Thomas Stöllner

Entangled Connections: Materialized Practices of Knowledge-Networks of Mining. From the Theoretical Level to its Empirical Consequences in Mining Archaeology

Instead of an introduction: An example at the beginning

Nobody would deny that knowledge and mining practices are tightly interwoven and that complex enterprises like mining stimulate and catalyze the technical and social knowledge transfer. As obvious as this seems at the first glance it is not at a second glance; invention did not distribute easily within mining communities and sometimes it took hundreds of years until a seemingly superior technique was established on a broad scale.

One example is the introduction of gun-powder blasting between the 16th and the 18th century.[1] Already used and practiced in upper Italian quarries and mines, it took more than 150 years to be established as a technique and 200 years to completely supersede the older fire-setting techniques. It often had been asked why it took so long to introduce this technical complex, and there are several answers to this. Although the miners had some experience in handling gun-powder in military contexts it was not as efficient as it was wished in mining, neither in a direct comparison to the wood-based fire-setting, nor in relation to hand-driven galleries whose work effectivity was not much less than the blasting.[2]

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1 See for instance: Kirnbauer, Franz: Die Geschichte der Sprengarbeit im Bergbau, in: Aktiengesellschaft Dynamit Nobel (Ed.), Festschrift zu Ehren Alfred Nobels aus Anlaß der Erteilung der ersten Sprengstoffpatente vor 100 Jahren, Wien 1967, pp. 115–129; Ludwig, Karl-Heinz: Die Innovation des bergmännischen Pulversprengens. Schio 1574, Schemnitz 1627 und die historische Forschung. Der Anschnitt 38/3–4, 1986, pp. 112–122; for the Alps and especially Salzburg: Günther, Wilhelm: Von der Schlägel- und Eisenarbeit zur Sprengtechnik im Bergbau – Die bergmännischen Gewinnungs- und Fördermethoden, in: Ammerer, Gerhard/Weiß, Alfred Stefan (Eds.): Das Tauerngold im europäischen Vergleich. Archäologische und historische Beiträge des Internationalen Kongresses in Rauris vom 7. bis 9. Oktober 2000. Mitteilungen der Gesellschaft der Salzburger Landeskunde 141, 2001, pp. 131–139, here: pp. 135–137.

2 See for example Weisgerber, Gerd/Willies, Lynn: The Use of Fire in Prehistoric and Ancient Mining: Firesetting. Paléorient 26/2, 2001, pp. 131–149.

https://doi.org/10.1515/9783110729955-014

The drilling technique especially was not as efficient before the 18th century (always a larger group of persons was needed to carry out the necessary preparations and drillings). There was also a high risk: casualties and serious injuries are reported in many cases when the new technique was introduced, such as in Gastein at the Radhausberg mines in 1642 when a blasting master brought it from the neighboring mining field in the Großarl-Valley. The blasting event failed in one case and did seriously injure the miner and blasting master and further assisting members of the team; so the report from 1642 ends with a conclusion that it already had been tried several times and that the outcome was more bad than good. The mining master concluded: „Die Gäng sind zu fest und brechen sich nit also wie an andere milderen Pürgen; mehr ist es an vielen Orten zu wassernötig. Viel Arbeit geht darauf und ist mehr Schaden als Nutz dabei. Man will's aber nit glauben und mit Gewalt erzwingen, bis dergleichen Schaden beschieht."[3]

It took another 100 years to introduce the technique at the Radhausberg. This introduction only became possible after the invention of another important side innovation – the drilling work that is nowadays an integrative part of all blasting work in general (Fig. 1).[4] It is therefore imperative to regard an invention not as a singular event, but as bundles of innovations that must be mastered practically. In general time must be ripe to make an invention into an economically and socially effective innovation.[5] In the case of blasting techniques in mining there are other examples that show barriers and conditions, which either favored or avoided the introduction. For Schemnitz and the Tolfa mountains as well as for the Venetian mines in Schio it was the acute depletion of usable forests and the lack of workmen that forced the operating people to introduce this technique and to improve it rapidly. It is obviously economic pressure that could accelerate the practical usage of this once done invention. But there are also opposite examples when the technique did not increase but lower the income of the hewers. In many mining fields they had also to pay for the mining means such as the powder and the blasting equipment, not to mention the risks they took in conducting the

3 Salzburger Landesarchiv, Montanakte, Ratschlag Libell in Gastein, 1642.
4 Kirnbauer, Franz: Die Geschichte der Sprengarbeit im Bergbau (note 1); Ludwig, Karl-Heinz: Die Innovation des bergmännischen Pulversprengens (note 1); see the description of the Professor of Mining technics in Schemnitz/Banská Štiavnica, Christoph Traugott Delius [1806], p. 215.
5 For this aspect already Schumpeter, Joseph: Theorie der wirtschaftlichen Entwicklung: eine Untersuchung über Unternehmergewinn, Kapital, Kredit, Zins und den Konjunkturzyklus, Leipzig 1911, here: pp. 85–86.

Fig. 1: Brixlegg, Austria, Early Modern Times Fahlore-mining, blaster's hewer tool equipment, consusting of a drilling set, a powder horn, a blaster's loam hod and a powder filling hod

work itself. And there were other preconditions such as the layout of a mine that could have been not in favor to introduce a new driving technique. Galleries and winning areas possibly were not arranged to implement the technique in order not to endanger other installations in the mine (e.g. by water installations, timbering a.s.o).

Routines and technoscapes: What archaeology can tell

Concluding from our initial example it is clear that not only the transfer of knowledge enabled the reception of practices in mining. It is also the circumstances that favoured adaptation and successful implementation. This truth also has direct bearing on the importance of work practices and their material manifestations. Daily practice in work processes and all the social interactions that are combined with it, are essential to embed an invention.[6] In many cases it is this embeddedness that allows the successful adaptation within a given amalgam of daily routines. The importance of daily routines for establishing identity is obvious and particularly discussed by M. de Certeau according to urban popular culture of the 20th century. His influencing study let us understand "acting routines" as a mostly un-reflected total system that not only influenced personal habits and beliefs but also what was regarded as "necessary" and "appropriate" for daily routines. This concept certainly spans wider than the more usual concept of the "chaîne opératoire" that archaeologists like to use explanatorily for their production and manufacturing debris.[7] What seems important for mining is that such is established also with small working gangs and therefore should be mirrored in residues of daily practices. In mining archaeological features such residues (e.g. as debris) can be found regularly and they allow a particular insight into such routines. There are areas where lighting tapers were put when they are burned down or where they got lighted before moving further in the mine: At the Bronze Age Arthurstollen the Bochum excavation brought to light a small rock ledge on which lighting tapers accumulated during work (most likely hand-by-hand or by rope hauling) to a deeper working area (Fig. 2).[8] The routines of the Bronze Age miners turn clearly before our eyes: He or they obviously came several times to this working site carrying out a similar routine thus appropriating also a place that had its special conditions according to a possible movability. For instance when carrying lighting tapers while working or when discarding tapers burned down. The miners could have put the splinters to any place in his/her surrounding but it was preferred to lay down them accurately on a heap. This heap possibly has occurred as a result of a special movement when changing the tapers in between other movements of his/her stationary work. This appropriation clearly

6 De Certeau, Michel: Kunst des Handelns [1980], Berlin 1988.

7 For example for the concept in general: Leroi-Gourhan, André: Hand und Wort – Die Evolution von Technik, Sprache und Kunst [1964/65], Frankfurt a. M. 1980; for mining see: Pfaffenberger, Bryan: Mining Communities, Chaînes Opératoires and Sociotechnical Systems, in: Knapp, A. Bernhard/Pigott, Vincent C./Herbert, Eugenia W. (Eds.): Social Approaches to an Industrial Past: The Archaeology and Anthropology of Mining, Routledge, London 1998, pp. 291–300, here: pp. 294–295; also: Stöllner, Thomas: Mining and Economy. A Discussion of Spatial Organisations and Structures of Early Raw Material Exploitation, in: Stöllner, Thomas et al. (Eds.): Man and Mining. Studies in honour of Gerd Weisgerber, Bochum 2003 (= Der Anschnitt, Beiheft 16), pp. 415–446; for crafts also: Rebay-Salisbury, Katharina/Brysbaert, Ann/Foxhall, Lin (Eds.): Knowledge Networks and Craft Traditions in the Ancient World: Material Crossovers, New York/Milton Park 2014 (= Routledge Studies in Archaeology 13).

