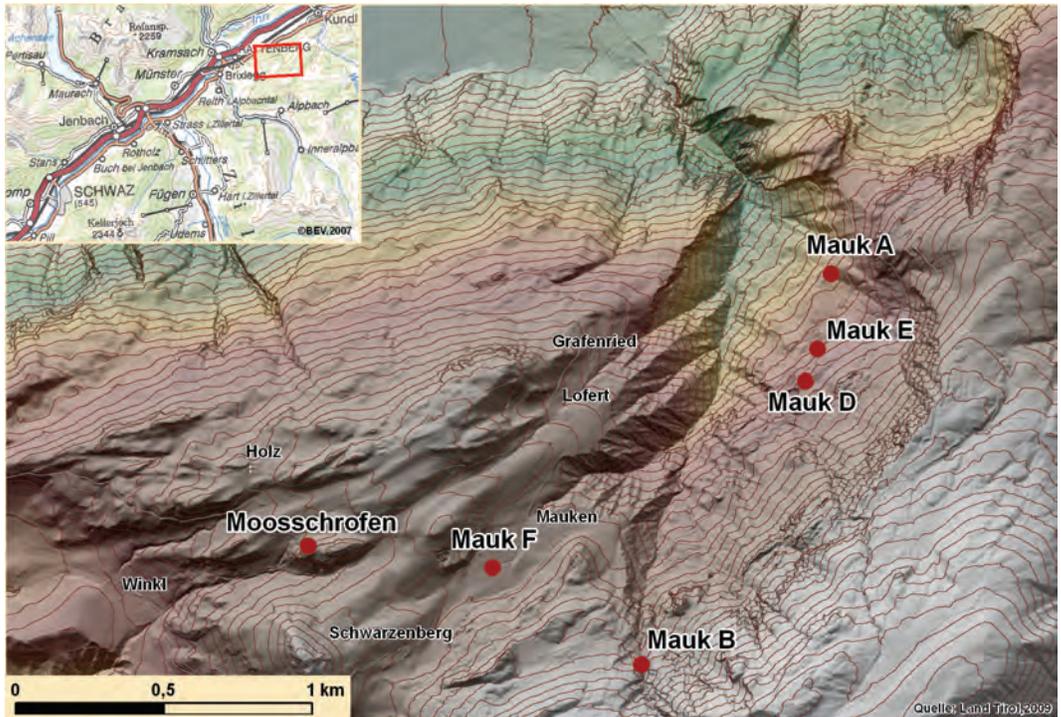


Figure 1. The prehistoric mining area of Mauken

from this site are available. They are stored in a variety of different formats, resolutions and media (digital or analogue) that do not match the requirements of a joint database to concatenate their content for further analyses.

Not only in humanities knowledge is often stored and transferred with documents that are not formalized. In order to make this information accessible to all disciplines a content management system was implemented at the start of the project to provide the infrastructure to handle these heterogeneous data like PDFs, MS Word documents, photos, maps, sketches or interviews. To enable a data exchange between all scientists involved, these documents have to be enriched with metadata based on the CIDOC CRM standard using the terms from a thesaurus [5].

In this paper we want to show how to model with CIDOC CRM and CRMgeo, specific data coming from observations and having a geometric or temporal component or interpretation. The integration of information achieved through the modelling in this ontology can help to answer research questions concerning the periods and locations of mining. Reconstructing the spatial organisation of the metallurgical production chain on the way from ore extraction over processing and

smelting to the raw metal is another research question that may be addressed with the results of the modeling.

3. METHODOLOGY

3.1 Represent mining history and research with an ontology

The CIDOC CRM ontology provides us with the concepts to model the past reality through the specification of relevant relations between Physical Things, Events, Actors, Places and Time Spans. An essential characteristic of this ontology is the event centric modelling. This means that Physical Things are not directly related to Actors, Places or Time Spans but through Events. The advantage of the model becomes obvious when thinking about movable objects. They may have been created at one place, by certain people, used at a different place by other people and may have been found at yet another place by a scientist.

