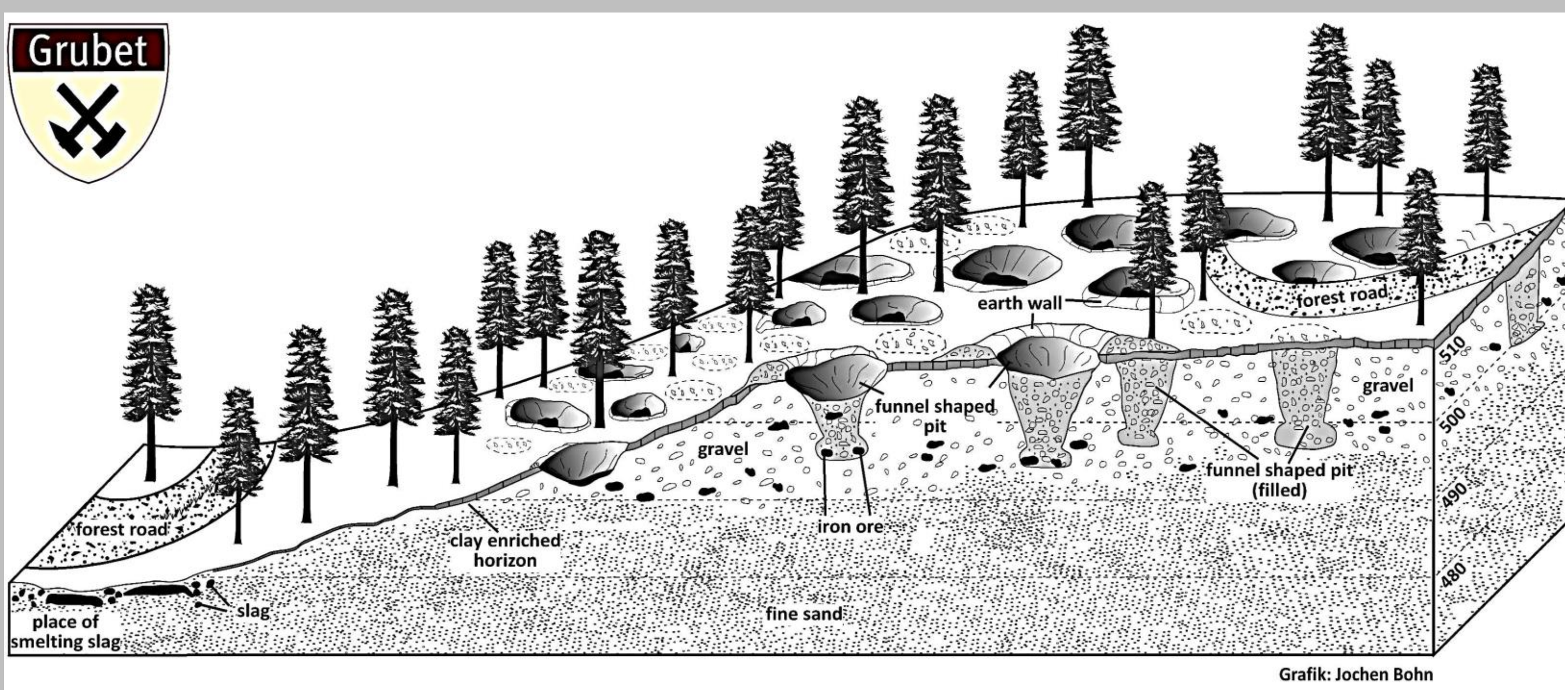


Grafik: Jochen Bohn

Resistance and vulnerability of relics of historical opencast mining - persistence of historical funnel shaped pits in the tertiary hills

Johannes Mahne-Bieder & Markus Hilpert

Historical mining in the region of Augsburg

Bavaria has a long history of mining. Iron ore mining and smelting are archaeologically proven by discoveries of slag near Regensburg. The slag originated from late Celtic smelting, about 2.000 years ago (BLfH 2013, p 56). The extraction of iron ore in the southwestern tertiary hills probably did not start before the early Middle Ages. At that time, people won ore primarily in opencast mining from so called funnel pits. The iron ore (see. fig. 2) was extracted from these normally unsecured, simple pits with a depth of up to 10 meters and smelted into iron on the spot.[1]

Left: Figure 1 - Illustration oft he Grubet. (Picture: Chair of Human Geography, 2015).

Right: Figure 2 - Iron ore form the tertiary hills. (Photo: Hans Frei).

Several theses exist about the origin of the iron ore. According to Frei (1966) the geological underground has a decisive influence on the genesis of the iron ore. Especially tertiary gravels of the upper freshwater molasse play a large role in this thesis. The iron was dissolved by acidic water in the upper coarse material and was then transported by colloidal leachate in deeper layers. With increasing depth, the flow rate decreased in the fine-grained substrate so that the dissolved iron flocculated in the fine gravel and sand. Normally a crystallization core (e. g. a grain of sand covered with a thin layer of iron) attracts the iron-bearing solution. This process results in concentric, patina-like iron layers around the core.[2] Straßburger (2012), however, states that the iron ore already originated during the formation of the upper freshwater molasse sediments in the Miocene (17-10 million years B.C.). The nodular deposits were formed in freshwater and, according to him, microorganisms (algae and bacteria) were involved in the process. At the boundary between sediments and oxygen-rich water, the microorganisms precipitated the dissolved, divalent iron by oxidation.[3]

[1] BLfH 2013, 54.
[2] Hilpert 2007, 60f.
[3] Straßburger 2012, 38.