8 Stöllner, Thomas: Arthurstollen, in: Fundberichte aus Österreich 55, 2016, pp. 418–419.

Fig. 2: Arthurstollen, Austria, Deep Gallery, Western-Lode part, lighting splinters deposition in situ and during the excavation and documentation under laboratory conditions

decided about the adaptation to the location but also about the way how the work could have been done. Routine and the affordance of the location therefore are enmeshed and inseparably combined. Another example was discovered and excavated some years earlier in the same mine: In a small side gallery (the "Cierny-gallery") a blaze pot was found, obviously (as it was fragmented but repaired by small schist stones) put there as stationary installation to light tapers (it was filled with small fragments burned down; Fig. 3).[9] As the area is on the cross junction of various galleries it was obviously the work space of someone (only one person can sit in this small gallery niche) who had to maintain the gloom for the working shift. Further persons could enter to light the tapers or even have a rest there.

9 Stöllner, Thomas: Der Mitterberg als Großproduzent für Kupfer in der Bronzezeit: Fragestellungen und bisherige Ergebnisse, in: Oeggl, Klaus et al. (Eds.): Die Geschichte des Bergbaues in Tirol und seinen angrenzenden Gebieten, Proceedings zum 5. Milestone-Meeting des SFB HiMAT vom 07.–10.10.2010 in Mühlbach, Innsbruck 2011, pp. 93–106.

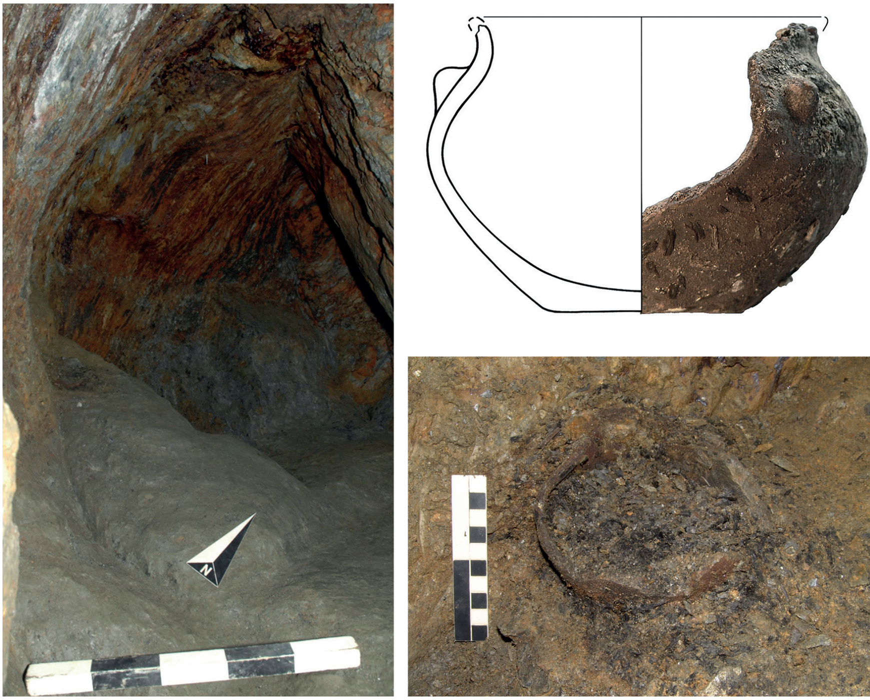

Fig. 3: Arthurstollen, Austria, Eastern-Lode part, Cierny gallery, emptied area with gloom-pot at the left, western wall, gloom pot in situ (below, right), gloom-pot (above, right)

I took these examples to explain which chances an underground excavation offers to understand work practices and daily routines that follow the necessities of a very specific work surrounding. Such routines are bound to specific technoscapes,[10] for instance to irregular (artisanal), regular (planned) and industrial mines. Their technical planning and the level of engineering determine the daily routines to a large extent. This already was true for prehistoric and ancient mining. Shafts sunk to considerable depths did require a geological understanding of the deposits and possibly even led to such during the first steps of exploring a deposit. At the European flint/chert/silex-mining fields shaft-sinking was obviously regarded the best way to reach but also to find the better silex-containing

10 Appadurai, Arjun: Disjuncture and Difference in the Global Economy. Theory, in: Culture and Society 7, 1990, pp. 295–310; for its archaeological usage for instance: Becker, Johannes/Jungfleisch, Johannes/von Rüden, Constance (Eds.): Tracing Technoscapes: The Production of Bronze Age Wall Paintings in the Eastern Mediterranean, Leiden 2018.

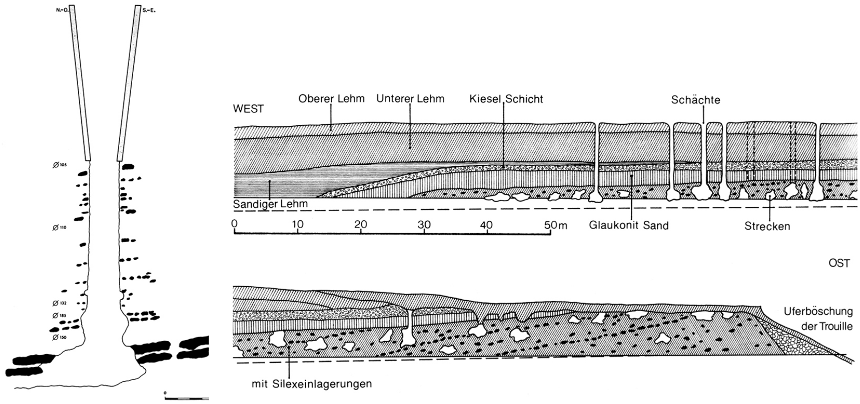

Fig. 4: Spiennes, Camp a Cayaux, shaft 2 and stratigraphic situation as observed during railway construction work in 1867

strata (Fig. 4).[11] The mining field of Arnhofen with estimated about 20 000 shafts provide us with insight into the daily routines when sinking the shafts into the softer loess-soils. The work was possibly planned for some days, including the time of approaching for the working gang and also to rest in camp nearby.[12] According to the calculations of Georg Roth the shafts were constructed in groups of three and were dug by smaller groups of 2 persons within 4 days per shaft.[13] So the shafts were ad-hoc work measures during which the decision where to put them (as the area was certainly covered by many already emptied and refilled shafts) was the most important task. According to Roth it was connected with expectations where to find a minimum of chert that made the expedition a successful one.[14] From the Bronze Age onwards mining enterprises and especially shafts got installations that required a higher level of engineering quality. As the shafts were constructed to a much greater depth, moving and transportation got

11 Weisgerber, Gerd/Slotta, Rainer/Weiner, Jürgen: 5000 Jahre Feuersteinbergbau. Die Suche nach dem Stahl der Steinzeit, Bochum 1999 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum, Nr. 77).
12 Rind, Michael M. (Ed.): Das neolithische Hornsteinbergwerk von Abensberg-Arnhofen. Die Auswertung der Ausgrabungen 1998–2009, Kallmünz 2020 (= Materialhefte zur bayerischen Vorgeschichte 112).
13 Roth, Georg: Geben und Nehmen. Eine wirtschaftshistorische Studie zum neolithischen Hornsteinbergbau von Abensberg-Arnhofen, Kr. Kelheim (Niederbayern), Köln 2008 [Diss.], p. 235.
14 Ibid., pp. 208–333.

important requirements: In Hallstatt Late Bronze Age mining shafts were timbered and sunk down to more than 100 m; at the Tusch-Werk-mine several items of the hauling practice have been found beneath fallen down timbers of the shaft, such as a massive rope made of lime bast fibre and protective chamois leather (similar to gloves) that had allowed miners to manipulate the rope.[15] Shafts got complex installations that required specialized routines, thus also representing a kind of small technoscape in itself (hauling, moving, timbering and maintaining etc.). Such insights require a detailed debate on the materialized evidences of practices. It seems clear that such observations decide after all what kind of interpretation is possible in direction of overall work organization or the amount of raw material being exploited. In prehistory such data are much harder to gain than in more recent periods when written sources allow at least some insights. But material sources are treacherous: At Hallstatt the late Bronze Age hauling bags and a staircase[16] made the impression of having been used as means of a hauling transport system that have required a group of haulers constantly occupied with this work (Fig. 5). According to agent-based modeling the opposite seemed the case: salt-transport and debris dumping were possibly done once a shift as even a larger group of getters never could produce enough to keep even one hauler constantly busy.[17] This example makes apparent that working with the material evidence allows the development of models that are more than reflections of historical records but inherit independent evidence and information. Such may help to decide how machinery or tool sets were handled and how rapid a winning process was made. The various elements of a technically induced mining strategy certainly had ample impact on social interactions, for instance, as the elements determine the size of work and the number of workmen involved. I would like to call this the *social skin* of mining work practice. It is this materialized reality in

15 Barth, Fritz Eckart: Ein Füllort des 12. Jahrhunderts v. Chr. im Hallstätter Salzberg, in: Mitteilungen der Anthropologischen Gesellschaft Wien 123/124 (Festschrift Karl Kromer), 1993/94, pp. 27–38.