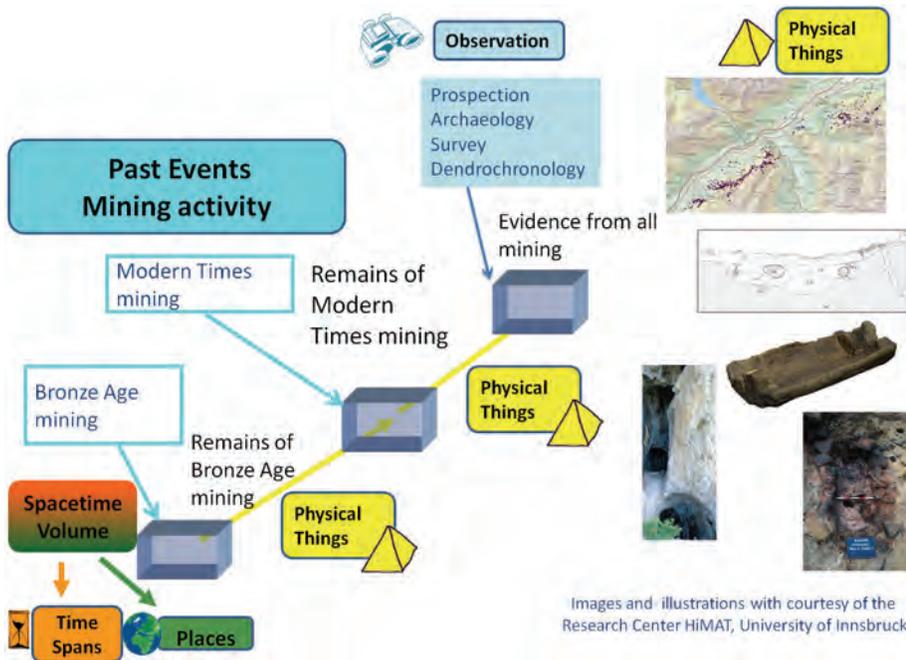


Figure 2. Mining History with ontological concepts

Traditional entity-relationship models often directly assign a place to a physical object and lose the possibility to represent the different stages in the lifetime of an object which are nevertheless relevant for scientific analysis. CRMgeo [2] lately introduced the Spacetime Volume as a concept between Events or Physical Things and their associated

Time Spans and Places. Observations are a special kind of Events and have been defined in CRMsci [6], an extension of the CIDOC CRM to model scientific research. Applying these concepts to our research interest and our research interest and area, this would mean that we found a landscape that was obviously used for mining activities and historical sources showing evidence of copper and silver mining in Modern Times since the 16th century AD. So we can assume a past Events of mining activity without knowing their exact temporal or spatial bounds. Research within the last 25 years proved Bronze Age mining in the area which leads us to the modeling of two distinct periods of mining, one in Modern Times and the other one in the Bronze Age. In the following examples we want to focus on the Bronze Age mining and show how scientific data with geometric or temporal information or interpretation can be modeled using CIDOC CRM and its extensions.

3.2 CRMgeo

The CRMgeo [2] extension closes the gap between an ontology for real world objects and detailed geometric information as defined in OGC Standards [7]. This is done through the central concept of a Phenomenal (or true) Spacetime Volume which is a four dimensional point set (volume) that phenomena like Events or Physical Things occupy in spacetime. It is regarded to be unique but unknown and unobservable in its exact extent. However, in general, there exist kinds of evidence of points in spacetime for which we can tell if they are in or out of a specific Phenomenal Spacetime Volume. This is necessary to compare and relate Events or Physical Things with each other. As Archaeology commits to one common reality regardless of the different opinions that exist of this reality the Phenomenal Spacetime Volume is a central concept representing this one reality. The Phenomenal Place is a spatial projection of the Phenomenal Spacetime Volume. Phenomenal Places derive their identity through Events or Physical Things by the Phenomenal Spacetime Volume that they occupy. After introducing the Phenomenal Place as the real place of an Event or a Physical Thing we want to provide the concepts in order to approximate its spatial position and extent with Declarative Places that are defined by humans through Geometric Place Expressions and are expressed in a Spatial Coordinate Reference System.

In the OGC world a Geometric Place Expression corresponds to the class Geometry and can be seen as a prescription to find the intended place in the real world. It may be created from an observation with a measurement device or the simple drawing of a point on a map. Both actions create a Declarative Place that can be visited in the real world. A Declarative Place derives its identity through