Regardless of its origin, the mined iron ore was of comparatively high quality and only appeared above an altitude of approx. 500 meters. The amount of Fe_2O_3 in the iron ore found in the Grubet (field of funnel pits near Aichach), for example, could be defined to be about 65 to 75%. In a, for the early Middle Ages, very sophisticated smelting process, workers smelted the iron ore in simple furnaces made of loam. The produced slag still consisted of about 50% of iron. This implies that the melting process was very inefficient.[4] However, modern attempts to understand the smelting process in the Middle Ages indicate that specialized knowledge and expertise were needed for control and proper execution of the smelting process.[5]

Especially the field of funnel pits near Aichach, called Grubet, was repeatedly examined scientifically. Frei wrote his dissertation also on this field of pits as early as 1966. In the following decades, excavations, surveys and other studies were conducted by different institutions and interested persons. The Grubet can be regarded as the best examined funnel-pit-field in southern Bavaria. Therefore, numerous findings about the early medieval mining of iron ore are based on the scientific analysis of the Grubet. This field of funnel shaped pits is not only examined intensively, but also relatively well preserved. Its location in a forest helps to preserve the structures, since interventions occur less frequently (due to the long growth period of trees) than for example in the case of agricultural use. Nevertheless, changes and also destruction of single pits cannot be excluded in a silviculturally used forest.

Threats for fields of funnel pits

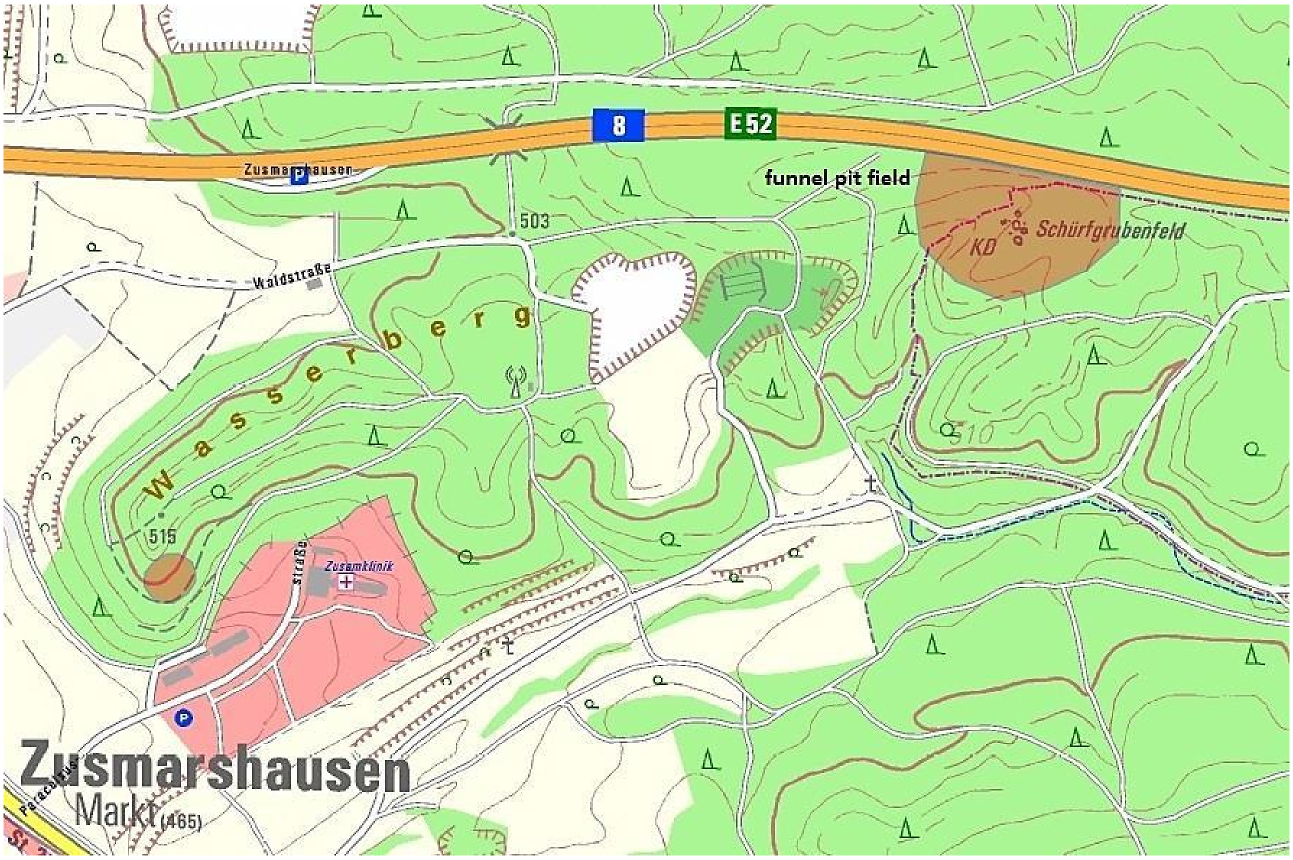
S Specific structures in space (settlements, roads, industrial areas, etc.) emerge from the satisfaction of fundamental human needs (habitation, transportation, economy, etc.). These often stay preserved for some time (so called time-lag), even if they lost their original function (brownfields, old streets, etc.). This phenomenon is referred to as persistence. However, persistent structures can also disappear for example by demolition or natural decay with a temporal delay.

It is the same with relics of medieval iron ore mining. The funnel pits were excavated in order to meet the raw material demand of the population at the time. After their exploitation the pits lost their original function and have been preserved for example in Aichach and Aystetten as persistent structures until today. Elsewhere, they are already completely destroyed by settlement activity or farming.

Due to their nature as hollow mould in a physically relatively soft ground, the funnel pits show relatively low resistance to mechanical influences, therefore, their resistibility to exogenous changes is also low. In contrast to massive objects, such as buildings, the funnel pits have a higher vulnerability. Therefore, they should be particularly protected against human intervention, especially since their formation is not yet fully understood (organization of mining, ownership, origin of the workers, etc.).

Five factors of the numerous potential hazards related to the preservation of the funnel pits are particularly dangerous: Firstly, their natural decay by erosion or backfilling with organic material. Their position on natural plateaus, usually on slopes, leads to a leveling of ancient pit-topography over centuries, and especially when heavy rain events occur. In addition, the pits function as sediment traps and therefore accumulate more ablated sediments and foliage than the surrounding terrain. The flora also influences the natural destruction processes.

[4] Hilpert 2007, 62.
[5] Straßburger 2012, XX.



Above: Figure 3 - Funnel pit field near Zusmarshausen (road construction). (Photo: BLfD, 2015).