16 See for example Barth, Fritz Eckart: Zu den Tragsäcken aus dem Salzbergwerk Hallstatt, in: Archaeologia Austriaca 76, 1992, pp. 121–127; Reschreiter, Hans/Kowarik, Kerstin: Die Stiege – technische Perfektion, in: Kern, Anton et al. (Eds.): Salz-Reich. 7000 Jahre Hallstatt, in: Veröffentlichungen der Prähistorischen Abteilung des Naturhistorischen Museums Wien 2, Wien 2008, pp. 61–63.

17 Kowarik, Kerstin/Reschreiter, Hans/Wurzer, Gabriel: Salz – Bergbau – Wirtschaft: Diskussion wirtschaftsarchäologischer Aspekte am Beispiel der prähistorischen Salzbergwerke von Hallstatt, in: Eisenach, Petra/Stöllner, Thomas/Windler, Arne (Eds.): The RITaK conferences 2013–2014. Raw Materials, Innovation, Technology of Ancient Cultures RITaK 1, 2017 (= Der Anschnitt 34), pp. 171–179.

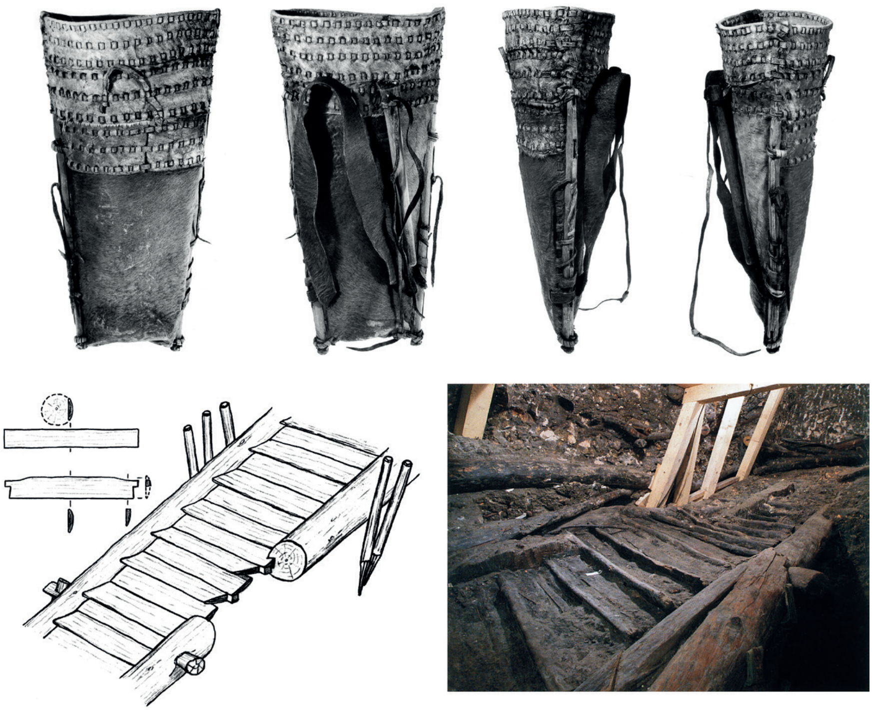

Fig. 5: Hallstatt, carrying bag from the Northern mining “group” at Hallstatt, Grüner Werk (after Barth 1992); below: staircase from the Tusch-Werk, reconstruction according the excavation feature

a mine that gave the frame for habitualized doings and experiences: As a simple example, did the amount of humidity and moisture result in specific outcomes for the work-experiences on corrosion of metal gear and machinery, to the slipperiness of ladders and pedals and the stress to personal clothes and shoes.[18] It also produces distinctive sensual experiences such as smells and touches on rocky surfaces and timbering for instance. It may be briefly shortly mentioned that sensual experiences and the concept of individualized perceptions are a par-

18 Prehistoric and ancient salt mining is for instance a particularly impressive source as tools and clothes and show best stress marks of their intensive usage: see various chapters in Stöllner, Thomas/Aali, Abolfazl/Bagherpour, Natascha (Eds.): Tod im Salz – Eine Archäologische Ermittlung in Persien. Begleitbuch, Katalog und Graphic Novel, Offenbach/Bochum 2020.

ticularly worthy category for “dark” underground working spaces.[19] It is not only since E. Husserl and M. Merleau-Ponty that phenomenology and the specific perceptions of life-worlds became a major category in the understanding of human mental constructions. The usage of phenomenological theory in conceptualizing the “dark underground” certainly needs more theoretical work: Merleau-Ponty’s groundbreaking foundation of the body-subject brings the mental and body experience to one interwoven embodiment, especially apparent when handling the specific conditions of a dark underground.[20]

These experiences make the metaphor of the social skin more apparent, something that made the mine for the worker the same as a protecting suit for a diver. However, the material world of actions constitutes the spheres of habitualized doing. This allows archaeology as primarily related to artefacts and their contextual setting to follow the material world as representations of a cultural setting that enables the reconstruction of approaches and appropriation of all sorts of things: Rocks, mined raw sources, already adopted tools and spaces as complex settings of life and work practices. It is clear that knowledge transfer is part of appropriation processes that require some sort of connectivity between the daily routines involved. With other words: Techniques and practices can only be successfully adopted if the counterpartying people already are acquainted to similar practices and mental constructs. Let me therefore first develop outlines of an archaeology of habitualized doing in order to understand the development of knowledge and its transfer within similar and different material worlds.

Spheres of actions – The archaeology of habitualized doing

I will briefly mention five examples that will explain how suitability to the learned spheres of habitualization directly influences the structure material environments of workmen in a production and mining processes. Embodiment theory does help to understand the role of internalized knowledge also in the frame of technical practices and their representations in a material world. It has already

19 Concepts of a “sensual” archaeology have been recently rediscussed in archaeology: Hamilakis, Yannis: Archaeology and the Senses: Human Experience, Memory, and Affect, Cambridge 2014.

20 Merleau-Ponty, Maurice: Phénoménologie de la perception, Paris 1945.

been discussed in anthropology and social sciences[21], only seldom with respect to materialized practices, which are the usual archaeological sources, as it is the usual archaeological sources.[22] It is obvious that mining, as every other craft, follows similar principles of habitualization to other craft spheres and therefore also conceptualizes daily routines as way to express identity. According to my own experience with mining work I would stress the fact that especially similar experiences that come along with bodily practices and internalized knowledge produce a certain companionship and a collective memory that goes with it. A mining community as any other community would therefore order the world of things on the pattern of the structure that prevails in the social world of its people.

Habitualized tools

Tools/crafts-person entanglement is certainly a very basic connection; as tools are principally extension of arm and hands as Andrè Leroi-Gourhan (1980) did emphasize on many occasions it is clear that movements and usage are tightly interwoven. This is for instance the case for handles and mining picks found between the Bronze Age Mitterberg and Kitzbühel districts, both related also by a similar ore- and host-rock geology.[23] The selection of tools followed obviously the necessities of a sub vertical, schist-embedded vein-deposit (Fig. 6). This is not only an externalized reflection of knowledge to use a certain tool according to a given structural condition. To a certain degree the picks and especially their kind of mounting are reflecting a specific habitualized movement during the process

21 See for example Ingold, Tim: The Perception of the Environment: Essays on Livelihood, Dwelling and Skill, London 2000; Marchand, Trevor (Ed.): Making knowledge: explorations of the indissoluble relation between minds, bodies, and environment, in: Journal of the Royal Anthropological Institute, Special Issue 16, Chichester 2010.

22 See for instance: von Rüden, Constance: Approaching Ancient Techniques. From Technology to Bodily Learning and Skill, in: Gauß, Walter/Klebinder-Gauß, Gudrun/von Rüden, Constance (Eds.): The Distribution of Technical Knowledge in the Production of Ancient Mediterranean Pottery. Proceedings of the International Conference at the Austrian Archaeological Institute at Athens, 23th–25th November 2012, Wien 2016, pp. 35–49.

