The Digital Terrain Model (DTM) and the evaluation of known and the search for new craters in the Chiemgau meteorite impact strewn field.

Kord Ernstson (2017)

Abstract. - For several known and a few newly proposed meteorite craters in the Chiemgau meteorite impact strewn field the LiDAR data of the Digital Terrain Model DTM have been processed to reveal various maps and cross sections based on a high-resolution mesh down to 1 m and contour interval down to 0.2 m. The data processing highlights particular crater features that remain hidden in fieldwork and on conventional topographic maps and even may debunk mistaken structures.

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1 Introduction

Since some time the possibilities of the Digital Terrain Model (DTM), also termed *Digital Elevation Model* (DEM) or *Digital Surface Model* (DSM) - in Germany: *Digitales Geländemodell* (DGM) - have become an important tool for many purposes in the geosciences of geography, geology and geophysics. Based on LiDAR data, topographic maps in a regular grid down to spacing of 1 m and with highest altitude resolution down to 20 cm (in Germany DGM 1) may be produced. Thereby the DTM represents the bare ground surface without any objects like plants and buildings and may even be processed in thick forest (Fig. 1).

Fig. 1. DTM shaded relief of a landslide in thick forest.

Frequently the DTM data can be gained from land surveying offices as digital (x, y, z) files for standard coordinate systems (e.g., UTM). The data may then be processed by various contouring and 3D surface mapping software producing maps as different as normal contour maps, 3D surface maps, vector maps, wireframe maps or shaded relief maps. Processing may elaborate the data files by various filter processes, computation of field gradients and producing any desired elevation profile.

Here I shall illustrate the enormous possibilities of the DTM to explore the Chiemgau (Germany) meteorite impact strewn field for new craters adding to the hitherto established roughly 80 objects in the diameter range between a few meters and 600 m (rim to rim). The DTM data processing is also applied to several craters already known for some time past. The location map for the here-discussed sites is shown in the Appendix.

2 The Holocene Chiemgau meteorite impact event

The Chiemgau strewn field (Fig. 2/3) has originally been discovered some 15 years ago by a group of local history researchers and amateur archeologists and has meanwhile been established by all evidence of meteorite impact (Rappenglück, M.A. et al. 2013, 2014, Rappenglück and Ernstson 2008, Ernstson and Rappenglück 2008, Ernstson et al. 2010, 2011a,b, 2012, 2013, 2014, Ernstson 2010, 2011, 2016, Isaenko et al. 2012, Shumilova et al. 2012, Hiltl et al. 2011, Bauer et al. 2013, Rappenglück, B. 2013, Rappenglück, B. et al. 2009, 2010, 2012, 2013, Liritzis et al. 2010) as is commonly and since fairly long time claimed within the international impact research, and only sporadic opposition is still maintained (Reimold & Koeberl 2014, Reimold et al. 2014, Doppler et al. 2011, Schmieder et al. 2011).

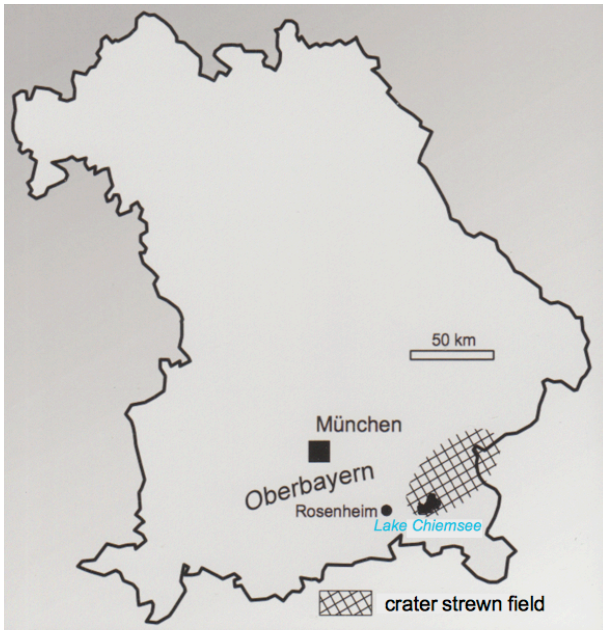


Fig. 2./ Fig.3. The Chiemgau impact strewn field in Bavaria (map to the right).