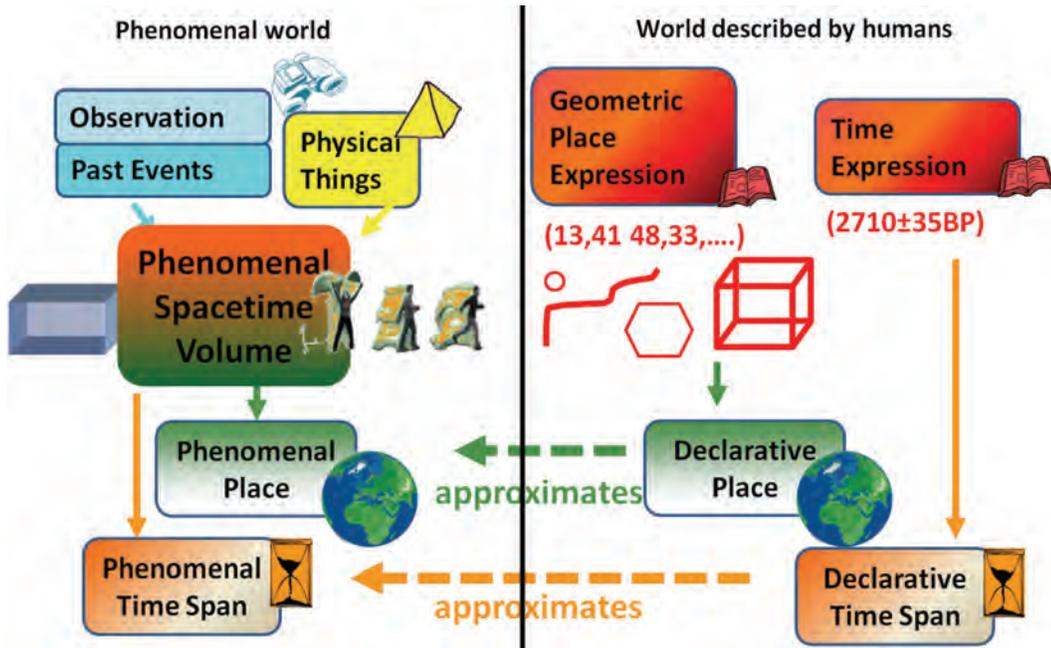


Figure 3. Relations of Phenomenal Spacetime Volume to Declarative Place as defined by a Geometric Place Expression

the description in the Geometric Place Expression and not through a Phenomenal Place that it may want to approximate. Figure 3 shows the relations between Phenomenal and Declarative Places and their related concepts. The same model applies to Phenomenal and Declarative Time Spans and Phenomenal and Declarative Spacetime Volumes.

4 EXAMPLES FROM MINING HISTORY RESEARCH

With examples from Archaeology, Surveying and Dendrochronology we want to show how we apply the concepts of the CIDOC CRM ontology and its extensions for the selected research questions concerning the periods and locations of mining as well as reconstructing the spatial organisation of the metallurgical production chain on the way from ore extraction over beneficiation and smelting to the raw metal. Main focus lies on the concepts of different aspects of Places and Time Spans and how we can define them. We like to show a way for integrating information based on real world objects, that may have been assigned different geometries depending on the research question or methodology of observation.

4.1 Archaeology

The field of archaeology is a discipline that - maybe more than any other discipline - has to handle data from different sources. Thereby it has to rely on data gained by modern research but deals with interpretations of past human activities and makes interpretations based on these data. As such they can only give a mere clue about what the past looked like. The more archaeologists have to focus on the documentation of the things they find as in the process of finding the context of the things gets destroyed. In the majority of cases either a survey, a prospection or an excavation is the starting point for collecting data and most of the subsequent research has to deal with and count on the documentation. Therefore we have to focus our attention on the preparation of data and the possibility to link the data. The following examples will show our attempt to represent and link data with CIDOC CRM and the recently developed extensions CRMgeo [2] and CRMarchaeo [8].

4.1.1 Modeling and information integration for prospection activities

In the 1960s the Schwaz/Brixlegg area was investigated by the geologist Herwig Pirkel. For several years he made surveys of geological features and features created through surface or deep mining. That resulted in two detailed maps of the area with the scale of 1:10000. At that time there was no knowledge of Bronze Age mining in this area. In the mid 1980s and 1990s prospection activities revealed indications for prehistoric mining that have been verified through excavations and dating of materials found in the Mauken area.

In 2012, a PhD student made a GPS survey of the whole Schwaz/Brixlegg area trying to identify traces of prehistoric mining. They are characterized by the method of putting fire in the mine to blast the stone [11]. Traces of this method are dome shaped mines with black walls derived from the fire. When we try to model the different prospection activities and put them in one picture we have distinct observations that create declarative places coming from different sources like map coordinates, descriptions of places that are identified later on a topographical map or GPS coordinates. These Declarative Places may denote the same Phenomenal Place as shown in figure 4.

A prospection activity in the 1980s gave us the description of a rock formation called Mooschrofen containing a presumed prehistoric mine. The rock formation is identified on a LIDAR scan of the area and a bounding box with coordinates is defined around the rock formation creating a Declarative Place. If we add the possible error of the laser scan to the bounding box and we believe the observation of the