For example, the field of funnel pits near Aystetten is situated in a beech-spruce-forest. Some drillings in selected pits revealed different states of backfilling with humus and foliage. In areas with beeches the pits were filled more than in spruce areas. Beeches produce more foliage than the evergreen spruces, because they shed their leaves in winter.

Human activities affect the fields of funnel pits in a much stronger way than natural processes. Secondly, numerous funnel pits are affected or completely destroyed by building measures. Sometimes streets or paved roads even cross the fields of funnel shaped pits (see fig. 3). Especially for road construction considerable earthworks, that could completely destroy funnel pits, are needed. Provisional access ways for the building machines affect the pits next to the main lanes. This results in destruction corridors that are wider than the marked-out route. Such dissected pit fields can usually be recognized on shaded relief maps by their shape, as they have unnaturally sharp delimitations or gaps. Such damage could be avoided, if bypasses around the pit fields would be taken into account in the planning process of new roads. The protection of the relics of medieval mining, however, is usually subject to the considerations regarding the increased costs of a bypassing route. In addition, overbuilt archaeological monuments below the surface are considered protected because their underground components remain unchanged.

The third factor is that, especially in modern times, settlement activities also affect the funnel pit fields. Quite a few rural settlements, particularly in the urban catchment area, are subject to high growth pressure. Furthermore, more and more commercial areas are designated in rural areas. Both processes, influx of population and industry, need space. Therefore, funnel pits located close to villages are endangered by the designation of new residential and industrial areas. After the development of those areas funnel pits are then usually completely destroyed.

Left: Figure 4 - Harvester. (Photo: John Allen, 2007).

Fourthly, preservation of medieval mining pits is also threatened by agricultural activities. Modern agricultural economics use huge and heavy machines. Large tractors and harvester solidify soil and backfill the ancient pits with displaced soil. Periodic ploughing levels the micro-topography created by ancient iron ore mining. Funnel pits in areas of arable land are, therefore, usually backfilled and destroyed. However, sometimes they can still be detected in aerial photos. Nevertheless, a complete preservation of funnel pits is impossible in agricultural areas but as new areas are rarely put under the plow today, no further destruction by agriculture is expected in the near future.

Left: Figure 5 - Forwarder. (Photo: Antti Leppänen, 2012).

Well-preserved funnel pit fields can usually be found in forests, because anthropogenic interventions were lower over the last centuries. Growth time of the trees is relatively long so that felling only occurs at long intervals. Up until a few years ago no huge machines were used, therefore, funnel pits in forests were only threatened by natural processes. Lately harvesters and forwarders are used more often for felling trees (see fig. 4 & 5).

Right: Figure 6 - tyre tracks of a harvester. (Photo: Pistnor, 2010).

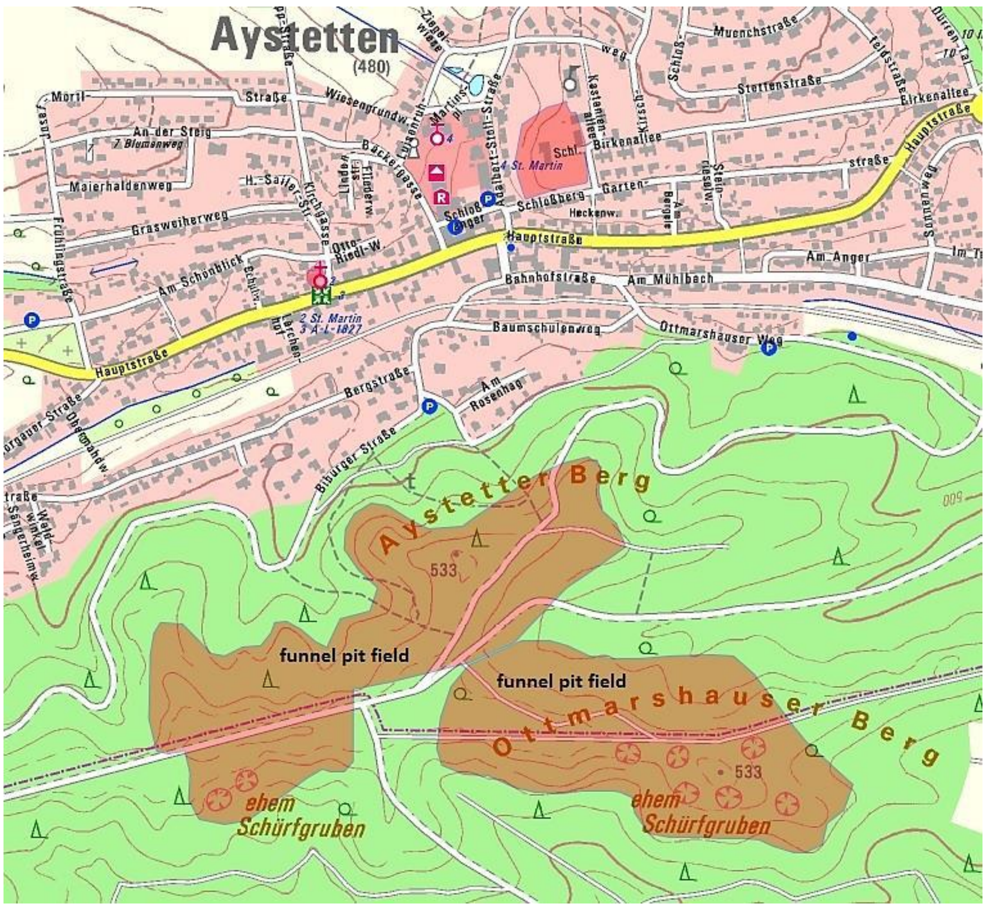
They are the fifth great threat for funnel pits. These heavy machines cause radical changes of the micro-topography, especially on sodden soils (see fig. 6). Due to their heavy weight harvesters and transport vehicles represent a threat to archaeological monuments in managed forests. The surveying of the funnel pit field near Aystetten reveals such destructions. An alley for harvesters leads across the study area. Today funnel pits could no longer be identified in this swathe without technical aids (see Map 2). It must be positively mentioned, however, that often the same alley is used for the machines and thus destruction remains locally restricted. This limitation is one of the most effective conservation measures to be implemented mainly through agreements with forest owners. Thereby damages by encroachments can be minimized. Nevertheless, funnel pits are also destroyed by other silvicultural measures (e. g. reafforestations). Moreover, sensibility to protection and sometimes also knowledge about the relics of medieval mining is missing among some forest owners.

