Agents in Archaeology – Agent Based Modelling (ABM) in Archaeological Research

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1 Introduction

The present paper discusses the use of agent based modelling in archaeological research.

The idea of using computer simulations in the social sciences in general dates back to the 1960s. But only in the 1990s with the rise of complexity theory and adequate computer technology became their use widespread (GILBERT & TROITZSCH 2009, 1). Since then computer simulations have come to be understood by some as a valuable tool for modelling and understanding social processes. But the situation today is still fundamentally different from the natural sciences where computer based simulation represents an established methodology, a basic tool (GILBERT & TROITZSCH 2009, 8).

Geographical discrepancies exist as well. Whereas in Northern America and Western Europe (United Kingdom and more recently Spain) computer simulations are frequently used in historical research, their acceptance in Central Europe has been more reluctant.

Agent based modelling represents one special segment of computer based modelling and is considered by many as especially well adapted to the study of complex social systems (e. g. EPSTEIN & AXTELL 1997; KOHLER & GUMERMAN 2000).

Before addressing this topic in more detail several fundamental concepts need to be discussed.

2 Preliminaries

2.1 Model

The term “model” is used in varying contexts but in general it can be said that: “A model is a simplification – smaller, less detailed, less complex, or all of these together – of some other structure or system.” (GILBERT & TROITZSCH 2009, 2).

A model can take many forms such as a graphic representation, a verbal description, a set of equations, a computer program and so forth.

2.2 Modelling

“One creates some kind of simplified representation of “social reality” that serves to express as clearly as possible the way in which one believes that reality operates” (GILBERT 2008, 2).

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In other words we all do modelling phenomena every day in order to understand our surroundings and "our" world. Modelling in the scientific world does not represent an exception. It simply has to follow stricter rules; it is a much more formalized process (e. g. mathematical modelling).

Modelling does not have to be computer based. But in the following only computer based modelling will be addressed or to be more precise modelling based on computer programs.

2.3 Simulation

In the following simulation is understood to be the action of experimenting / working with a model in order to understand system behaviour and/or its underlying causes (BREITENECKER & POPPER 2011, SHANNON 1975).

2.4 Why model?

Formalization, understanding, prediction and learning represent four of the most important reasons for modelling (EPSTEIN 2008; GILBERT & TROITZSCH 2009, 4 f.). I will discuss the first two points in more detail:

One of the advantages of mathematical and computational modelling is that it forces one to be precise. Theories and models expressed in natural language are rarely precise in all and every aspect, but they still work (EPSTEIN 2008). This is not possible with a computational model. Here ambiguities cannot be tolerated if the model is to run. Every aspect of the model needs to be laid out precisely. Model building highlights logical gaps and data gaps in the verbal model. Basic assumptions can be rigorously tested.

But computer based modelling not only "allows us to formalise our thinking about how the past worked" (GRAHAM 2009, 2), it also enables us to *explore our assumptions systematically and experiment with them* (GRAHAM 2009, 2). A model can be set up and run under changing conditions. System behaviour under changing conditions can be observed. Numerous "what if scenarios" can be run with little amount of time. This approach is well adapted to identifying underlying dynamics of social processes and to clarify causal relationships and interdependencies.

3 Agent Based Modelling (ABM)

ABM is used in a wide array of disciplines in the natural and social sciences for very different research questions. It can be used to model crystal growth, the flocking of birds, economic systems, traffic, social networks, segregation, conflict and war, the behaviour of ants amongst many other things.

One major interest for the historical sciences lies in the fact that it enables us to grow "artificial societies" composed of individuals – so called agents – and allows us to use them as cultural laboratories (PREMO 2008, DEAN et al. 2000, 201 f.).

The development of agent based modelling techniques is closely related to the study of non-linear dynamics, complexity theory and research into Artificial Intelligence.

One of the starting points at the beginning of the 1990s was that mathematicians and physicists tried to understand the properties of large aggregates of matter. "They developed models to explain dynamics such as turbulent flow in liquids, soil erosion (…). In all these cases the properties of the material as a whole can be modelled by simulating the interactions between the component units..." (GILBERT & TROITZSCH 2009, 8-9).