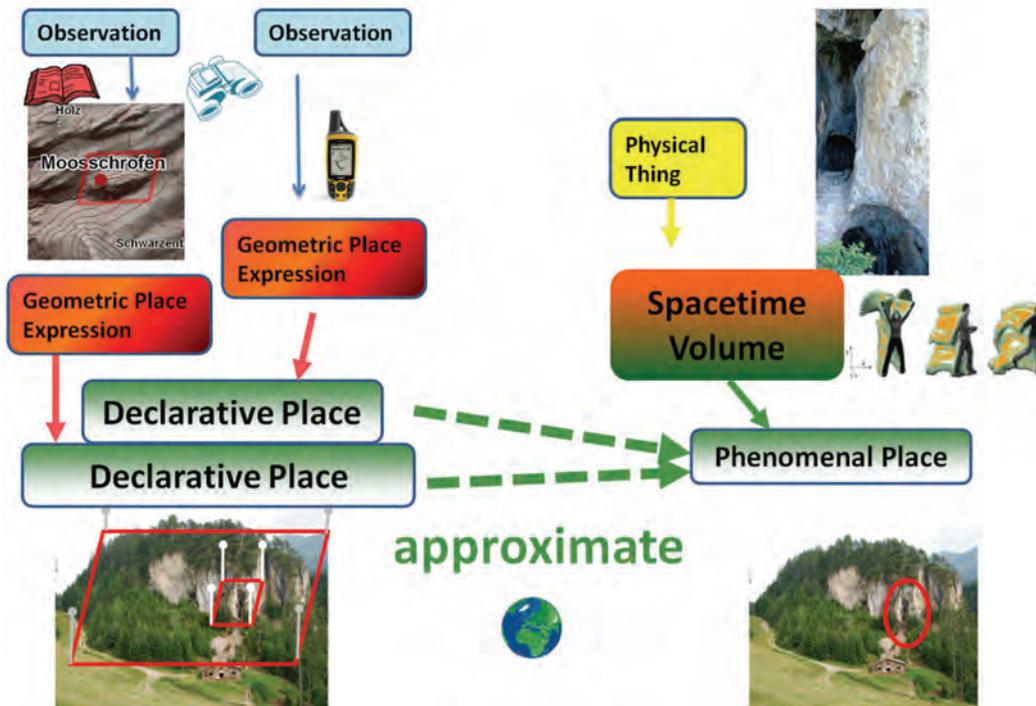


Figure 4. Representation of prospection activities

1980s was true, we can be sure to find the mine within the extent of the Declarative Place. In 2012, the rock formation was visited again and a GPS point was taken at the place of the mine in addition to photos and various samples of charcoaled wood. The GPS point with its assumed error creates another bounding box for the mine which will lead to another Declarative Place. Both Declarative Places can be related to the one Phenomenal Place and this relation enables the information integration of the two observations that took place at different times and defined the location of the mine with different accuracy. In our following examples we will have different Declarative Places coming from excavation and 3D laserscanning activities for the mine Mauk E.

4.1.2 Modeling excavation activities

A similar pattern of problems appears when it comes to dealing with excavation data gained on different places, at different times and with different aims that pursued different targets. Here we want to examine new ways to model data with the help of the extension CRMarchaeo[8] that allow answering our research question of how ore production in Mauken in Late Bronze Age was organized. As is

detected by several excavations in this area particular places represent different stages considering the ore production chain. There is evidence that the extraction of copper ore was proceeded at Mauk E, whereas the beneficiation of copper ore exclusively took place at Mauk F and the last link of the chain at Mauk A.

In a first step we want to restrain to the question of how we can model the excavation of a wooden trough that was found in an archaeological layer in Mauk F and that indicates the activity of Late Bronze Age ore beneficiation at this place (Fig. 5).

All evidence of past human activities and events can only be provided by remains gathered in archaeological layers. These layers are associated with the term Stratigraphic Unit in the CRM archaeo. One Stratigraphic Unit is the result of one genesis event causing the existence no matter if human intervention can be detected or not. As such it can be identified by some homogeneity of granulation, colour or structure.

All information about the past can be derived by these stratigraphic units and their topological relation to each other. The vertical sequence of these layers displays the temporal sequence of their formation and thus determines if one layer can be dated later or earlier than another. So there is always a group of layers the archaeologists have to focus on and draw their conclusions from. These constellations whose extent depends on the research questions are defined by the CRM archaeo as Segment of Matter.

Archaeologists try to find the boundaries of these layers, distinguish them while excavation and document them as accurately as possible. Thereby they can only approximate the real extent of a stratigraphic unit. In some cases - e.g. by creating a profile – the stratigraphic unit is only recorded in a small section. Consequently, differentiation between the stratigraphic unit as a feature and the work archaeologist do to determine these features has to be done.

As has been stated above CIDOC CRM is an event centric model. Therefore focus lies on modeling events and activities performed by human beings. To express the activity of excavating CRM archaeo delivers the term Excavation Process Unit. Hereby it is understood as the activity executed by archaeologists in order to dig a single stratigraphic unit or to cut several units (=segment of matter) e.g. for documenting a profile as has been done on the excavation in Mauk F. Within the CRM the Excavation Process Unit is seen as a specialization of an Observation.

In the course of this activity there are also material objects that can be found as they are deposited in the archaeological layers. In the model it is via the Excavation Process Unit that we relate to all Physical Objects – although they are also connected to a Stratigraphic Unit. In our example it is a wooden trough that was found in Stratigraphic Unit

No. 3 by an Excavation Process Unit that documents the trough and further objects in a so called Situation C and the SU 3 and related layer that lie above or under this one in a profile.