Identification and measurement of changes

In order to detect, measure and document changes of funnel pit fields, their state at a particular time (t0) must be known. The pit fields in Bavaria are catalogued area-wide by now. They are published in publications of the Bavarian State Office of Historic Monuments (BLfD) as well as online in the Bavaria Monument Atlas (see fig. 7).

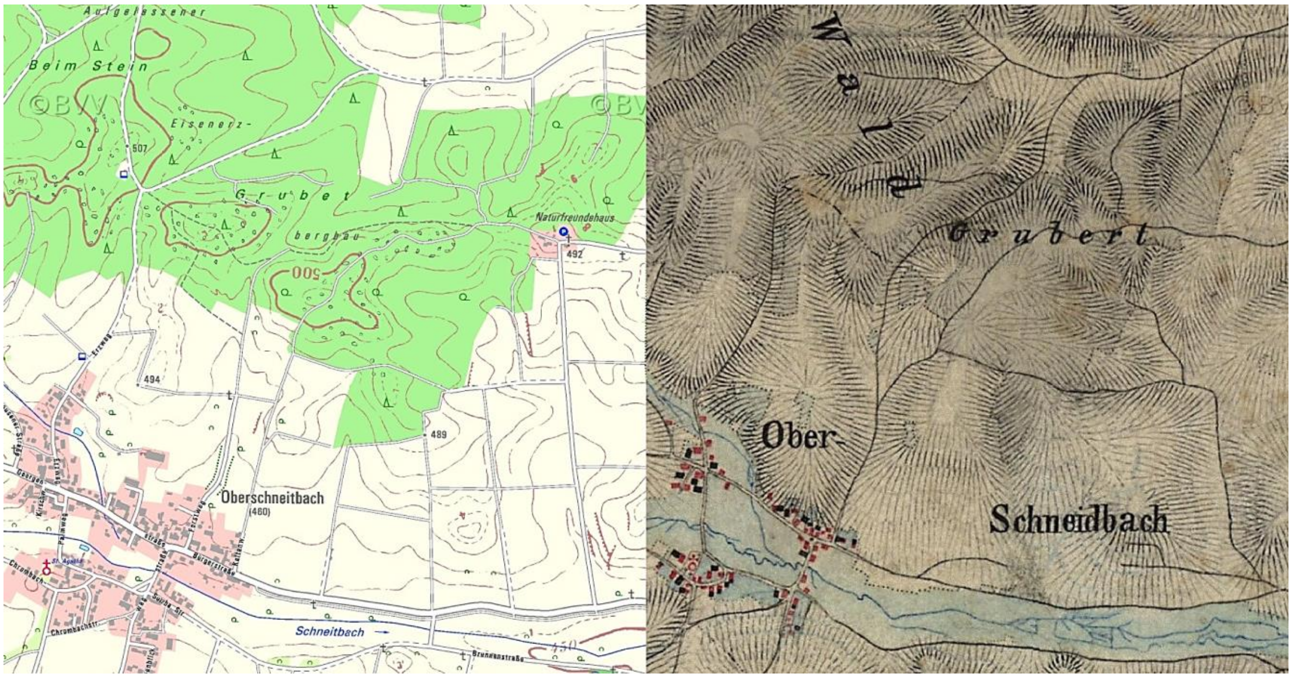
Therefore, the records of the BLfD provide a serviceable source for the dimensions of the funnel pit fields at the time t0. However, the BLfD does not regularly update important characteristics (eg. number of funnel pits, spatial extent) of the funnel pit fields. Thus, changes in extent of the funnel pit fields and condition of single pits are rarely monitored and documented. Current measurements are therefore needed to determine changes in state between the times t0 and t1 (current measurement).

In order to measure changes of funnel pit fields before being documented by the BLfD for the first time, older records must be available. Often only old maps can be used. Up until today no records of institutions or groupings which once organized the mining of iron ore are known. Therefore, there are no cartographical records about the extension of the medieval mining activities at their time of origin. Also there are hardly any maps before 1800 in which it is possible that mining is recorded.



Left: Figure 7 - Funnel pit field near Aystetten.(Picture: BLfD, 2015).

Because of that only the analysis of the first comprehensive survey of Bavaria, the Urpositionsblätter from the early 19th century, remains. These are maps at a scale of 1:25.000 which originated from the original drawings (sketches made during the survey) between 1817 and 1872. Initially the Urpositionsblätter should not be published; originally, they were templates for the copperplate engravers who were working on the topographical Atlas of Bavaria at a scale of 1:50.000. Every Urpositionsblatt displays an area of approximately 87 km^2. They all look different because the regulations of drawing changed several times during the many years of recording. The oldest ones are monochrome and only have hachures. Later contour lines were added and two colors were used for the maps, the last recordings are even threechromatic. In later revisions of the Urpositionsblätter (from 1901) design regulations (guidelines for displaying symbols and land use) also changed due to the work on the new edition of the map of the German Reich at a scale of 1: 100.000 (Landesamt für Digitalisierung, Breitband und Vermessung, 2015).



Above: Figure 8 - Funnel pit field called Grubet near Aichach. (Picture: TK25, 2015; Urpositionsblätter, 19th century).