3.1 Complex systems

Complex systems are understood as systems that are composed of many different parts. Interactions of the system parts can lead to new und unpredictable behaviour at the system level. Cause and effect relations are non-linear. Consequently system behaviour cannot be explained by looking at the system parts (BENTLEY 2003, KOHLER & VAN DER LEEUW 2007). Thus system behaviour is created through actions and interactions of individuals (i. e. the system parts) from the "bottom-up".

Agent based modelling is a modelling approach well adapted to deal with these systems. "The ability to study non-linear dynamics generated from the bottom-up not only distinguishes agent based models from top-down, deterministic models, but it also makes them especially attractive to social scientists" (PREMO 2008, 44 following EPSTEIN & AXTELL 1996).

3.2 Agents

DORAN describes "agents" as follows (1999):

"…agents, that is, software entities that have (or, at least, may reasonably be viewed as having) in some sense the ability to perceive their surroundings, to take decisions and to act in the light of their perceptions and decisions" (DORAN 1999, 33)[1].

Agents can be given simple behavioural rules. These rules can be chosen to guide interactions of agents with each other or of agents with the environment or both. In addition they can be given knowledge and the "ability to learn". On this basis they will be able to make "independent" decisions (ALTAWEEL 2006, 37 ff.).

It is possible to define a different set of behavioural rules for any single agent. The agents can represent different entities such as: individuals, households, firms, institutions – whatever we need them to be. Different groups of agents can be put into one model, e. g.: individuals, households, tribes, segments of tribes, and can be made to interact.

3.3 Environment

"The environment is the world in which agents interact" (GILBERT 2008, 6). Depending on what is to be modelled the environment can play an important role or be of no importance at all (e. g. focus on agent-to-agent relations). Very often the environment represents a geographical space and is thus – spatially explicit. But environment does not have to be a geographic space with physical features (GILBERT 2008, 6). The environment can also represent e. g. a "behaviour space" (see below PatronWorld, GRAHAM 2009).

[1] But there is still no universally accepted definition of an „agent“ so far.

4 Agent based modelling in archaeology

As already mentioned ABM was introduced to archaeological science in the early 1990s (ALTAWEEL 2006, 30). It has been applied to a multitude of research topics, from the development of social complexity and socio-cultural evolution (DORAN et al. 1994, PREMO 2006, DEAN at al. 2000) to the exploration of civil violence in the Roman World (GRAHAM 2009). In addition there has been much discussion on how ABMs should be used for archaeological and anthropological research and the heuristic implications of the application of ABMs to archaeology and anthropology (CLARK & HAGEMEISTER 2006, 23-67; COSTOPOULOS & LAKE 2010; PREMO 2006, 2008). But until today the application of ABM has been mainly restricted to North America and Western Europe with few exceptions[2].

Very generally speaking issues commonly addressed to ABM in archaeological research are:

- Socio-ecological dynamics
- Spatial processes
- Culture Change (long-time-perspective)
- Social interaction
  - emergence of social complexity
  - evolution of sociality
  - decision making

These can be subdivided into:

- Identifying drivers of historical change
- Social complexity (e. g. emergence of hierarchies)
- Emergence of centralized decision making
- Population aggregation and abandonment (civilization collapse)
- Emergence of specialization
- Selfishness vs. altruism (e. g. food sharing)
- Response to changing environmental and social conditions
- Impact of ecological stress
- Impact of population aggregation
- System resilience
- Mechanisms of adaptation
- Emergence of territories
- Settlement dynamics
- Site selection
- Resource management
- Land use
- Culture contact
- Maintenance of ethnic boundaries
- Formation of political entities

[2] To promote the use of ABM in archaeological research the author organized a Workshop on ABM in Vienna especially seeking starting researchers in Central Europe, AIA 11, 3rd/4th of March 2011, website: http://aia11.nhm-wien.ac.at/.

4.1 Examples of "archaeological" ABMs

The models presented in the following section were chosen from a wide array of ABMs with the intention to provide a general overview and highlighting important trends and issues in archaeological modelling[3].