In addition to the example described here we can model all the other excavations and their outcomes in a similar way. By combining these data with information about chronology as will be shown in chapter 4.3 an integration in a wider context is possible.

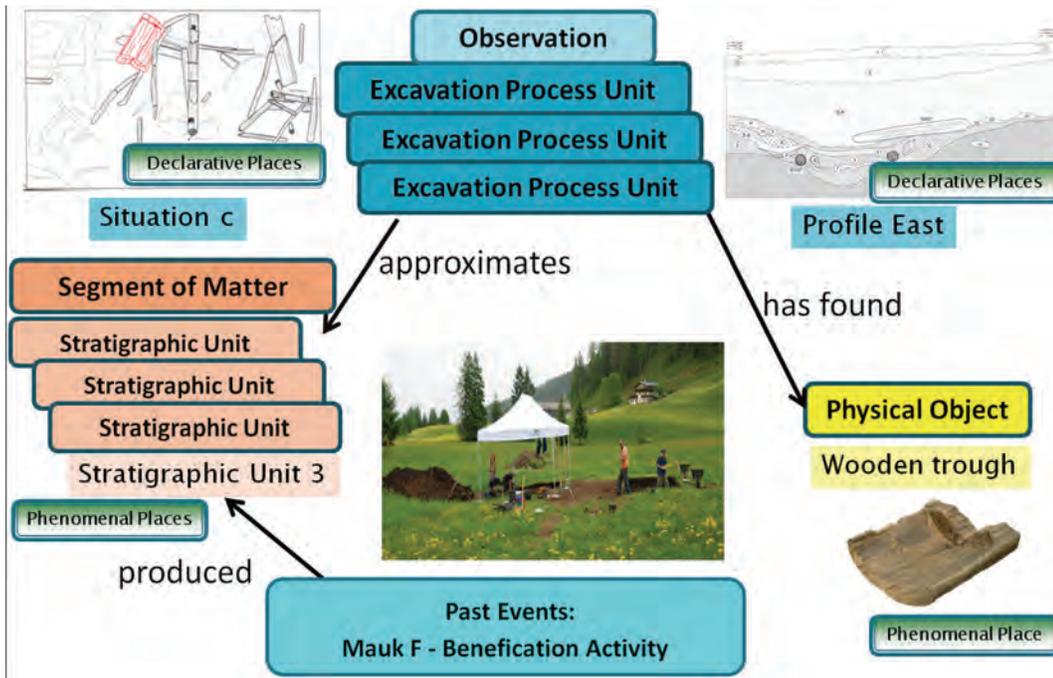


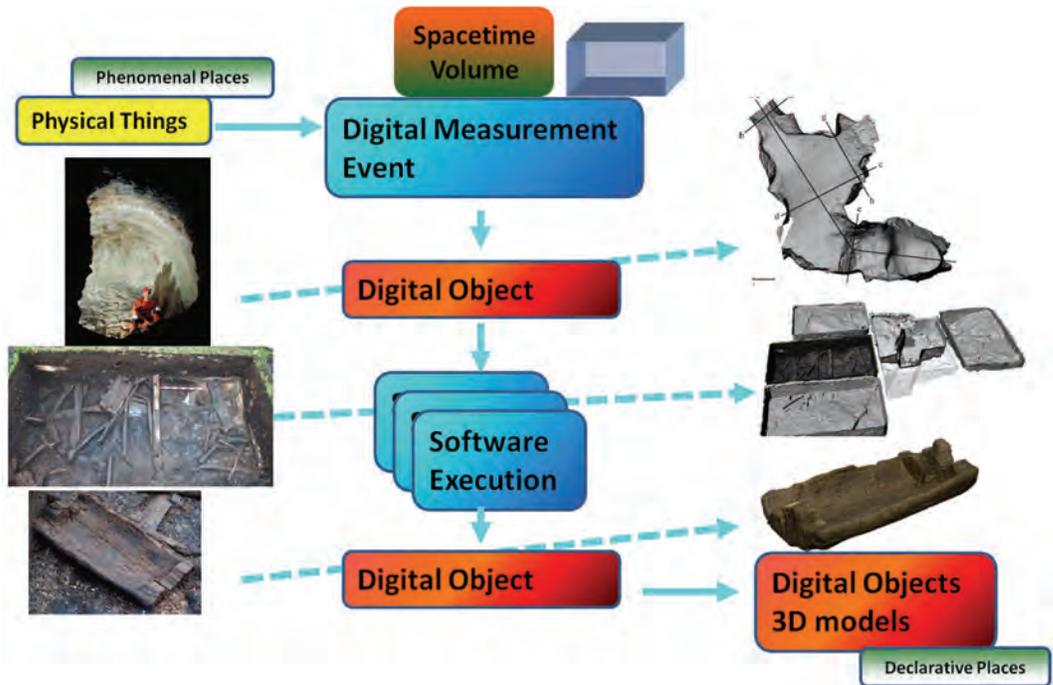
Figure 5. CRMarchaeo with Excavation

4.2 Surveying and 3D modeling

Objects of archaeological interest are surveyed as part of the archaeological documentation. As technical possibilities evolved, 3D documentation of sites, excavations or artifacts are executed and often provide stunning results in terms of visualization. We want to model the relation of 3D documentation to the underlying reality, in order to integrate 3D models with the observations obtained from other research, that investigated the same or related objects in the real world. The CRMdig [9] extension provides the concepts and relations to link Physical Things of the real world with the Digital Objects created within 3D documentation. The first step is a Digital Measurement Event that was performed under certain conditions and

with specific equipment. Several Software Executions with specific parameters usually follow to obtain the result that is again a Digital Object. Through the modelling of this processing chain the original Physical Thing as well as the steps that lead to the final 3D model can be retrieved. For scientists of other disciplines a modelling of this kind means that they are able to retrieve the provenance information attached to a 3D object to judge the fitness of the data for their purpose or research question.

Figure 6.
CRMdig