23 See the discussion of it: Stöllner, Thomas et al.: The Enmeshment of Eastern Alpine Mining Communities in the Bronze Age. From Economic Networks to Communities of Practice, in: Körlin, Gabriele et al. (Eds.): From Bright Ores to Shiny Metals. Festschrift for Andreas Hauptmann on the occasion of 40 Years Research in Archaeometallurgy and Archaeometry, Rahden/Bochum 2016 (= Der Anschnitt, Beiheft 29), pp. 75–107; Thomas, Peter: Studien zu den bronzezeitlichen Bergbauhölzern im Mitterberger Gebiet. Mitterberg-Forschung 1, Rahden/Bochum 2018 (= Der Anschnitt, Beiheft 39).

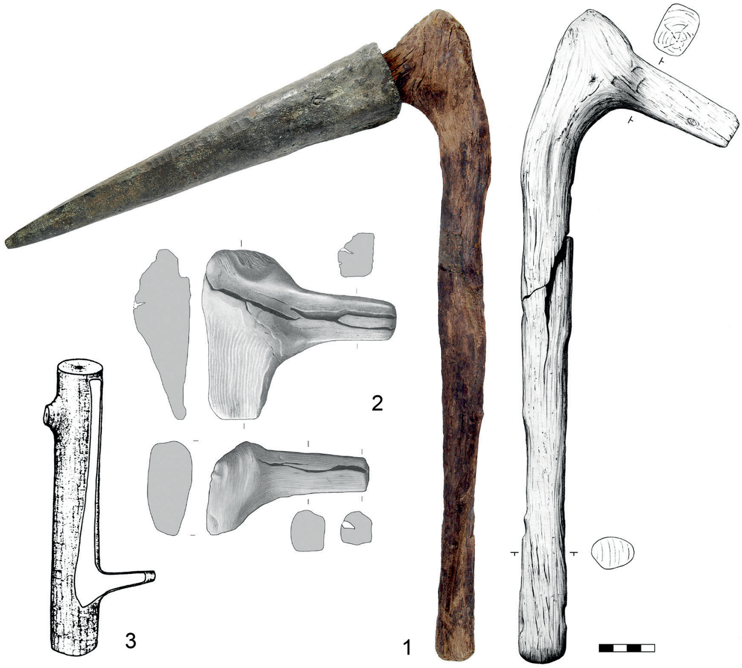

Fig. 6: Socketed picks and their haftings/handles from Mitterberg (1) and Kitzbühel, Kelchalm (2); usage of beech trunks and branches to produce handles of this kind (3)

of mining. Similar to a blindman's stick, a pick also becomes a prolongation of the worker's body and through practice he or she even starts to "feel" with the tip of the tool.[24] Consequently any change in the layout of a tool would necessarily result in an adjustment of whole movement, which has been habitualized and embodied through many years of practicing.[25] This is a reason why many of today's craftspeople often resist working with tools that are not their own, even though they might have the same layout – even slight differences in the other tool's wear is often enough for the craftsperson to feel uncomfortable.

24 Polanyi, Michael: Implizites Wissen [1966], Frankfurt a. M. 1985.
25 Ingold, Tim: The Perception of the Environment (note 21); von Rüden, Constance: Approaching Ancient Techniques. From Technology to Bodily Learning and Skill (note 22).

Entanglement to locations

People are entangled to locations in a working and related social process. Although we consider a working space as deduced by the knowledge of the winning process and its technical need on the one hand, we often forget the broad and specific adoptability of such spaces to distinct daily routines on the other. Even in technically highly advanced mining systems there are unsaid rules of doing, such as where to carry loads inside a larger working space, where to put provisions and how to organize toilets and rest areas. These are rules adopted by a larger group of persons that are not reflected by written regulations. Archaeological excavations sometimes unravel individual habits and routines that result in concrete material compounds. At the Bronze Arthurstollen-mines we were able to investigate two areas of maintaining light for underground workings[26]: As mentioned above the miners accustomed themselves to the location by specific movements (for instance where to put the lighting tapers and how to manipulate the blaze-pot) in the daily routine (Fig. 3). There are many other examples of which I took another one to explain how the customization to a given space also gave daily routines a special direction: In the Early Bronze Age gold mine of Sakdrisi (Georgia) a working area was discovered that was used by miners to refill the already exploited mine part with debris. For doing so an area to kneel or squat was established that allowed the handing down of hauling vessels (e.g. leather containers or baskets) and or dumping it down to fill the lower gallery. The area was protected by two smaller revetments made of already discarded stone hammers in order to avoid dumping in the kneeling or squatting ledge (Fig. 7). As the area was relatively narrow the inconvenient work condition and how the miner had to adopt his body the rocky surrounding got impressingly clear. He/she only could take the hauling vessel from above and he/she had to decide first in which direction this vessel was manipulated before taking it from one of his/her companions. Many more aspects of the daily work condition can be reconstructed and described by analysing the spatial condition: The rocky surrounding that possibly scraped the skin or protective clothes, possibly also the exhaustion that work in such a place resulted in. It is clear that such work not only ends in a reconfiguration of already existing underground conditions, but also leads to the adaptation of the human being to handle the given conditions.

26 Stöllner, Thomas: Der Mitterberg als Großproduzent für Kupfer in der Bronzezeit (note 9); Stöllner, Thomas: Arthurstollen (note 8), for description see above.

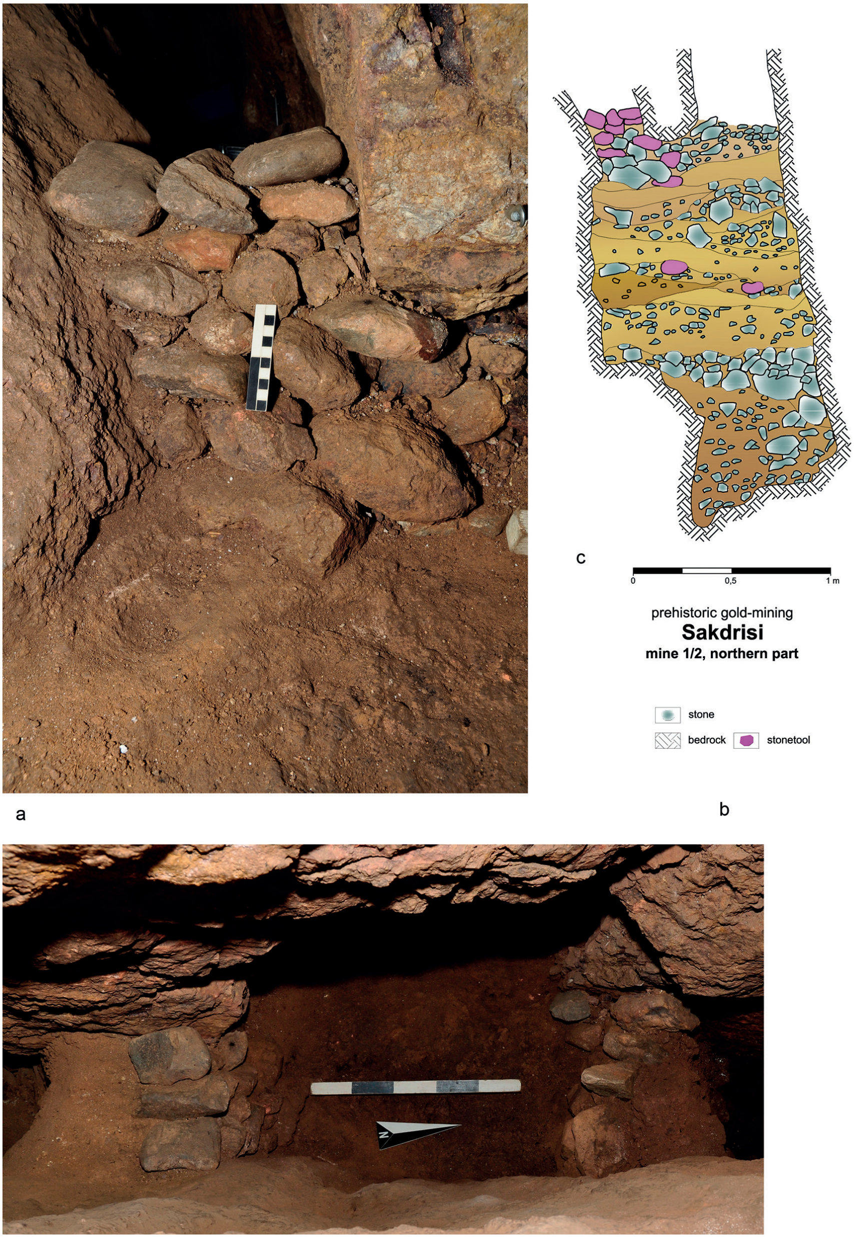

Fig. 7: Sakdrisi, west of Bolnisi, Georgia. Typical Kura-Araxes back-fill-stratigraphy from underground at mine 1/2 – north-extension (junction between main lode and western side-lode). (a) Hammer-stone wall at the South-profile; (b) South-profile at the junction; (c) Top view to the northern and southern hammer-stone-walls at the above mentioned junction