The impact evidence from mineralogical-petrologic, geochemical, geologic and geophysical investigations has been featured by heavy rock deformations, melt rocks, strong shock metamorphism, geophysical GPR, gravity and geomagnetic evidence, abundant occurrence of metallic, glass and carboneous spherules, accrecionary lapilli, strange matter in the form of iron silicides such as gupeiite, xifengite, hapkeite, and various carbides, e.g., moissanite and khamrabaevite, microtektites, and an impact-induced Lake Chiemsee tsunami. In the beginning of the investigations the large number of about 80 mostly rimmed craters in an elliptically shaped strewn field of about 60 km x 30 km size (Fig. 2) attracted the attention of the discoverers who had thoroughly documented the craters even in the very beginning. Meanwhile, for some of these craters another than an impact origin has been considered probable (e.g., Ernstson and Neumair 2011), but at the same time many new objects were discovered that show all evidence of belonging to the impact crater strewn field. In part, hints for their existence came from the interested population, but a systematic search using the Digital Terrain Model DTM provided a significant new impulse.

As for the target geology and rocks I mention the age of the impact event to have happened in the Bronze Age/Celtic era when the impact-affected ground consisted of moraine material and gravel plains. Beyond that I refer to the established literature (e.g., Ernstson et al. 2010).

3 Data processing

3.1 Terrain imagery

The herein discussed terrain imagery for the Chiemgau impact strewn field is in all cases based on the German DTM (DGM1) with a 1 m mesh and an elevation resolution of 0.2 m optionally in the UTM or the Gauß-Krüger coordinate system. Simple data processing enables the reduction of the 1 m and the 0.2 m standards by interpolation.

The most familiar transfer of the DTM data produces topographic maps based on arbitrary contour intervals. In Fig. 4 such a topographic map with a 10 cm contour interval is shown for the 15 m-diameter Einsiedeleiche crater in the Chiemgau impact strewn field. Taking into account that the conventional 1 : 25,000 topographic maps in general consider a 5 m (rarely 2.5 m or 1.25 m) elevation contour interval, the map in Fig. 4 covering only 3 m height difference would trace no more than a single contour line, if at all, and nobody would recognize the existence of that crater.