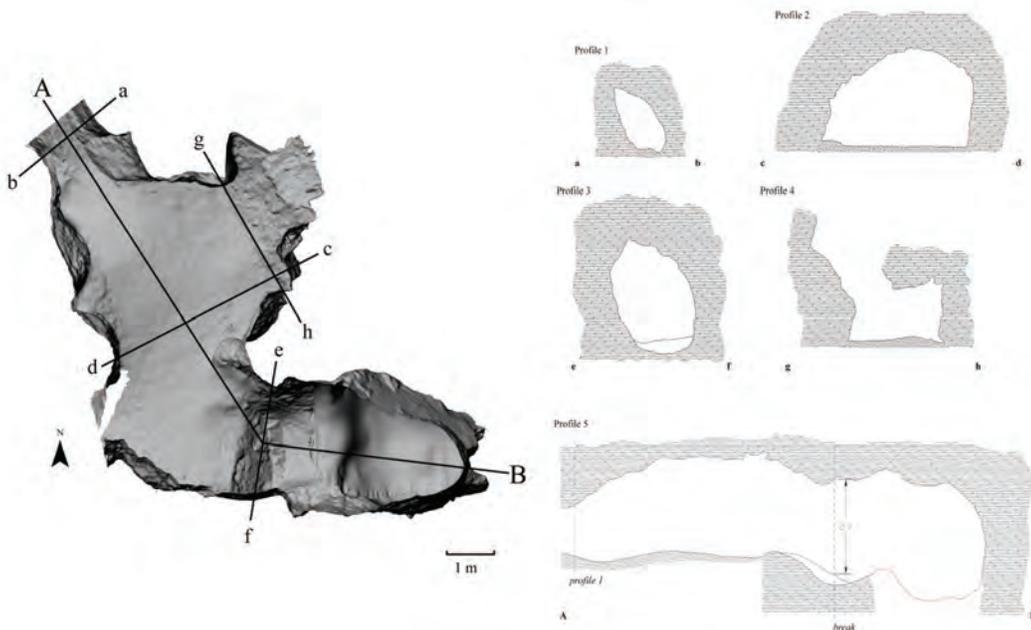


4.2.1 Mauk E

Terrestrial laser scanners are state-of-the-art tools for surveying the 3D geometry of objects of any type and shape. In this case the amount of volume of the Mauk E mine and several cross-sections were created. As the space inside Mauk E is quite narrow, nine individual instrument positions were needed to guarantee a consistent 3D acquisition of the entire structure of the interior part of the mine. Scanning was accomplished with a Trimble GX 3D terrestrial laser scanner with a spatial resolution of 2 cm.

The resulting 3D point clouds of the laser scans were registered, filtered and modeled to achieve a complete 3D surface representation of the entire underground mining gallery.

Figure 7. 3D model of mine Mauk E and sections



In addition, 58 digital photographs were taken at the site in a panorama-type configuration with a Nikon D200 p 18 mm lens. These photographs were precisely matched to the geometry model to allow successive photorealistic texturing of the interior hull for visualization and for further archaeological analyses of the entity's surface. The prehistoric ground surface of the backmost part of the mine was reconstructed for the volume calculation of the prehistoric exploitation.

4.2.2 Mauk F

Surveying is a significant part of every archaeological excavation. The advantage of a three dimensional and comprehensive recording using a laser scanner is not only in the contactless and non-destructive data acquisition of sensitive and complex objects. The high resolution of modern equipment makes an accurate and objective 3D documentation of excavations and finds feasible [13].