Ad hoc and planned trouble shooting

A third element of daily routines is to provide the ongoing winning process with ad-hoc solutions to enable the continuation of the winning and production process. Such practices are most of the time decisions made quickly and on the basis of experiences and materials that are available in the near neighbourhood of the work-place. In prehistoric and antique salt mines such solutions are evidenced for instance in the repairs of handles by fixing and binding broken pieces with leather and textile straps (Fig. 8, Nr. 1). At the Iranian salt mine of Chehrābād the Sasanian salt miners changed their handles when broken near the working space and had therefore to quickly adjust their handles to the iron tool[27]; heaps of shaved wooden bark and wooden debris had been produced that sometimes also were reused as firing material. Often wooden pieces had been used to fix a handle to a pick, such as leather straps and textiles had been used for the same purpose. The range of creativity is wide with such processes which allows insight into individual troubleshooting strategies. Another example is textile material that is used on a wide scale in mining: rags are used as such until today on various occasions in industrial mining machinery. Prehistoric and antique salt mining are good comparisons as most of the fabrics found at such mines were not used as clothes any more: They are used as binding material to connect and fix or to be used as sanitary dressing material (Fig. 8)[28]; it is assumed that rags of already discarded clothes were carried to the mines as worthy work equipment to enable repairs and ad-solutions of any kind.

This is certainly different with techniques and practice that required some sort of planning and preparation such as techniques in opening a mine or driving a gallery. Such need experienced people especially when facing a possibly expected

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27 Kosczinski, Katja: Die Abbaugeräte im antiken Salzbergwerk von Douzlākh (Chehrābād, Zanjān, IR), Eine taphonomische und experimentelle Annäherung, Bochum 2019 [Master-Thesis]; Kosczinski, Katja/Vollmer, Philipp: Das Experiment Salzbergbau, in: Stöllner, Thomas/Aali, Abolfazl/Bagherpour, Natascha (Eds.): Tod im Salz – Eine Archäologische Ermittlung in Persien. Begleitbuch, Katalog und Graphic Novel, Offenbach/Bochum 2020, pp. 147–152, here: pp. 148–149, fig. 3.

28 See for example Stöllner, Thomas: More than old rags. Textiles from the Iron Age Salt-mine at the Dürrnberg, in: P. Bichler et al. (Eds.): Hallstatt Textiles. Technical Analysis, Scientific Investigation and Experiment on Iron Age Textiles. Proceedings of the Symposium Hallstatt 2004, BAR International Series 1351, Oxford 2005, pp. 161–174; Grömer, Karin/Amin Shirazi, Shahrzad: Textilien – eine bunte Welt, in: Stöllner, Thomas/Aali, Abolfazl/Bagherpour, Natascha (Eds.): Tod im Salz – Eine Archäologische Ermittlung in Persien. Begleitbuch, Katalog und Graphic Novel, Offenbach/Bochum 2020, pp. 181–186; for Hallstatt already Hundt, Hans-Jürgen: Vorgeschichtliche Gewebe aus dem Hallstätter Salzberg, in: Jahrbuch des RGZM 34, 1987, pp. 261–286.

Fig. 8: Leather and textile repairs and secondary use of textiles in the Iron Age salt mines of Hallein-Dürrnberg (Austria) (1–3) and Douzlākh-Chehrābād (Iran) (4–6), (1) handle with leather-strap repair; (2) textile bandage, strapped by a bast stripe, (3) textiles knotted, (4) bundle of felt, strapped, (5) torch, enwrapped with textile, (6) textile stripe ripped for an after-use

trouble in order to cope with the task of a complex challenge. In mines this is for certain the geological and tectonic variations causing water events by tectonic faults, the instability of the rock face or any other trouble.[29] Such is unpredictable

29 See for instance for German industrial mining: Kroker, Evelyn/Farrenkopf, Michael: Gruben-

and therefore hazardous and not manageable by a daily routine. Therefore experienced people and technical engineering skills are successful strategies to adopt and alter the routines and develop strategies that outmatch simple ad-hoc solutions. This certainly can be seen already in the 5th and 4th millennium BCE mining when comparing the systematic backfilling of tunnels with ad-hoc solutions as it was documented in a mine at Grimes Graves, where an antler pick was used as a prop safeguarding a hanging block.[30]

A good example is the Middle Bronze Age mine Arthurstollen in the Mitterberg-mining zone in the Eastern Alps. Due to a geological drift the old miners lost their copper ore vein what resulted in a series of test drives they advanced in northern direction.[31] What they did not know at the beginning was that it was their own geological stratum, the hanging wall that had moved northwards. How should they know? After several attempts they gave up and tried to find the lost vein further in the depths where they finally came to the drift zone and understood about the geology and where to look for the lost ore-body: in the footwall and towards south. By trial and error they experimented with the deposit but finally understood and therefore even accumulated more knowledge than they originally had. This knowledge was used for their benefit when they had to build up a ventilation connection for the two mining areas already evolved in the east and the west of the drift. With the help of surveying techniques they were able to find the right concept and area to interconnect the foot- and the hanging wall from both sides. The example show after all the constant learning and knowledge accumulation process and the fact that the surveying technique could be successfully applied only based on this practical knowledge. The area shows even

unglücke im deutschsprachigen Raum. Katalog der Bergwerke, Opfer, Ursachen und Quellen, 2. Auflage Bochum 1999 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum, Nr. 71).

30 See for example Fober, L.: Feuersteinbergbau, Typen und Techniken, in: Weisgerber, Gerd/Slotta, Rainer/Weiner, Jürgen: 5000 Jahre Feuersteinbergbau. Die Suche nach dem Stahl der Steinzeit, Bochum 1999 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum, Nr. 77), pp. 32–47, and Fig. 541.

31 The feature is described on various occasions, for example Stöllner, Thomas: Der Mitterberg als Großproduzent für Kupfer in der Bronzezeit (note 9); Stöllner, Thomas: Der Mitterberg als Großproduzent für Kupfer in der Bronzezeit, in: Stöllner, Thomas/Oeggl, Klaus (Eds.): Bergauf Bergab. 10000 Jahre Bergbau in den Ostalpen. Wissenschaftlicher Beiband zur Ausstellung Bochum und Bregenz, Bochum/Rahden 2015 (Veröffentlichungen aus dem DBM, 207), pp. 175–185; Stöllner, Thomas: Resources, innovation, technology. Theoretical approaches to abstract concepts and research content, in: Eisenach, Petra/Stöllner, Thomas/Windler, Arne (Eds.): The RITaK conferences 2013–2014. Raw Materials, Innovation, Technology of Ancient Cultures RITaK 1, Rahden/Bochum 2017, pp. 11–23 (= Der Anschnitt, Vol. 34).

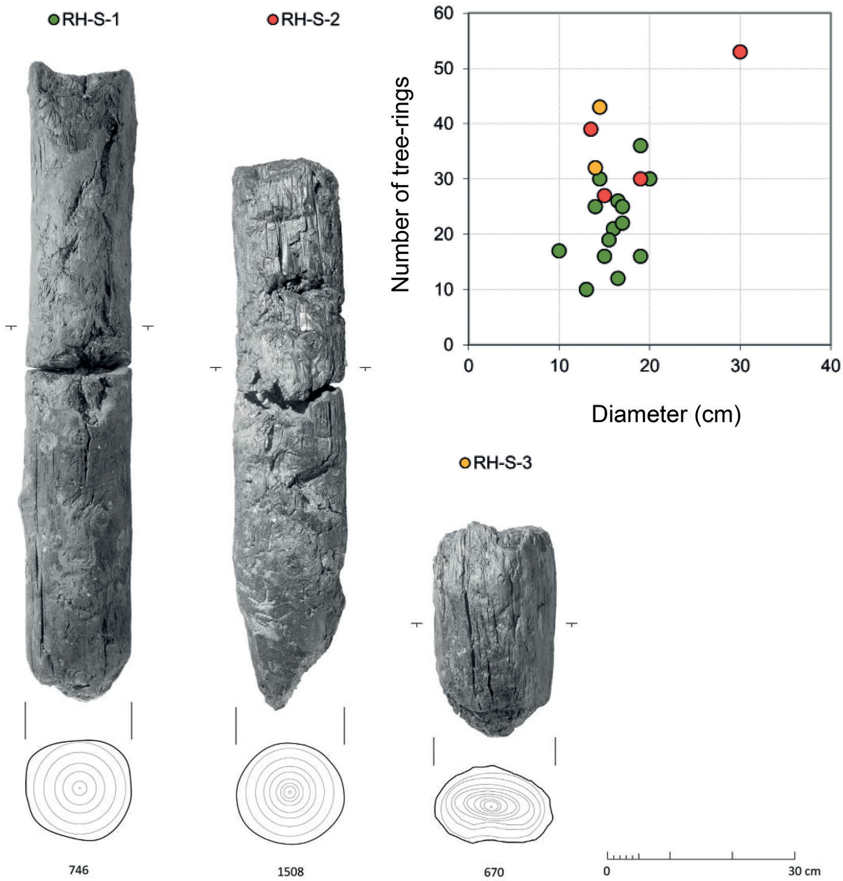

Fig. 9: Arthurstollen (Austria), types props from the underground mine, according to adaptation of their ends and their diameter and amount of tree-rings (after P. Thomas)

other adaptations by which knowledge and the risk assessment of the Bronze Age miners become apparent: The tectonic rift area (the so called deep mine at 4750 m), where they learned about the shift of the originally connected ore bodies, was timbered with several props. This propping, possibly induced by the imagination of a certain risk, has been studied in detail.[32] What is noticeable about the