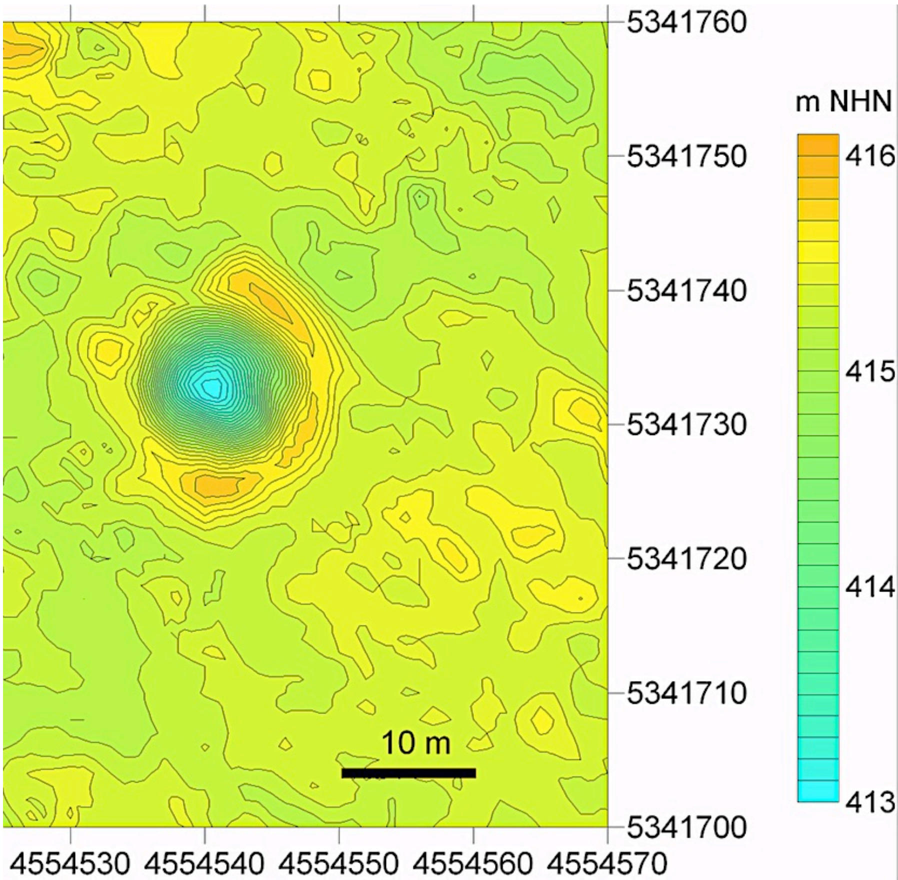


Fig. 4. Einsiedeleiche crater. DTM topographic map; contour interval 0.1 m. Here and in all other cases to follow the crater diameter is assigned to the rim crest diameter (here: 15 m).

Elaborating a 3D surface from the digital data provides a more picturesque version of terrain imagery, in particular for the visualization of rimmed craters, as is shown in Fig. 5 for again the Einsiedeleiche crater. In suitable data processing programs arbitrary colors and grading can be selected, and an elevation mesh may be superimposed or omitted.

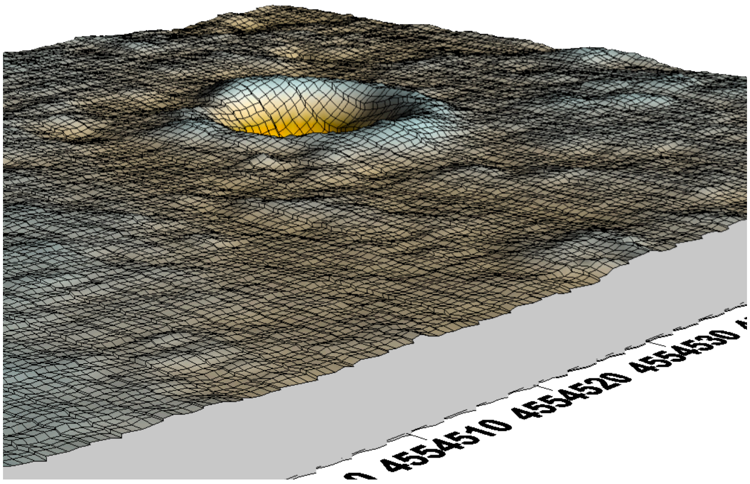


Fig. 5. DTM 3D surface of the Einsiedeleiche crater.

Maps of shaded relief that can digitally be lightened from various directions and under various angles of entry such highlighting arbitrary topographic features give a similar 3D visualization of the terrain surface. The shaded relief map in Fig 6 shows the Einsiedeleiche crater in its somewhat larger environments as a distinct anomaly but not as impressive as in the 3D surface map in Fig. 5. The special importance of shaded relief maps is due to their nature to enable a quick look at selected features also on larger terrains. Fig. 7 is an instructive example from the Chiemgau impact strewn field. The area is insofar exceptional as the remarkable cluster of craters initiated a geophysical campaign, and in a first step earth magnetic field measurements revealed extensive magnetic anomalies of exceedingly high amplitudes and rocks sampled from the ground that showed unusually high magnetizations (Neumair and Ernstson 2011).