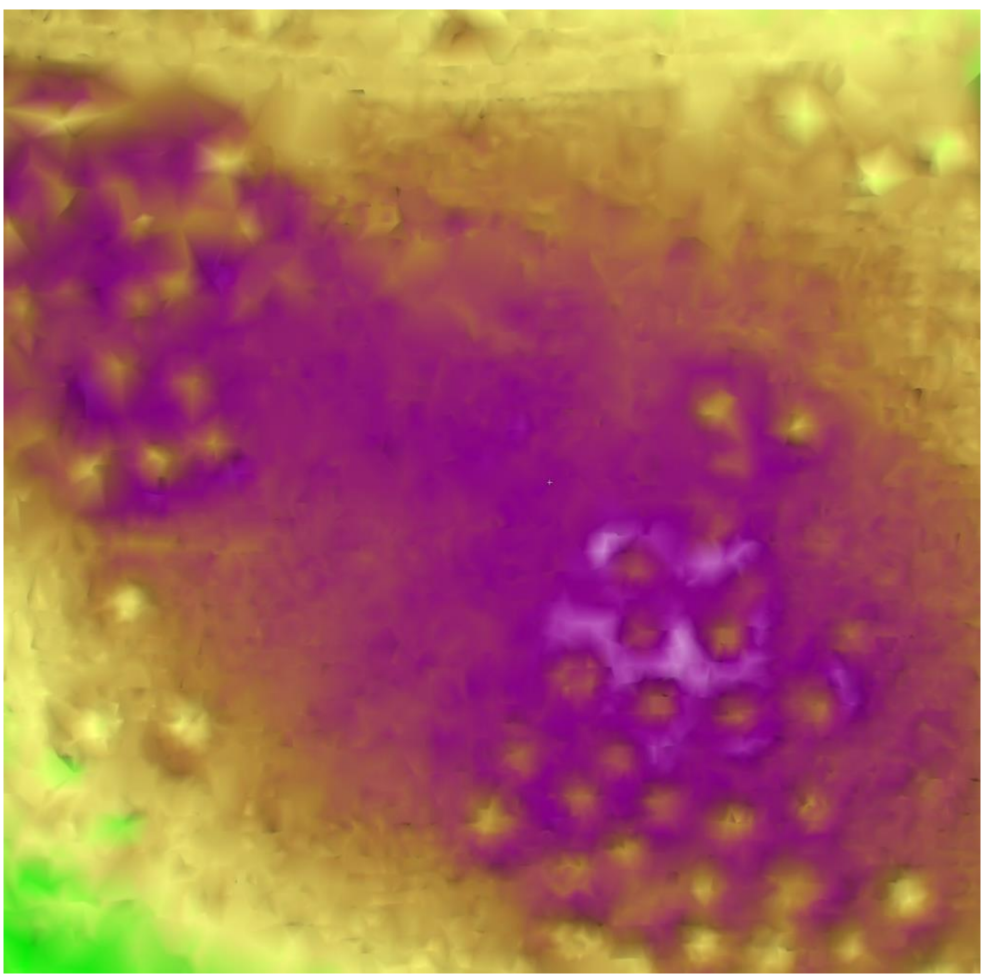
Some funnel pit fields are already named in the Urpositionsblätter, including the Grubet near Aichach. But as the focus of the Urpositionsblätter was an exact representation of the topography, waterways and roads, archaeological monuments were not documented in a particular manner. Thus the maps of the 19th century do not display the dimensions of funnel pit fields.

Modern topographic maps of Bavaria show much more information today. Besides topography, bodies of water, roads and land use numerous other objects, such as power lines, natural monuments and, of course, archaeological monuments are shown. Therefore, funnel pits have their own unique symbol. However, only the rough dimension is charted and the symbols do not represent individual pits (see fig. 8). The display of dimension is also less accurate than for example in the Bavarian Monument Atlas. Therefore, modern maps are also neither suitable for a comparison of the dimensions nor for the state of single pits at the time of the drawing of the maps and today.

A measurement of changes of funnel pit fields prior to their first documentation by the BLfD therefore can neither be done with the Urpositionsblätter nor the latest topographic map. Thus, this possibility is limited to cases in which even older cartographic records can be found.

In order to measure changes of the condition of funnel pit fields between their first documentation (t_0) and today, new recordings are required. Today satellite or aerial photos of Bavaria exist area-wide. In order to identify the funnel pit fields, they should not be located in woods or be overbuilt. In addition, only experts with many years of experience can analyse these satellite or aerial photos and can recognize small changes of micro-topography caused by funnel pits. The date of the picture is also a crucial factor. Many ancient monuments, such as former moated castles or funnel pits, can be identified on satellite or aerial pictures particularly well if they are covered with snow. If such pictures are not available, new ones must be taken, which entails some costs. If it needs to be to examine whether there are old pits on a field, the pictures must be taken in the fallow period. Moreover, destroyed funnel pits may only be identified by changes in the color of the soil. But these discolorations cannot always be assigned to old pits.

Other remote sensing techniques can compensate for the disadvantages of aerial and satellite images. Micro-topography can also be visualized with airborne laser scanning (ALS), even in forests. For this purpose a helicopter or airplane with a mounted laser scanner traverses the study area. The laser scanner emits a laser beam that is reflected from surfaces it impinges. Then sensors measure the transit time of the reflected beam and can determine the distance between the scanner and the reflecting object. Some scanners can emit short laser pulses. With this technique it is possible to distinguish between the reflections of trees and soil, by their intensity. This is the great advantage of this method for the generation of digital terrain models and identification of smaller topographic phenomena like funnel pits. To create a cohesive terrain model the data of course must be georeferenced. In addition, the exact altitude of the helicopter or aircraft must be known at all times in order to adjust the measured heights. The collected data must then be edited with a special software. To illustrate the soil surface, measured points of the trees must be removed. Therefore, only a cloud of points arises which is very difficult to interpret. But adequate software can create a closed surface from the cloud of points. So that even laymen can interpret the very illustrative results with some practice (see fig. 9). However, raw ALS-data are not freely available and must be purchased from the respective national mapping agencies.