4.1.1 Artificial Anasazi (AA)

The Artificial Anasazi model (Figure 1) has been described as "one of the icon models of the modelling community" (JANSSEN 2009, 1). It represents by far the most famous archaeological ABM and is well known outside the archaeological discipline.

The description of the AA follows DEAN et al. 2000 and JANSSEN 2009: On a general level AA deals with cultural change, it was designed to "experimentally examine the contributions of internal and external factors to socio-cultural evolution" (DEAN et al. 2000, 179) and the responses to changing environmental and social conditions. AA models the site selection behaviour and demography (population aggregation and abandonment) of Anasazi farming households in the Long House Valley of Arizona between 800-1350 (DEAN et al. 2000, JANSSEN 2009).

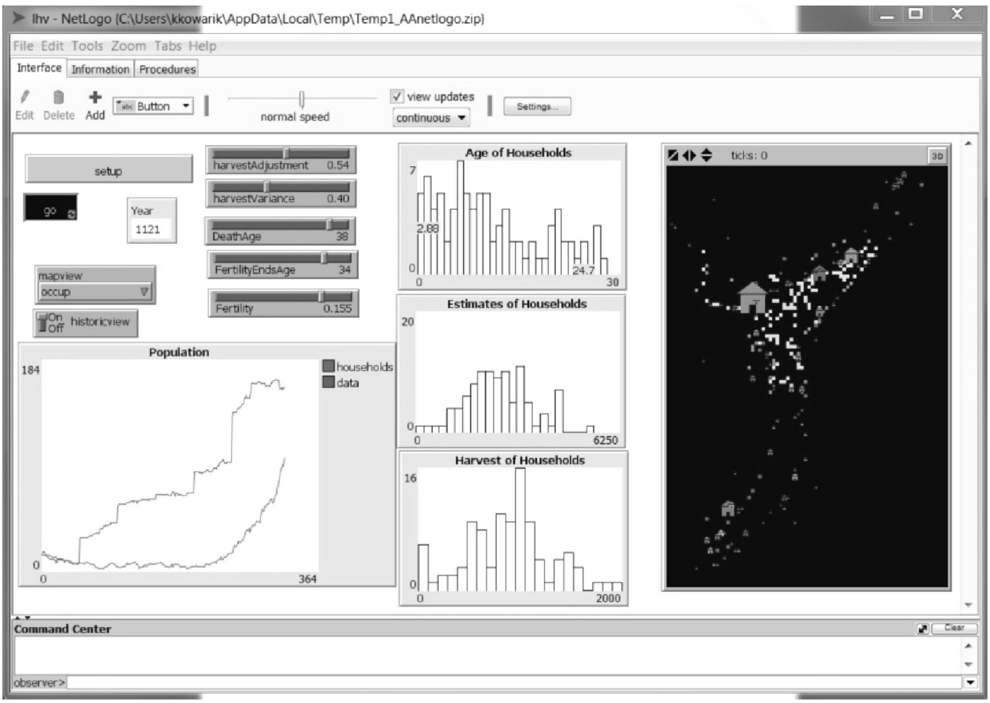

Fig. 1: Screenshot Artificial Anasazi in NetLogo, model JANSSEN 2009. http://www.openabm.org/model/2222/version/1/view.

[3] For more examples see KOHLER & GUMERMAN 2000, BEEKMAN & BADEN 2005, CLARK & HAGEMEISTER 2006, 23 ff.

Environment (DEAN et al. 2000, 181 ff.; JANSSEN 2009, 2.5-6): The environment of the Artificial Anasazi is “a landscape of annual variations in potential maize production values based on empirical reconstructions on low- and high-frequency paleo-environmental variability in the area” (DEAN et al. 2000, 181). It incorporates different zones of land corresponding to the layout of the Long House Valley. The world is cell based. Each cell (patch) represents a specified geographic space. Each cell is within one of the different zones of land. These zones have a specific agricultural productivity.