32 Thomas, Peter: Studien zu den bronzezeitlichen Bergbauhölzern im Mitterberger Gebiet (note 23).

props the miners used that they predominantly took a special kind of more stable trunks, which they selected according to these trees' more dense growing/tree-ring pattern. And they worked the trunks in special way at their endings (Fig. 9). It is obvious that the miners selected what they regarded as more stable and suitable for this kind of a more risky underground hollow. This not only reflects experiences but also risk-assessment in order to avoid an incalculable situation. Although the rock pressure never was that problematic as possibly considered by them; the props still were standing upright when an archaeologist entered the mine 3400 years later. At the end this shows the quality of their considerations.

However, the conceptualization of risk certainly led to adoption and stepwise inventions. It is often hard to decide on the basis of material culture and archaeological sources, whether there was a gradual or a sudden invention involved. Often this has to do with consciousness and extended levels of knowledge to regard a risk as such.

Hazards and protection

Let us take the mining catastrophes in Chehrābād mines, where at least three times a mining hall had been destroyed by an undervaluation of the tectonic risks of the surface near salt deposit.[33] Either the dangers were accepted while mining and producing was regarded as more important than personal endangerment or a part of this knowledge about the tectonic risks were lost or kept in secrecy by some. However, protection gear, such as fur bonnets preventing painful knocks to the miners' heads certainly are the result of a series of experiences made in this direction (Fig. 10,1). Some of these have been found in the Hallstatt and Dürrnberg Salt mines[34], but interestingly have not been found in the mine of Chehrābād. A Sasanian clove instead demonstrates how sophisticated protection clothes could

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33 Aali, Abolfazl/Stöllner, Thomas (Eds.): The Archaeology of the Salt Miners. Interdisciplinary Research 2010–2014, in: Metalla, 21.1–2, 2014 (2015), pp. 1–141 (Persian: pp. 143–216); Stöllner, Thomas/Aali, Abolfazl: Chehrābād: Ein antikes Salzbergwerk und seine bergbauarchäologische Erforschung: Von Produktionsverfahren und Unglücken, in: Stöllner, Thomas/Aali, Abolfazl/Bagherpour, Natascha (Eds.): Tod im Salz – Eine Archäologische Ermittlung in Persien. Begleitbuch, Katalog und Graphic Novel, Offenbach/Bochum 2020, pp. 117–130.

34 Pany-Kucera, Doris/Reschreiter, Hans/Kern, Anton: Auf den Kopf gestellt? Überlegungen zu Kinderarbeit und Transport im prähistorischen Salzbergwerk Hallstatt. Mitteilungen der Anthropologischen Gesellschaft in Wien 140, 2010, pp. 39–68; Stöllner, Thomas: Der prähistorische Salzbergbau am Dürrnberg/Hallein II. Befunde und Funde der Untertageausgrabungen zwischen 1990–2000, Rahden 2002/2003 (= Dürrnberg-Forschungen, 3/1–2).

Fig. 10: Hallein-Dürrnberg (Austria) (1) and Douzlākh-Chehrābād (Iran) (2): Protective gear from the Early Latène (fir bonnet) and Sasanian period (glove)

have been: A part of the thumb leather was made of extra fine wool, possibly coming from a Karakul lamb thus demonstrating how skilfully the mining society looked after its protective clothes (Fig. 10,2).[35]

It is clear that the level of knowledge involved in the material world of mining is entangled to the life- and work practices in a mining environment. The constant transfer of experiences and declarative knowledge is a decisive point that might have altered also daily work routines. But in many cases a knowledge flow stays invisible for us especially in archaeology as the transmission leaves no traces in the material sphere and in our archaeological record and only superficially in historical notices. The transmission is related to the practices and daily-routines themselves.

For a long time we have been used to differentiating between various ways of knowledge and learning. Unlike the declarative knowledge, which does not necessarily mean you know how to master a technique but principally know about the effectiveness of it, mastering a technique is often non-declarative and implicit,

35 Grömer, Karin/Ruß-Popa, Gabriela/Amin Shirazi, Shahrzad: Wie waren die Salzmänner gekleidet?, in: Stöllner, Thomas/Aali, Abolfazl/Bagherpour, Natascha (Eds.): Tod im Salz – Eine Archäologische Ermittlung in Persien. Begleitbuch, Katalog und Graphic Novel, Offenbach/Bochum 2020, pp. 165–174, here: pp. 172–174.

and part of, as Michael Polanyi called it, tacit knowledge.[36] As Tim Ingold laid out in several articles, people accumulate knowledge by doing and hence experiencing a technique, so they incorporate its specific characteristics stepwise.[37]

Worlds of experiences: Daily practice – "Things" – Knowledge: A possible theoretical approach for ancient mining

There are many similar tool-kits in our mining-archaeological record (e.g. hauling or advancing the gallery picks; protective gear). But it certainly has to be asked carefully if those tool-kits require practicing in a similar habitualized way. If looking to mining-picks it is clear that handles and picks and also the mineral mined are in particular interdependency with each other. This can be easily seen when comparing tools used in a similar mineral context by different mining communities (e.g. Kosczinski and Vollmer 2020). It can be shown that a different way how to use tools with iron points also is a result of different technical solution developed over time in certain experimental niches and in different social and environmental settings. The iron picks used at the Austrian Dürrnberg and the Iranian Chehrābād are different tools by manipulating and maintaining them. One important consequence is at hand: Similar tools do not require a similar handling, producing and maintaining concept. Such would be a necessary precondition for any decision about if such a technique was transferred from one area to another by skilled people. Although knowledge transfer always requires people involved it cannot be determined that such people did really master their technique or if such a knowledge was only superficial because they were not allowed to take all the secrecies of knowledge from the masters or they were not trained successfully in an apprentice-master relation. Transfer certainly requires the "things" to be practiced in a similar way to enable a "complete" knowledge transfer of all sorts of knowledge involved (Fig. 11), a fact much debated also in modern innovation theory.[38]

36 Polanyi, Michael: Implizites Wissen (note 24).

37 Ingold, Tim: The Perception of the Environment (note 21).

38 Rogers, Everett Mitchell: Diffusion of innovations, 5th edition New York 2003. See also the discussions in: Burmeister, Stefan/Bernbeck, Reinhardt (Eds.): The Interplay of People and Technologies. Archaeological Case Studies on Innovations, Berlin 2017 (= Berlin Studies of the Ancient World, 43); some critics on evolutionary thinking: Shortland, Andrew: Hopeful Monsters? Inven-

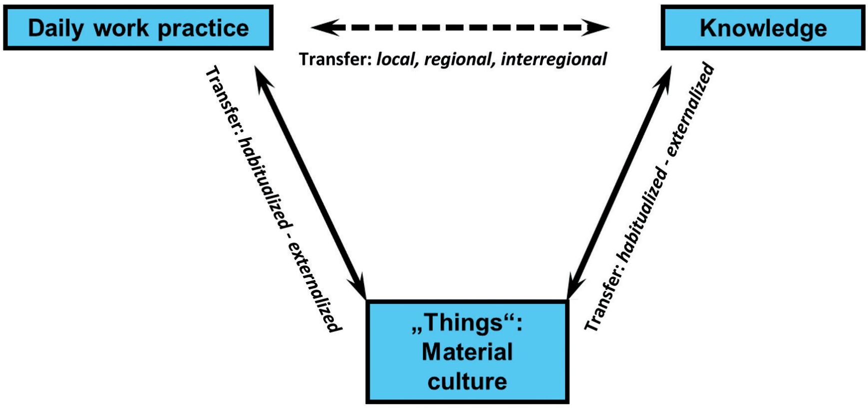

Fig. 11: Knowledge transfer as daily practice and the role of "things" in transmission of knowledge