In comparison to conventional methods the number of accurate details can be increased in the same period of time. For the subsequent analysis and interpretation by various experts, using high-resolution images for texturing the model can increase the information from 3D objective documentation significantly. The aim is to support the different project parts in their documentation as well as possible, to transfer the evaluated data in a common coordinate system and to give project partners the results in an appropriate manner [14].

Many finds are not available for an indefinite period of time, because of the protracted conservation procedures. The following analysis of geometry and texture with digital models can be done either using a 3D plotter with these copies being further on used as exhibits for museum and teaching, or using directly the digital model where any view is possible and there are even more options of analysis available. This is a huge advantage if the finds and places are no longer accessible. Also for the understanding of complex forms it is very helpful to construct sectional drawings and counter lines for respectively developed views of the section surface.



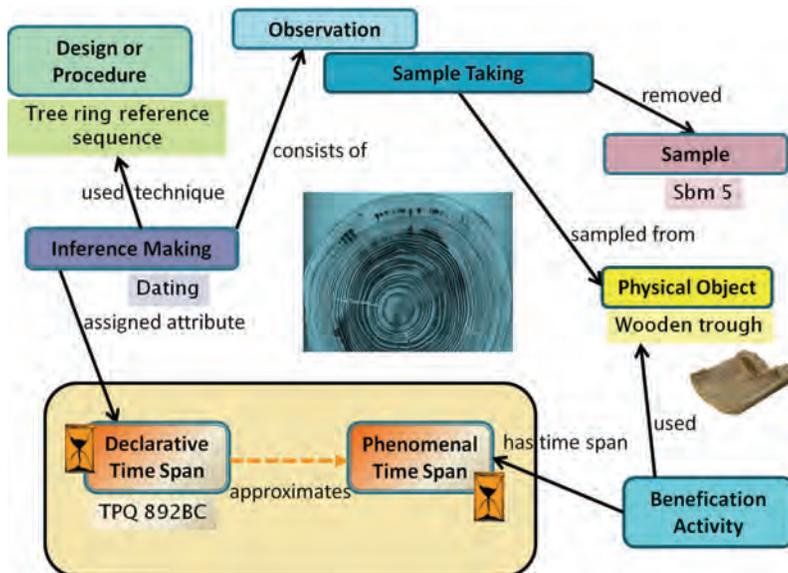
Figure 8. 3D model of Situation C (Excavation unit C) with scan of wooden trough (find nr. 5)

4.3 Dendrochronology

Archaeology is not a stand alone discipline and as such it has like many other disciplines to rely on the research done by other sciences. This is the case in dating objects or samples that appear at an archaeological survey or excavation. Archaeology by itself can often only deliver a relative chronology by e.g. the typology of objects. To permit an absolute dating that gives archaeologist a time span that is expressed in centuries, decades or even years it has to revert to methods like radiocarbon dating or dendrochronology. The latter was done on remains of wood and timber that were numerous found in Mauk F whereof the wooden trough is only one example. To link the

different data that were gained by dating this object we used parts of the extension CRMsci. In our example we want to model data that represent the taking of samples of the wooden trough to use it as a basis for counting tree rings and thus determine the age of this sample by comparing it with dated tree ring sequences (Fig. 9). As in the many examples before, the focus lies on modeling activities of human beings. By the act of Sample Taking, which is a specialization of an Observation, a Sample was removed of the Physical Object, the wooden trough. CRMsci provides us with the possibility of qualifying the activities that were carried out by a researcher. Thereby we can determine the dating of the wooden trough – the counting of the tree rings – as an Inference Making which is described as “the action of making propositions and statements about particular states of affairs in reality” [6] including evaluations and calculations.

The matching and comparing of the measured tree rings with already dated ones - the tree ring reference sequence - can be described as a Design or Procedure in CIDOC CRM which specifies the kind of Inference Making. With this activity the determining of a Declarative Time Span is also associated. In our case a terminus post quem¹ 892BC was calculated [10]. Here we have to differentiate between the Declarative Time Span that was assigned by a researcher by dating the trough and the Phenomenal Time Span the trough really had but which we presumptively will never can determine. Nevertheless we have to model the activity which used the trough regarding the beneficiation of the ore to assign the Phenomenal Time Span.