Agents are households with a predefined number of persons (DEAN et al. 2000, 186 ff.; JANSSEN 2009, 2.7-2.15). Each household requires a certain amount of food. To obtain food the households perform agriculture. Every year each household has to decide whether the chosen patch of land has yielded enough food. If this is not the case the household makes the decision to move. It searches for a patch to farm and a close by patch to settle. The decision is determined by the availability of arable land, the patch to settle must be close by, it can be inhabited and it must be close to water resources. If a household cannot produce enough food within a certain amount of time, it will be removed from the model. There are no direct interactions between the agents. Indirectly they interact by occupying potential farm plots.

Results (DEAN et al. 2000, 189 ff.; JANSSEN 2009, 5.1): The model was run iteratively under changing conditions such as fecundity, food consumption, changing environmental conditions or social factors such as raiders. These results were then compared against the archaeological record. One thing that clearly emerged from the Artificial Anasazi was that environmental factors alone could not explain the sudden abandonment of the Long House Valley.

The authors of the study understand the Artificial Anasazi model as agent based models in general to be a laboratory “where competing explanations can be tested and judged in a disciplined an empirical way” (DEAN et al. 2000, 201).

Related work:

- Pueblo populations of the Mesa Verde Region (KOHLER et al. 2000)
- Bronze Age Mesopotamia (WILKINSON et al. 2007, ALTAWEEL 2006)
- Lake Titicaca Basin (GRIFFIN & STANISH 2007)

The above mentioned models are typical of an important segment in archaeological work with ABM: They deal with pre-historic/early-state agrarian societies, modelling demography, population aggregation and decision making as well as ecology and agriculture. They are geographically and time specific and they are characterized by a certain validation approach (GRIFFIN & STANISH 2007, 1 ff.): they “validate the model by comparing model outcomes to empirical data or a chronology of events indicated in the archaeological record during the corresponding time span” (GRIFFIN & STANISH 2007, 3). This of course is only possible with geographically aware and time specific models.

4.1.2 ABM with environment and space

The physical environment plays an important role in many archaeological ABMs. The interaction between the agents and the physical environment is frequently given much attention[4]. But connecting ABMs to space i. e. to Geographical Information System software has proved difficult.

Models such as the Artificial Anasazi exhibit carefully crafted physical environments based on large amounts of paleo-environmental data sets. ALDENDERFER describes the spatial dimension of the AA as follows: “The spatial metaphor that underlies the simulation is a grid of cells (...) each cell has attributes that can be modified (...). Each of these cells is tied to a raster in a GIS (...)” (ALDENDERFER 2010, 60 f.). Through the connection to a GIS the model performance can be visualized (ALDENDERFER 2010, 61). Thus according to ALDENDERFER an “important display capability” has been gained but “real dynamic spatial behaviour” cannot be integrated (ALDENDERFER 2010, 61).

But recent developments in the field of “geosimulation” (BENENSON & TORRENS 2004) move quickly towards a stronger integration of ABM and GIS, enabling modellers to have agents actually moving in a GIS model and not to simply export model output to raster layers (ALDENDERFER 2010)[5].

4.1.3 EOS and PatronWorld: Putting the emphasis on inter-agent relations

The EOS project (Evolution of Organized Society, DORAN et al. 1994) was designed to investigate the development of social complexity at an early stage of human evolution. As a case study the Upper Palaeolithic in south-west France was chosen (DORAN et al. 1994; GILBERT & TROITZSCH 2009, 195 ff.).

The EOS model is geographically explicit and time specific. “The environment consists of a landscape with a population of mobile agents and a scattering of resources which provide “energy” for the agents” (GILBERT & TROITZSCH 2009, 196).

What sets EOS apart is its focus on inter-agent relations. EOS especially focused on investigating the development of relationships between agents (DORAN et al. 1994). These have been crafted in much detail.

In order to survive the agents have to acquire resources. They have to make the choice whether they will provide for themselves alone or include other agents and acquire resources collectively. For acting together the agents need to develop plans and negotiate these plans with the other agents.