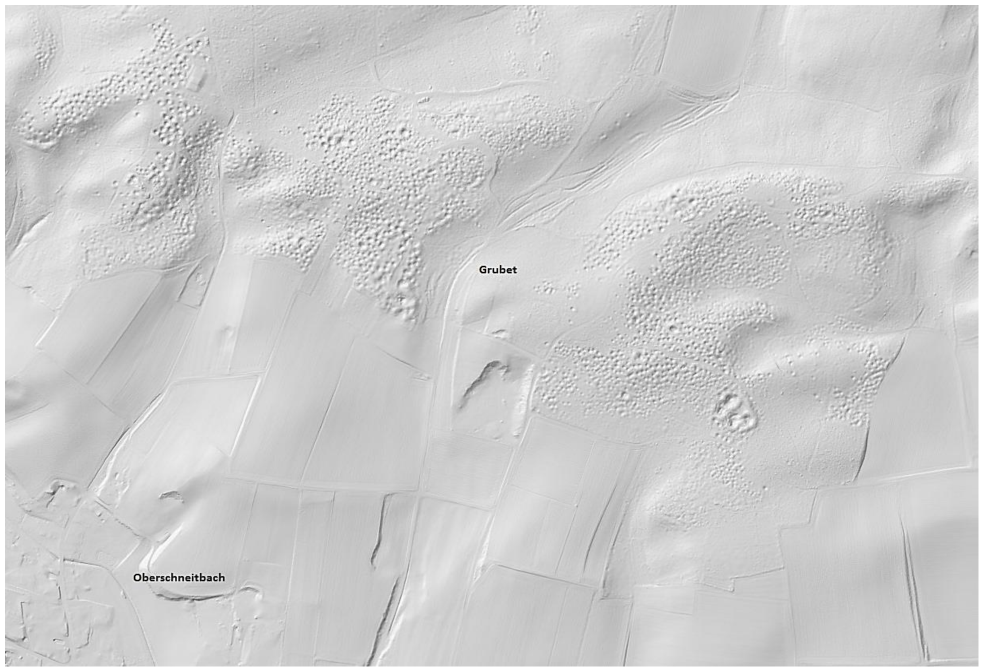


Left: Figure 9 - ALS-data of a funnel pit field near Aystetten (section). (Picture: Chair of Human Geography, 2015).

However, terrain models, such as maps with relief shading based on ALS-data, are published by the Bavarian national survey. These maps are available for free online at the RISBY (online service of the Bavarian national survey), but are highly generalized. Therefore, not every change in the micro-topography, as for example alleys for harvesters, can be recognized on these maps with relief shading. But greater destructions of pit fields, for example by roads, can be identified clearly, even by laymen.

Funnel pits can be clearly recognized as small hollow patterns on maps with relief shading, because of an exaggerated presentation of relief. To create maps with relief shading, the terrain model is virtually illuminated from a designated position. The shadows, produced by the virtual illumination, are depicted by different shades of grey. These shadows create the impression of three-dimensionality to the human eye. This means, that even beginners intuitively interpret the micro-topography of an area correctly and can, therefore, identify single funnel pits (see fig. 10).

Right: Figure 10 - Shaded terrain model of the pit field called Grubet near Aichach. Picture: RISBY, 2015).



Besides using remote sensing methods, funnel pit fields and single pits can also be measured on site. Two methods are common: The survey with GPS and theodolite. With the help of numerous satellites arbitrary positions can be determined exactly (up to 1 cm). Satellites are constantly transmitting their position and time. A receiver on the ground measures the transit time of the signal, with the help of the co-sent time, and thus can determine its position and even altitude above sea level, if it receives the signals of at least four different satellites. The more signals are being received, the more accurate the position can be determined. The most common system, the US-American GPS, was originally developed for military use and is still in operation primarily for this purpose today. Therefore, its accuracy for operations by civilians is limited to prevent any misuse, for example by terrorist organizations. The times satellites are transmitting are always slightly wrong, thus a position can only be determined within in a range of a few meters, without corrections. However, there are three ways to compensate this internal error and increase the accuracy of the measured position. The first solution would be to leave one GPS-receiver in a permanent position. This device registers its change in position, caused by the time error transmitted from the satellites. The measured error can now either be sent in real time directly to the GPS-devices used for positioning or later be used to correct the measured coordinates. Such a system is called DGPS.

The second procedure requires an internet access. Several reference stations are installed in Germany. They consist of a GPS-device, which is placed on a precisely measured position with known coordinates. The reference stations constantly measure the time error of the time signal. The data of the runtime error of each satellite is available online. If the error is known, this information can either be forwarded in real time to all GPS-devices in use or can be used in post-processing to correct the measured coordinates.

The data of the runtime error of each satellite is available online. If the error is known, this information can either be forwarded in real time to all GPS-devices in use or can be used in post-processing to correct the measured coordinates.

The third possibility can be applied, if neither DGPS-capable devices nor internet access are available. Relatively simple and inexpensive GPS-receivers are needed. Modern GPS-devices can perform multiple measurements at stated intervals and save them. The GPS-device interpolates the different measurements and can therefore determine its position more accurately. Although no measurements within the centimeter range are possible with this method, the measured position can be determined within a range of 10 to 50 centimeters.

Method	Advantages	Disadvantages	Usage
Map analysis	low costs, can be done by laymen	maybe outdated data, relatively inaccurate	Identification of position and rough measurement of dimension of funnel pit fields
Shaded terrain model	low costs, interpretable by laymen	small changes, sometimes not visible	Relatively accurate measurement of dimension of funnel pit fields
ALS	very high resolution of terrain, interpretable by laymen	special software required, high costs	Accurate measurement dimension of funnel pit fields and possibility for small-scaled analysis
GPS	low costs, relatively fast, can be done by laymen	multiple measurements required, possible in nearly every terrain	Relatively accurate positioning (coordinates) of single funnel pits
Tachymeter	very accurate possible in every terrain	expensive devices training needed, time-consuming	Accurate positioning (coordinates) and measurement of single funnel pits

Left: Chart 1 - Comparing of methods. (Image: Chair of Human Geography, 2015).