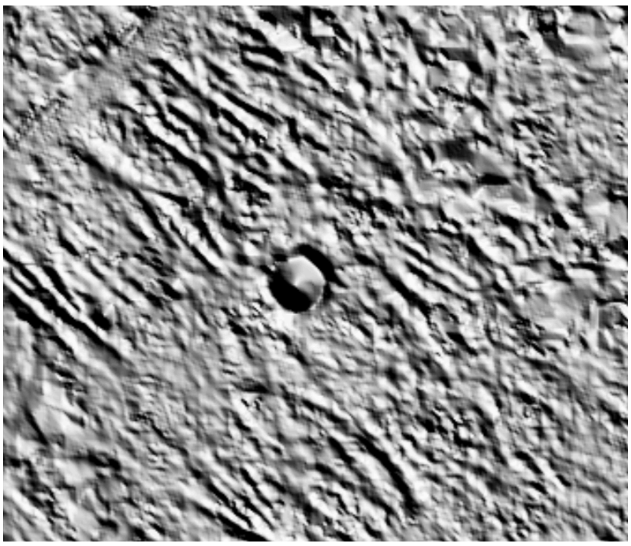


Fig. 6. DTM shaded relief map of the Einsiedeleiche crater.

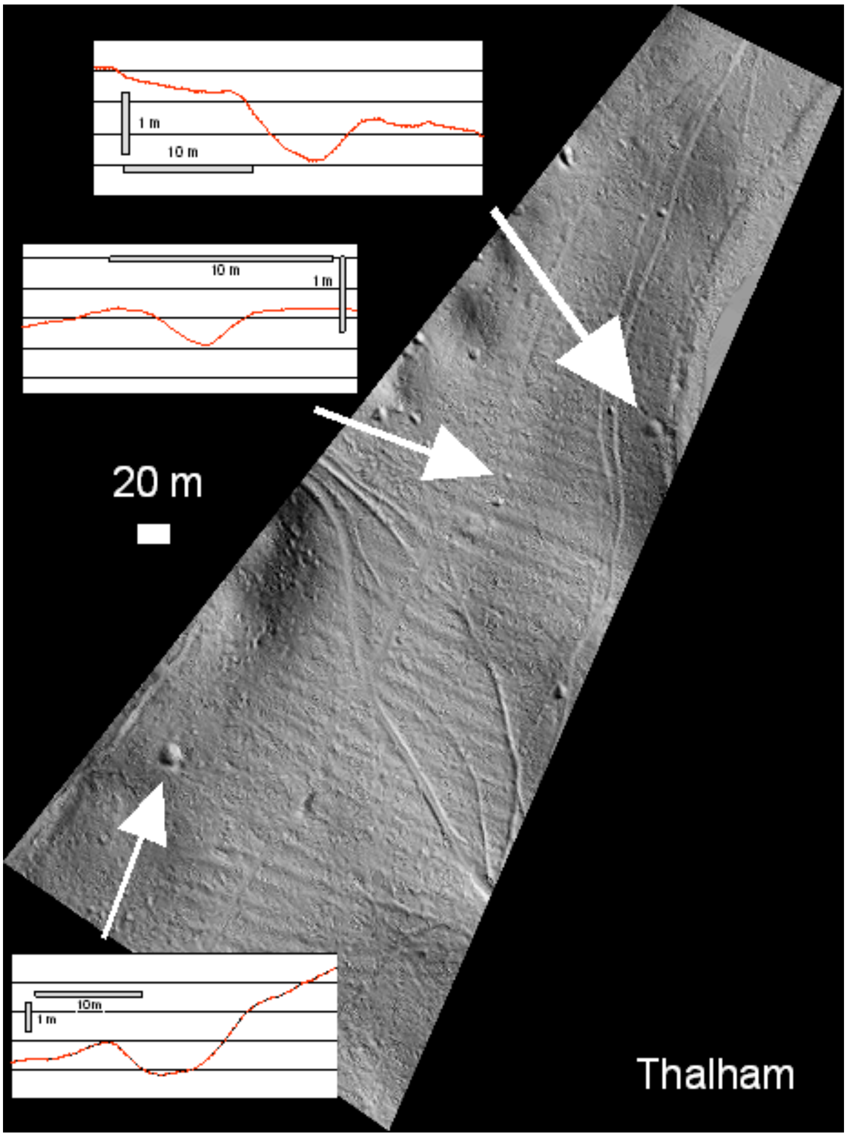


Fig. 7. A DTM shaded relief map of a forest area suggests a cluster of rimmed craters with diameters between a few meters and about 20 m probably belonging to the Chiemgau impact strewn field. For three selected craters diametrical cross sections have been plotted, which is in more detail discussed in paragraph 3.4.