Agents are able to (DORAN et al. 1994; GILBERT & TROITZSCH 2009, 195 ff.):

- communicate with each other
- develop plans

The plans involve:

- determine resources to be selected
- select agents for work
- calculate expected result
- plan distribution

4 BEEKMAN draws attention to the fact that detailed investigations of inter-agent relations are strongly neglected (BEEKMAN 2005).

5 For further details see: ALDENDERFER 2010, GIMBLETT 2002, GIMBLETT et al. 2002.

In the beginning all agents make plans thus the agents must choose from several plans. The criterion for selection is to identify the plan with the greatest payoff. So the agents must in addition evaluate and calculate these plans.

Results (DORAN et al. 1994; GILBERT & TROITZSCH 2009, 195 ff.): During the course of the model run some agents might accept plans proposed to them by a certain agent again and again. They will become his followers. Depending on resource distribution either working alone (thinly distributed resources) or working together and building detailed hierarchies (concentrated resources) proved to be more successful. Interestingly temporary follower-leadership relations guaranteed better chances of survival than persistent hierarchies.

PatronWorld (Figure 2) simulates Roman social life with the intention of exploring the outbreak of violence and civil unrest (GRAHAM 2009). The model's "…fundamental "procedure" is the morning ritual of the salutatio, the morning greeting clients gave their patrons. … I describe how spontaneous purges and proscriptions can be modelled and the circumstances under which they are generated" (GRAHAM 2009, 1.0).

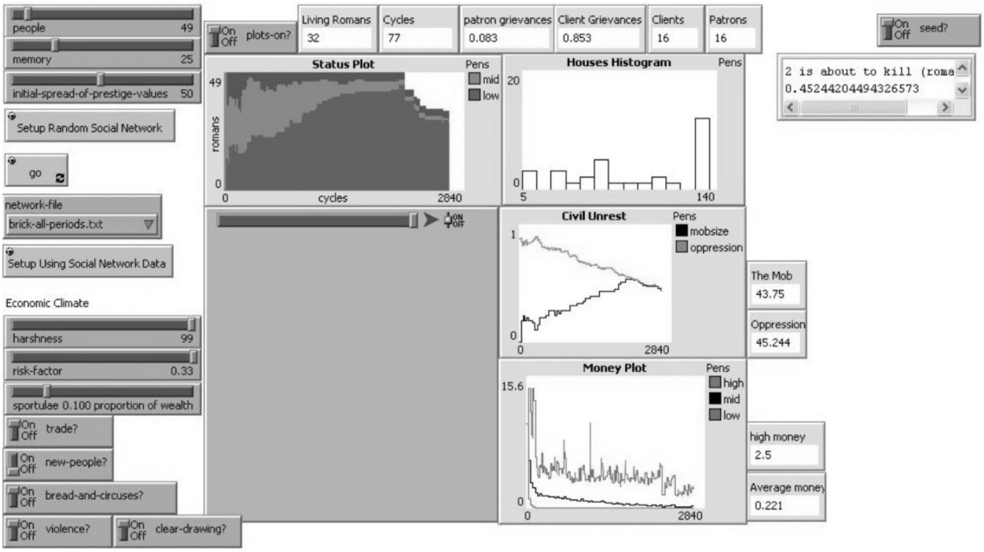

Fig. 2: PatronWorld according to GRAHAM (2009, fig. 1).

PatronWorld's environment is entirely different from the above described models as environmental data is of no importance. In this model the environment is not physical but socio-economic (GRAHAM 2009).

Agent actions, description follows GRAHAM 2009, 6.0:

- Examine their own level of status
- Examine the status of others
- Seek audience with higher status patrons
- Select to receive clients with high status
- Deny to receive clients

- Exchange gifts when paying respects
- Trade with counterparts of similar status level

Modelling the outbreak of violence (GRAHAM 2009, 7.0, 8.0, 9.0):

- Agents can be denied audience due to their low status
- Agents can thus be limited in their access to patronage networks
- Agents can remember who has denied them
- Agents can hold grudges
- Each agent has its own tolerance for rejection
- No agent does act on its own, its neighbours need to be prepared to act as well
- Agents turn violent: agents kill agents whom they hold a grudge against

One important factor that can be modified before starting a model run is the “economic climate”. This is determined by three factors: the severity of the economic climate (harshness), willingness to take financial risks (risk-factor), and a maximum size of the gift exchanged between patron and client (sportulae) (GRAHAM 2009, 9.0).