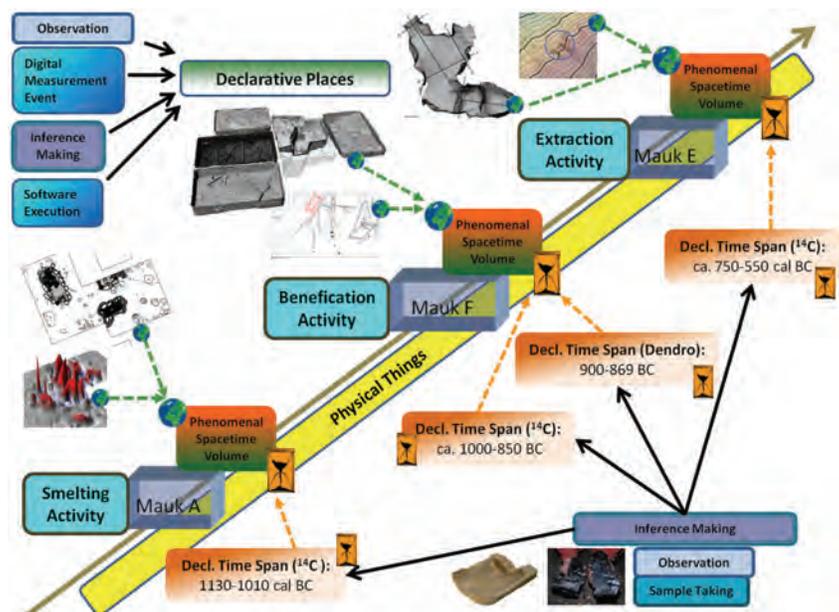
¹ The terminus postquem gives us the earliest time this object can be dated.

By the possibility to model the activity of dating wooden objects that were discovered while archaeological investigations with CIDOC CRM and its extensions we are able to combine these data with all other data from the Mauken area presented above. Further research like radiocarbon dating of charcoals, which were numerous found in Mauk F but also in Mauk A and E, can be modeled in a similar way and therefore integrated in an overall analysis.

4.4 Integration of modeled information

Taking into account all the modeled information described above we are able to approach our first research question concerning the periods and locations of mining within the restricted area of our example. Figure 10 shows on the upper left side a selection of Declarative Places generated within our research and their relation to the Phenomenal Places of Mauk A, Mauk F and Mauk E. The lower right side of Figure 10 lists the Declarative Time Spans generated either through Dendrochronology or through radiocarbon dating of charcoal. Declarative Places and Time Spans try to approximate the real Phenomenal Spacetime Volume of the activity related to mining that took place at these sites. The brown arrow in Figure 10 heading from the lower left corner to the upper right corner represents the timeline and therefore shows the temporal sequence of the mining activities at the three places. This also includes the three corresponding Spacetime Volumes. The Physical Things took part in the activities related to mining and represent the basis for the conducted

Figure 10. Integration of example information



research. Thus they must have existed at least from their participation in the mining activity and must have continued to exist or must have been destroyed during the research.

Our second research question of reconstructing the spatial organisation of the metallurgical production chain is achieved by the typing of mining activities. We created types for ore extraction, beneficiation and smelting and through the topological relations of the Spacetime Volumes we can build up a hypothesis of the spatial organisation. This question is only addressable by the use of Spacetime Volumes. Only by assigning two or more archaeological sites to the same area and the same time span we can match them to one Spacetime Volume. And only if different types of mining activities belong to the same Spacetime Volume they can also belong to the same production chain. The concept of Spacetime Volumes allows us to group different sites by determining their spatial and temporal properties and thus gives us the possibility to carry on our and the archaeologist's research with data represented with a new semantic meaning.

5 CONCLUSION

Within the interdisciplinary research center HIMAT the CIDOC CRM was used during the first five years to model the research conducted by the various disciplines. The level of modelling was sufficient to find out which kind of research was realised by whom on a specific site and what the results in form of presentations or papers were. Through recently developed extensions of the CIDOC CRM it is now possible to model the objects of research as well as the methods with greater detail. Formalising the differentiation of Observation and Inference Making in CRMsci is a crucial disambiguation for the interpretation of scientific research. The CRMgeo extension closes the gap between ontology and detailed geometric information as defined in OGC Standards and thus enables the integration of causal information coming from the CIDOC CRM ontology and geometric information that was derived from measurements or interpretations. Making explicit the relation of geometries with real world objects improves the capacity for the interpretation of geometric information and enables automated inference. A wealth of information on cultural heritage exists in the form of geometries within the examples given in this paper coming from archaeological investigations and related research. We wanted to show how to integrate this information including the geometries that have been created in the course of the research and apply the results to practical research questions. The next step after the modelling is the formal implementation of the data with their geometries to test automated inferences.

Although we don't want to go in much detail concerning technical issues, by implementing all information e.g. in RDF, reasoning and checking for inconsistencies regarding various research questions would be possible. A relevant research question that could be answered with a formal implementation of the proposed modelling would be to detect inconsistencies between archaeological dating based on stratigraphic information and typology and dating based on other methodologies like dendrochronology or ¹⁴C. A very interesting application would be to apply the modelling to integrate legacy data with modern data in one data model and make such kinds of analysis. Complexity is an issue in the proposed modeling. For an implementation, research questions should be specified and formal modeling limited to the data that is necessary for the specified research questions. If additional questions arise the proposed model allows for integrating more formal data in addition to the already transformed. Thus, we have a scalable approach to handle the complexity arising from the detailed modeling.

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