Very accurate positioning is possible with GPS-devices today, nevertheless, this technique cannot be used always and everywhere. For example in times of war the US-military concentrates all satellites over the crisis region to allow its troops positioning as accurately as possible. Then the satellite signal is not receivable in other regions of the world. In this case there is still the possibility to use the Russian satellite system called GLONAS, if the receivers are suitable for this system. The European equivalent, Galileo is not yet ready for operation. But even if all GPS satellites are available or the use of GLONASS satellites is technically possible, the use of GPS receivers is not suitable for every terrain. In order to receive the satellite signals the GPS-receivers require a direct line of sight to the satellites. Therefore, in areas with a reduced sight of horizon (as in towns or forests), sometimes even the least required 4 satellite signals cannot be received. Then a determination of position with GPS-devices is not possible.
Compared to positioning with GPS, surveying using a theodolite requires neither satellites nor internet access and is therefore possible anywhere. The theodolite is still used for surveying work, even if it is being replaced more and more by DGPS systems. A theodolite can only measure angles, current devices even distances, then they are called tachymeter. If the location of the tachymeter is known, an unknown position can be determined. For that a reflector is placed on the target to be measured and the distance is determined by tachymeter. After that, the angle to the next measurement point (point with exactly known coordinates) must be determined. After that it is possible to specify the position of the newly surveyed point in a geographic coordinate system. If there is no measurement point nearby, the theodolite can be oriented to the north by using a compass. Also clearly visible objects in the distance (eg. church towers) can be used as a target of reference. The coordinates of church towers are usually known exactly and are therefore particularly suitable as reference points. The point to be measured can also be determined in a different way.

The tachymeter must stand on the point to be measured and the angels as well as the distances between the tachymeter and two reference points have to be measured in order to determine the position of the tachymeter. However, this method of measurement shows also disadvantages. The reference points have to be visible at all times, therefore, buildings or trees can block the line of sight. In order to generate visual reference points, one or more intermediate points must be measured. Another difficulty is the determination of position of the first location of the tachymeter. There are numerous measurement points in most villages and towns whose coordinates are known exactly, in forests this is often not the case. In extreme cases the closest measurement point is one measured in a village several kilometers away. Is the line of sight also blocked to objects in the distance, a reference point must be triangulated from the last known measurement point or its coordinates have to be determined by GPS. Even if measurement using a theodolite is possible everywhere, this method is very time consuming, especially if lines of sight to reference points or objects in the distance are blocked. In addition, some practice is needed to use a tachymeter correctly. The calculation of the geographical coordinates with the help of distances and angels requires additional work.

Changes of funnel pit fields in the Grubet

OOnly few conclusions can be drawn about the changes of the funnel pits between medieval and modern times, as comparative data or maps are not available for the different epochs. The plurality, depth and diameter of the still existing pits imply that human impact on the morphology was comparatively low in former times.

In 1964, parts of the Grubet were systematically surveyed and mapped for the first time (Frei 1966). Based on this first survey it is possible to measure and asses anthropogenic changes as a new, systematic field survey was performed in the year 2005.
Map 1 shows, based on a mapping of Frei (1966), exemplary the human encroachments on the morphology of the pit field in an area of 2.74 ha near the Erzweg. It is evident that a lot of pits were significantly leveled in the past 41 years, in some case even completely destroyed. Particularly along new forest roads numerous funnel pits have almost completely disappeared from the surface (leveled or filled).

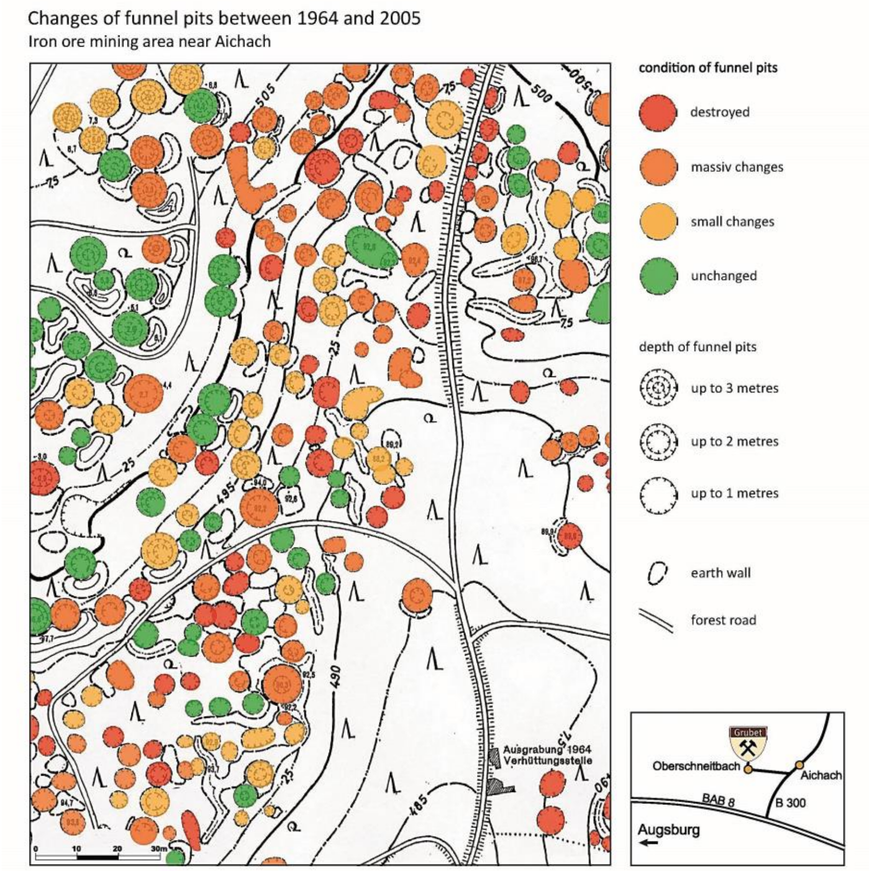
Right: Chart. 2 - Changes of the pits in the Grubet. (Image: Chair of Human Geography, 2005).

	total		unchanged		small changes		changes		destroyed	
	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
1964 - 2005	219	100	40	18,3	51	23,3	71	32,4	57	26,0
2005 – 2046	219	100	7	3,2	19	8,7	38	17,4	155	70,8

The statistical analysis of the cartographic evidence result in a percentage of undisturbed or unmodified The statistical analysis of cartographic findings shows that only 18.3 percent of the funnel pits remained unimpeded or unmodified. Accordingly, just one out of five pits remained unchanged since 1964. In the last 41 years, four-fifths (81.7 percent) of the total 219 pits showed changes of different intensity (natural and anthropogenic). More than a quarter (26.0 percent) of the pits even disappeared completely between 1964 and 2005.