Results: According to GRAHAM PatronWorld is still work in progress but gift-exchange between patron and client could already be identified as a key factor for the emergence of civil violence in ancient Rome (GRAHAM 2009).

4.1.4 Mining with agents

Until rather recently work with agent based simulations in archaeological research has been mainly restricted to Northern America and Western Europe. Thus the author would like to draw attention to a work group located at the Natural History Museum Vienna and the Technical University Vienna.

We have been focusing on simulating aspects of the Bronze-Age salt mines of Hallstatt addressing the working process (agent based simulation, see Figure 3) and consumption (system dynamics simulation, see Figure 4) (KOWARIK et al. 2010).

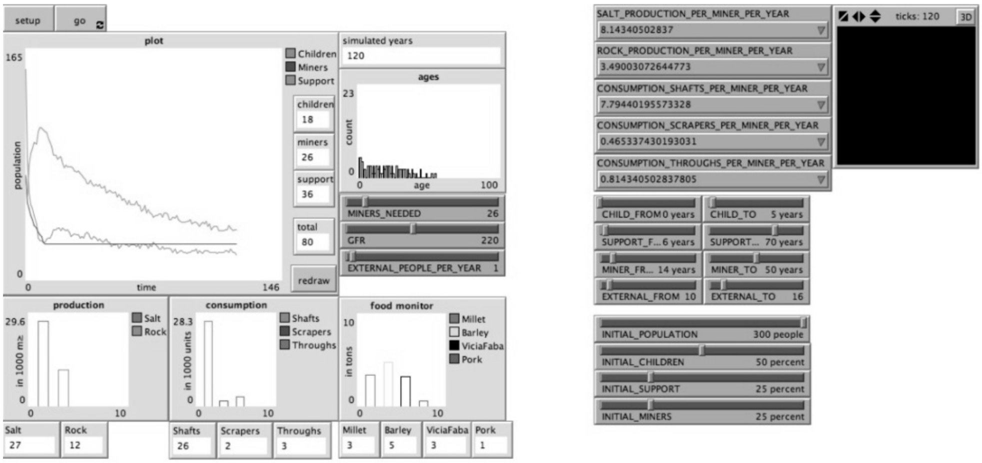

Fig. 3: Agent based simulation of the working process in one mining hall of the prehistoric Hallstatt salt mines (KOWARIK et al. 2010).