Much what has to be said in concern of knowledge has to do with the specific forms of knowledge that is connected with mining and raw material acquisition. This is without doubt already the case with the appropriation of raw materials and their specific material properties that create a specific affordance.[39] In contrast to natural raw materials, resources are human-made. They are socially produced constructions expressing what people perceive as relevant. Both is knowledge based but in both cases charged in a different way with experiences and expectations. While raw materials are experienced by trial-and error, by sensual and technical testing, by visual expressions (e.g. colour and matrix) this is not the case with declarative knowledge of resources. Within the declarative knowledge, there are already commonly shared expectations regarding what to gain from an ore-deposit or a processed material. These are expectations of social value, technical usability and economic exploitability.[40] The knowledge evolution starts

tion and Innovation in the Archaeological Record, in: Bourriau, Janine/Phillips, Jacke (Eds.): Invention and Innovation. The Social Context of Technological Change 2. Egypt, the Aegean and the Near East 1650-1150 BC, Oxford 2004, pp. 1–11.

39 In the sense of Gibson, James Jerome: The Theory of Affordances, in: Shaw, Robert/Bransford, John (Eds.): Perceiving, Acting, and Knowing: Toward an Ecological Psychology, Hillsdale 1977, pp. 67–82; Gibson, James Jerome: The Ecological Perspective to Visual Perception, Boston 1979. Discussion for instance: Stöllner, Thomas: Resources, innovation, technology (note 31).

40 Knapp, A. Bernhard/Pigott, Vincent C./Herbert, Eugenia W. (Eds.): Social Approaches to an Industrial Past: The Archaeology and Anthropology of Mining, London 1998, pp. 8–13.

then from this point and leads to individual knowledge adaptations, if the expectations are not met by the current material properties. The constantly renewed knowledge-process about deposits and their exploitation and production aspects leads to a culturally embedded knowledge amalgam that could include several aspects of knowledge on the subject. This includes also daily work routines but also social and ritual norms how to practice and use such materials. It should be mentioned at this stage that social value and ritual knowledge how to handle this material were most of the time of similar importance to economic properties.[41] This also includes cultural limitations that could have led also to a conservative and limited knowledge amalgam that would have directed the practicing with raw materials and possibly prevented the usage of them at all.

It is therefore obvious that complex bundles of knowledge could not evolve without the curiosity and the willingness of people to adopt them. We therefore can understand special mining zones as regional knowledge networks, in which technical and social experiences could evolve over a long time in a very specific way.[42] Contrary to crafts-networks it should be stressed that regional mining networks have a stronger binding to geology and environment.[43] We have seen already examples from the Alps of such a knowledge networks.[44] But the concept is much older: The exploitation of special sources, such as the flint mining of Lower Bavaria or of the Netherlands and Belgium or such as specific salt-exploitation zones, led already in prehistory to regionally larger mining complexes in which also the flow of knowledge was more easily possible. This is the case for

41 Stressed with arguments: Stöllner, Thomas: Resources, innovation, technology (note 31).

42 Knapp, A. Bernhard/Pigott, Vincent C./Herbert, Eugenia W. (Eds.): Social Approaches to an Industrial Past (note 40); Stöllner, Thomas: Mining and Economy (note 7); Stöllner, Thomas: Mining Landscapes in Early Societies – Imprinting Processes in Pre- and Protohistoric Economies?, in: Bartels, Christoph/Küpper-Eichas, Claudia (Eds.): Cultural Heritage and Landscapes in Europe. Landschaften: Kulturelles Erbe in Europa. Proceedings International Conference Bochum 2007, Bochum 2008 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum, 161), pp. 65–92.

43 Some examples are discussed by Rebay-Salisbury, Katharina/Brysbaert, Ann/Foxhall, Lin (Eds.): Knowledge Networks and Craft Traditions in the Ancient World (note 7).

44 For Bronze Age copper mining networks: Shennan, Steven: Producing copper in the eastern Alps during the second millennium BC, in: Knapp, A. Bernhard/Pigott, Vincent C./Herbert, Eugenia W. (Eds.): Social Approaches to an Industrial Past: The Archaeology and Anthropology of Mining, London 1998, pp. 191–204; Stöllner, Thomas: Enmeshment within Resource-Scapes – Eastern Alpine Copper Production of the Bronze- and Early Iron Age, in: Turck, Rouven/Stöllner, Thomas/Goldenberg, Gert (Eds.): Alpine Copper II – Alpenkupfer II – Rame delle Alpi II – Cuivre des Alpes II. New Results and Perspectives on Prehistoric Copper Production, Rahden/Bochum 2019 (= Der Anschnitt, Beiheft 42), pp. 13–30.

instance in the Romanian Bronze Age Salt mining districts in Eastern Transylvania.[45] Recent research proved the evolution and expansion of this innovative bundle to other surface near salt-sources. As a whole landscape and their inhabitants dealt with all the aspects of producing and trading the goods the knowledge amalgam could be handed down and furtherly developed over generations.

The complexity of knowledge involved certainly has reached a level that made it impossible to transfer easily it to other regions. Knowledge amalgams of this kind were tightly interwoven to the cultural experiences of communities, which makes it understandable why it could not be transferred by single miners with their personal experiences. The case-examples of the blasting master from Großarl who failed when he had to adopt his knowledge to another ore-district with different ore-geology is a simple but understandable example.[46]

Regional prehistoric mining networks as "innovation hubs" with broad knowledge amalgams involved

On the other hand it was possible to master complex problems within such knowledge hubs and regional or even interregional knowledge networks (such as mining regions); here we come to a further important aspect of how knowledge could evolve if massive problems occurred and a practical solution on the basis of a general understanding of the circumstances was needed.

The widening of shafts in the later Neolithic chert mining (such as in 3rd mill. Poland and Britain) have been mostly interpreted as way to increase the security of the shafts for the underground work.[47] Whether this also helped to increase the productivity is not so clear and if this had an effect to the individual labour achievements is nearly impossible to understand. Although we do not understand the ways of interconnectivity of the British and Polish flint mines during the 3rd millennium so far (even if they were such at all), it is astonishing to learn about similar adaptations in the same time.

45 Harding, Anthony/Kavruk, Valerii: Explorations in salt archaeology in the Carpathian Zone, in: Archaeolingua Main Series 28, Budapest 2013.
46 Ludwig, Karl-Heinz: Die Innovation des bergmännischen Pulversprengens (note 1).
47 Migal, Witold: Reconstruction of the Flint Extraction System in Krzemionki, in: Ramos-Millán, Antonio/Bustillo, María Ángeles (Eds.): Siliceous rocks and culture, Granada 1997, pp. 315–325; Barber, Martyn/Topping, Peter/Field, David: The Neolithic Flint Mines of England, Swindon 1999.

What can be seen in large scale enterprises like the Bronze Age East Alpine mining fields are larger adaptive systems in technologies chosen for deep mining, beginning with winning and driving techniques, the techniques to control and haul the water and how to share labor, and followed by similar concepts of beneficiation and smelting as well as of managing supply and trade.[48] It was therefore rather a "closed shop" system that probably was not able to react quickly to fundamental changes. This dependency to once chosen paths is certainly a remarkable aspect.[49]

We should keep in mind these social, economic and environmental linkages when trying to understand the diffusion of technical concepts such as the fire-setting technique in prehistoric times.[50] The oldest evidence is known from the Balkans and Central Europe in the 5th millennium.[51] Later during the 4th millennium the technique is known in wider geographical contexts including the Caucasus and Anatolia. By the 3rd and 2nd millennium it expanded to many ore-producing areas especially along the Tethyan Eurasian Metallogenic Belt (TEMB) which indicates the preference in using it in volcanic and carbonic rocks. It is interesting to note that the technique was combined with a tool-set that conventionally was used with it for a long time, including hafted and un-hafted hammer-stones, bone scrapers and antler-picks, sometimes also with wedges.[52] It is further interesting to observe this tool-set over large regional distances but also in a broad chronological range (Fig. 12). Interestingly it did not spread to mining fields of Egypt

48 In general Shennan, Stephen: Cost, benefit and value in the organization of early European copper production, in: Antiquity 73, 1999, pp. 352–363; Stöllner, Thomas: Enmeshment within Resource-Scapes (note 44).