Changes of the pits that are expected in the future are interesting in this context. If the percentage of change is interpreted as temporary probability of occurrence for the four stages of change (18.3 % for the first stage, 23.3 % for the second stage, etc.), it can be assumed that this percentage distribution (there are no indications for other probabilities) is always valid for a linear development.

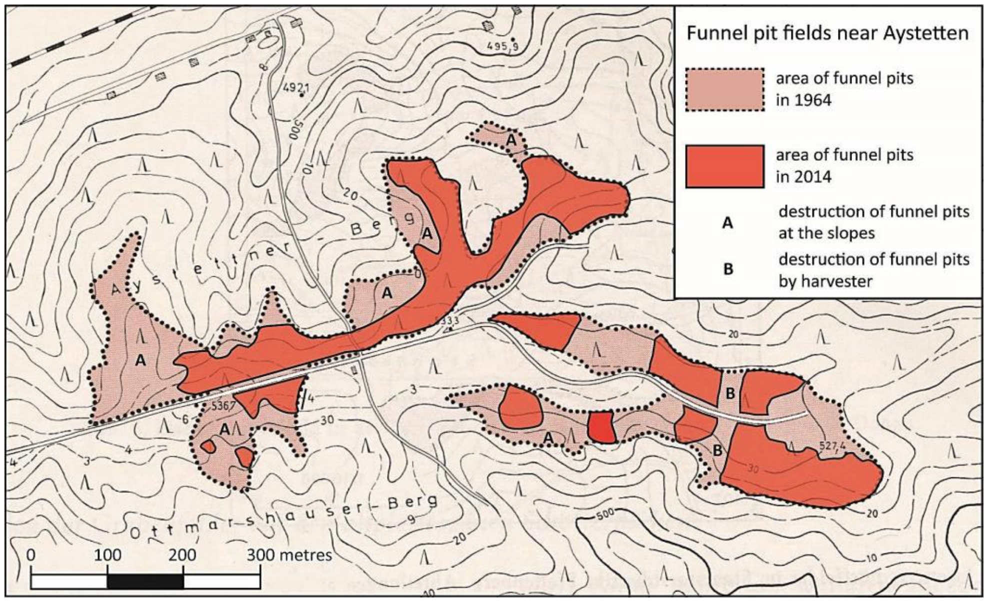
There is every indication for that, because result of the percentage distribution already includes all factors of change (development of forestry technology, monument protection, etc.). Therefore, the development of the percentage distribution of different types of change in the past (1964-2005) also takes effect in the next 41 years (2005-2046). If interventions remain constant only 3.2 percent of funnel pits are expected to be unchanged in 2046 and 70.6 percent will have completely disappeared (see chart 2).



Left: Map 1 - (Image: Chair of Human Geography, 2005).

Changes of funnel pit fields near Aystetten

South of Aystetten there are two surface pits. Both are situated on hills, the Aystetter Berg and the Ottmarshauser Berg. The underground, approximately 510 m ASL, consist of gravel from the glacial period. Beneath the gravel lies the fine-grained upper freshwater molasse (USM) (in the Grubet the gravel starts at a lower level). The funnel pits have been trenched exclusively into this underground. Because, according to the thesis of Frei, the genesis of iron ore is only possible at the boarder of gravel and sand. At slopes pits become flatter, because of the thinner layer of gravel; therefore, iron ore could be found in lower depth. In 1964, the first simple survey of the pit fields near Aystetten was conducted by Frei. A survey of the medieval mining areas was conducted again 50 years later. The measurement of the pit fields was carried out in 2014 by analyzing shaded terrain models, because the dimensions of the funnel pit fields could be easily identified this way (see Chart 2). Furthermore, an area-wide survey with GPS is not possible, because the dense forest blocks the signals of the satellites. The mapping by remote sensing was verified by numerous field surveys. The two surveys, 50 years apart, allow a comparative analysis of the funnel pit fields. By comparing the two surveys, it becomes apparent that the expanse of the overground relicts of medieval mining decreased about approximately 50% (Aystetter Berg: 53%, Ottmar Hauserberg 50%). Three factors contribute to the destruction of the pits in the study area: road construction, natural erosion and forestry.



Right: Map 2 - (Image: Chair of Human Geography, 2015).

Firstly, new forest roads superpose all pits on their route, therefore, overground elements of the pits are no longer visible today (see Map 2). Secondly, natural erosion damages flat pits especially on slopes (see Map 2, A). On the one hand the higher relief energy causes higher erosion; on the other hand the pits on slopes are less deep, because of the thinner gravel layer and are, therefore, filled in in shorter time. Even small differences in height are sufficient, because a pit with a depth of 0.5 meters is backfilled quicker than one with a depth of 1.5 meters. Finally, modern harvesters threaten the funnel pits south of Aystetten. This can be seen on shaded terrain models of the Ottmarshauser Berg where there is a corridor in the middle without funnel pits (see Map 2, B). During the field surveys this corridor was identified as a harvester alley. No more pits are perceptible due to the usage of those heavy machines on the alley. Due to the destructtion by the three factors mentioned, there is a separation of the still visible funnel pits. First the formerly contiguous fields are cut by new forest roads and tree back alleys. Second, natural erosion destructs flatter funnel pits on slopes. Even small differences of height lead to the backfilling of one pit, while other ones remain preserved until today. Thus the area of the former iron ore mining does not shrink uniformly, the rates depend on their small-scale location and depth of the pits. The natural decay of the pits by erosion cannot be avoided without complicated measures. Therefore, anthropogenic damages should be minimized, especially since pits, which are very resistant against natural decay, due to their depth, could also be destroyed this way. For example, the building of new forest roads should be renounced, whenever possible. Also, the same alleys should be used for harvesters to minimize the destruction related to the increased use of heavy machines. Furthermore, a classification of protection zones in which any human intervention is prohibited would certainly be conceivable. In managed private forests this can only be realized through agreements with forest owners, who are willing to protect the funnel pits.

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