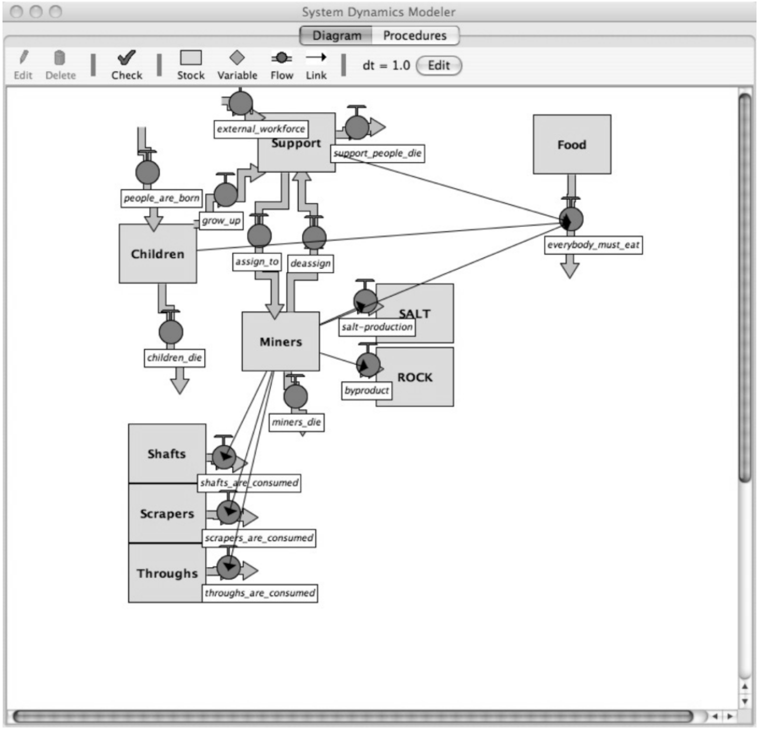

Fig. 4: Schematic representation of some aspects of the consumption structure of the prehistoric Hallstatt salt mines for the system dynamics simulation (KOWARIK et al. 2010).

The data base for both models consists mainly of data sets gained through experimental archaeology (Figures 5a and 5b).

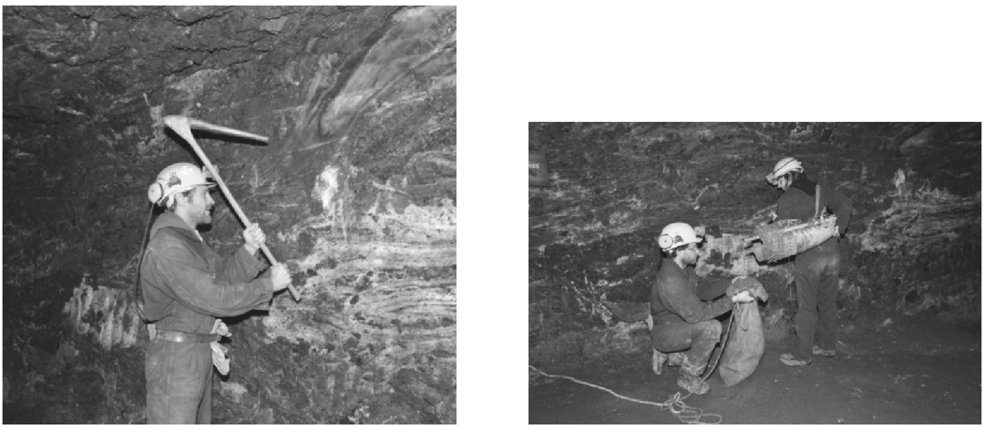

Fig. 5a-b: All steps of the Bronze Age mining process were reconstituted and time measurements taken (KOWARIK et al. 2010). Photographs: A. Rausch.

Currently we are broadening our modelling approach in cooperation with the Institute of Analysis and Scientific Computing/Technical University Vienna.

5 Conclusion

The aim of this paper was to present an approach hitherto mostly unknown in the archaeological research community of Continental Europe.

In conclusion, I would like to discuss potentials and problems of this approach:

With ABM we can build artificial societies and experiment with them – using them as cultural laboratories (DEAN et al. 2000, 201 f.; PREMO 2008). Jim Doran has stressed that ABM allows us to deal with, respectively explore human cognition (DORAN 1999).

This enables us to:

- explore our ideas about the past
- experiment with those ideas
- test our hypothesises

But building models represents a substantial effort in time and other resources, even where very simple models are concerned (GILBERT 2008, 30 ff.). It will be necessary to:

- specify a model
- collect data
- program and implement
- verify
- validate
- question basic assumptions

Still there are more substantial problems. As has been stressed before ABM enables us to explore our ideas about the past. Consequently we must take into account that we are not modelling the past itself but rather our idea about the past (PREMO 2008).

Although ABM helps us to explore our ideas, the model does not tell us how things were. Even if simulation results perfectly match the archaeological record there is finally no proof that things actually happened that way (PREMO 2008, 2010).

Against this background, an important discussion is taking place in the modelling community. It is fundamentally concerned with the question where agent based modelling should be headed (summing up COSTOPOULOS & LAKE 2010, especially LAKE 2010 and PREMO 2010). The argument centres on the question whether:

- models should try to emulate the real world as closely as possible with as much detail and data as possible
- Or should models be as simple as possible, maybe even stylized and mainly be used for exploration and experimentation?

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