49 For path-dependencies in early mining see Stöllner, Thomas: Resources, innovation, technology (note 31), pp. 13–15.

50 Generally: Weisgerber, Gerd/Willies, Lynn: The Use of Fire in Prehistoric and Ancient Mining (note 2).

51 Rudna glava and Kleinkems: Jovanović, Borislav: Rudna Glava. Der älteste Kupferbergbau im Zentralbalkan, in: Posebna Izdania 17, Belgrad 1982; Schmid, Elisabeth: Der jungsteinzeitliche Abbau auf Silex bei Kleinkems, Baden-Württemberg (D1), in: Weisgerber, Gerd/Slotta, Rainer/Weiner, Jürgen (Eds.): 5000 Jahre Feuersteinbergbau. Die Suche nach dem Stahl der Steinzeit, Bochum 1999 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum, Nr. 77), pp. 141–165.

52 See examples: Garner, Jennifer: Das Zinn der Bronzezeit in Mittelasien II. Die montanarchäologischen Forschungen der Zinnlagerstätten, in: Archäologie in Iran und Turan 12, Mainz 2013 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum, 194), pp. 209–216; Stöllner, Thomas et al.: Gold in the Caucasus: New research on gold extraction in the Kura-Araxes Culture of the 4th millennium BC and early 3rd millennium BC. With an appendix of M. Jansen, T. Stöllner, and A. Courcier, in: Meller, Harald/Pernicka, Ernst/Risch, Roberto (Eds.): Metalle der Macht, Halle 2014 (= Tagungen des Landesmuseums für Vorgeschichte Halle, 11), pp. 71–110; O'Brian, William: Prehistoric Copper Mining in Europe. 5500-500 BC, Oxford 2015.

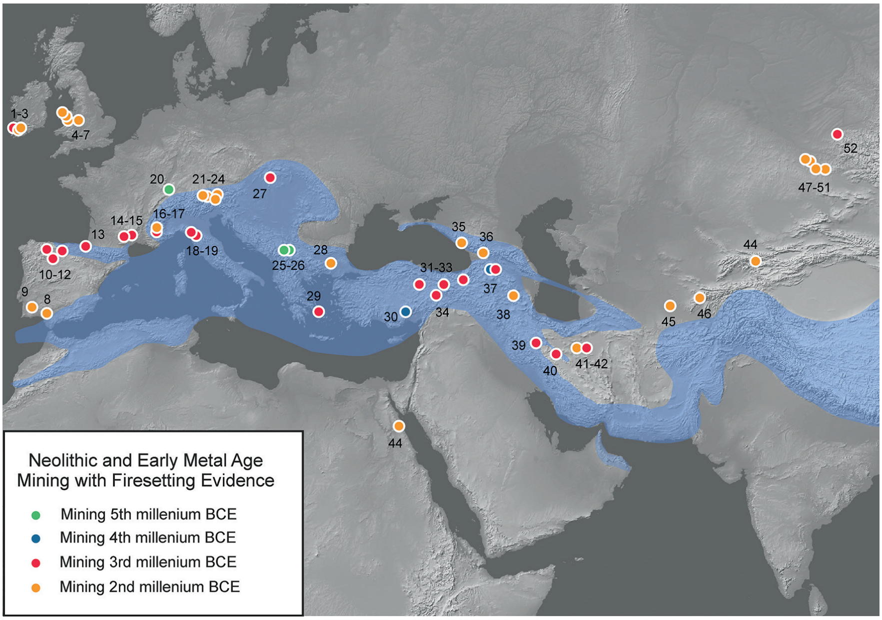

Fig. 12: Firesetting in prehistoric mining (5th till 2nd millennium BCE) and the TEMB-girdle (blue): 1. Ross Island, 2. Mount Gabriel, 3. Derrycarhoon, 4. Parys Mountain, 5. Great Orme, 6. Cwmystwyth, 7. Alderley Edge, 8. Chinflon, 9. Mocissos, 10. El Aramo, 11. El Milagro, 12. La Profunda, 13. Causiat, 14. Cabrières, 15. Bouco-Peyrol, 16. Saint-Vérant, 17. Les Rousses, 18. Libiola, 19. Monte Loreto, 20. Kleinkems, 21. Schwaz, 22. Brixlegg, 23. St. Veit, 24. Mitterberg, 25. Rudna glava, 26. Jamovac, 27. Špania Dolina, 28. Adatepe, 29. Siphnos, 30. Kestel, 31. Gümuşhane, 32. Kozlu, 33. Murgul, 34. Zeytindağ/Keban, 35. Bashkazara, 36. Saarkasch, 37. Sakdrisi, 38. Mazrayeh, 39. Shakin, 40. Veshnaveh, 41. Kuh-e Zar, Anaru, 42. Kuh-e Baba Ahmad, 43. Gebel Zeit, 44. Aktaš, 45. Karnab, 46. Mushiston, 47. Karagoin, 48. Askaraly, 49. Kalai Topkan, 50. Urunchaj, 51. Čerdojak, 52. Vladimirovka (Altai)

and the southern Levant most likely because of the desert-based aridity of mining fields and the lack of fuel in those areas. Wood and fuel for fire setting simply was not available. Does this mean that the environmental aspect did prevent the diffusion? One could take the opposite position if looking to the fire-setting activities in the semi-desert areas of the tin-mines of Karnab in Uzbekistan.

There the Andronovo-miners consumed the sparse bushes of the landscapes (such as the tamarix bushes) to burn the hard rock before hammering it.[53] This actually means that even under unfavorable conditions a technique could be

53 Garner, Jennifer: Das Zinn der Bronzezeit in Mittelasien II (note 52).

applied if the knowledge-complex of the miners involved did require it. It is clear that their cultural-technical experience did force them to organize the fuel instead of changing their traditional habitualized work routines when mining. This pinpoints another argument that seems decisive for the expansion of this technique from the older TEMB mining centres in Anatolia, the Balkans and the Caucasus (Fig. 12). Once learned and adopted to knowledge systems the Bronze Age communities of the Eurasian steppe zone remained with their standard technique until the Iron Age. This clearly points to a large interregional knowledge network, established already in 5th millennium in Europe and later expanded during the 3rd and 2nd millennium to many parts of the TEMB girdle where it was successfully applied by various mining communities.

In our examples we can learn much about the question of what triggered the transfer of complete technologies and socio-economic systems in a materialized world of practices. It has certainly to do with the level the mobility had once connected with the knowledge transfer. If there was a workmen's and specialist's mobility or if there was the migration and colonization of resource-landscapes by specialists and communities at a large scale, is a question that bears scrutiny.

Archaeology is in a very uncomfortable situation most of the time when understanding diffusional systems. I rather assume that Childe's diffusion theorem was only possible from a chronological bird-eye view.[54] It becomes more uncertain when looking more into the details. Therefore we are required to know more about the first usage of a technique, the question of adopting to regional social and technical knowledge amalgams and also why a technology was welcomed or rejected.[55] Our information is most of the time much too sparse to give more than general answers.

54 For example: Childe, Vere Gordon: Man makes himself, London 1936; see also the comments in Sherratt, Andrew: Gordon Childe: Paradigms and Patterns in Prehistory, in: Australian Archaeology 30, 1990, pp. 3–13.

55 For example also the comments on innovations in Shortland, Andrew: Hopeful Monsters? Invention and Innovation in the Archaeological Record, in: Bourriau, Janine/Phillips, Jacke (Eds.): Invention and Innovation. The Social Context of Technological Change 2. Egypt, the Aegean and the Near East 1650-1150 BC, Oxford 2004, pp. 1–11.

Conclusions

However, all our models of how to transfer practices adopted to special material worlds require a discussion about the sort of connectivity involved.[56] Connectivity was a necessary precondition for a successful implementation of practical knowledge and knowledge bundles to foreign communities, geological and environmental settings that were environmental skins to the miners. Some familiar, some alien. It is therefore necessary for our work as mining archaeologists to analyze carefully this connectivity background in order to better understand under which materialized conditions a flow of knowledge could have been successfully implemented. What we should not forget is that there were always individual choices of miners and entrepreneurs triggered by their sensual and/or analytical appropriation of these material worlds that directed the way of knowledge implementation.

56 See for example Taylor, Philip. D. et al.: Connectivity is a Vital Element of Landscape Structure, in: Oikos 68, 1993, pp. 571–573; a general critical review of network analyses: Brughmans, Tom: Thinking Through Networks: A Review of Formal Network Methods in Archaeology, in: Journal of Archaeological Method and Theory 20/4, 2013, pp. 623–662.