3.2. Horizontal gradient

The computation of the horizontal gradient is a useful tool with data processing of the DTM. For every point in the elevation grid the maximum slope with regard to the neighboring points is determined as a figure (unit m/m), and all figures constitute a new map of the horizontal gradient, in other words a map of the terrain slope. Because structures are now shown in higher resolution, this procedure may be considered a kind of high-pass filter. In Fig. 8 the Einsiedeleiche crater is used again to emphasize the multiple possibilities of the DTM by presenting the horizontal gradient map. The smaller Einsiedeleiche 2 crater is interpreted as a probable impact companion that in the thick forest was unknown previously.

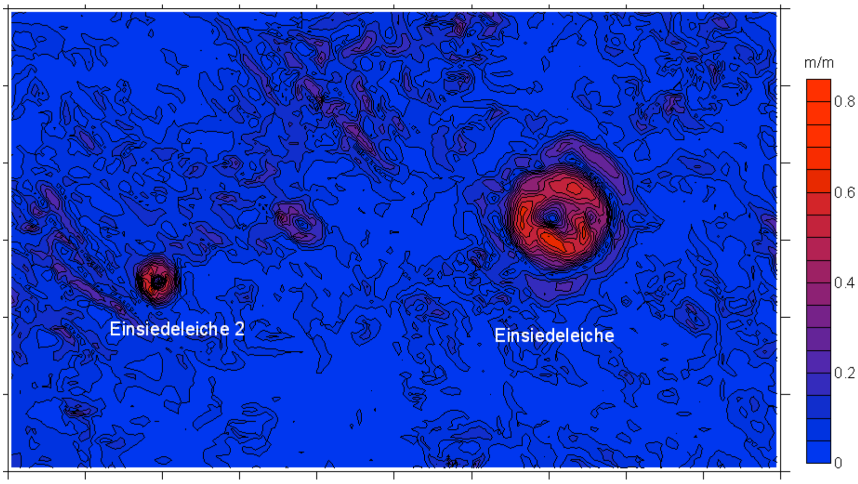


Fig. 8. Horizontal gradient of the elevation data accentuates a smaller companion crater of the Einsiedeleiche crater.

3.3 Data filtering

2D data filtering offers various possibilities to DTM processing starting from the concept that the terrain is composed of the superposition of various elevation wavelengths. Low-pass filters are enhancing topographic general trends while high-pass filters are accentuating smaller, local topographic features. Filtering does not produce new field data but may highlight particular terrain attributes for the eye.

Frequently, small-scale bumps may largely mask general terrain trends of interest, and a simple low-pass filter may easily clarify the matter. A procedure borrowed from geophysical potential fields (e.g., gravity and geomagnetic fields) can also be helpful with DTM data processing for separating local anomalies from a general trend in a field of contour lines. In gravimetry e.g., a regional trend field may be derived from the measured data by various procedures, and subtracting the regional field from the measured field will result in the local or residual field mostly being the main subject of interest.

The procedure may be copied for DTM data processing if one wants to separate local topographic features from a general trend in the terrain elevation. An example for crater evaluation in the Chiemgau strewn field is shown in Fig. 9. Top down we see the original topography for the Leonberg #012 crater situated in a mountain slope. A trend field for the terrain slope is computed from the original data by applying a strong low-pass moving-average filter. The resulting trend field in Fig. 9 then visualizes the smoothed mountain slope before - simply put - any event produced the distinct hole in the ground. Focusing on the residual topography after removal of the trend there is no way of overlooking that the change in the ground can be attributed to a roughly circular bowl-shaped structure surrounded by a likewise distinct rim wall. Here the data evaluation need not end, and a subsequent low-pass filter may yet beautify the crater topographic anomaly. At this point of having illuminated the DTM terrain imagery and its fundamental properties it is largely irrelevant whether the Leonberg crater was formed in the Chiemgau impact event. If it were however, a fragmented closely spaced triplet impactor must be taken into consideration.

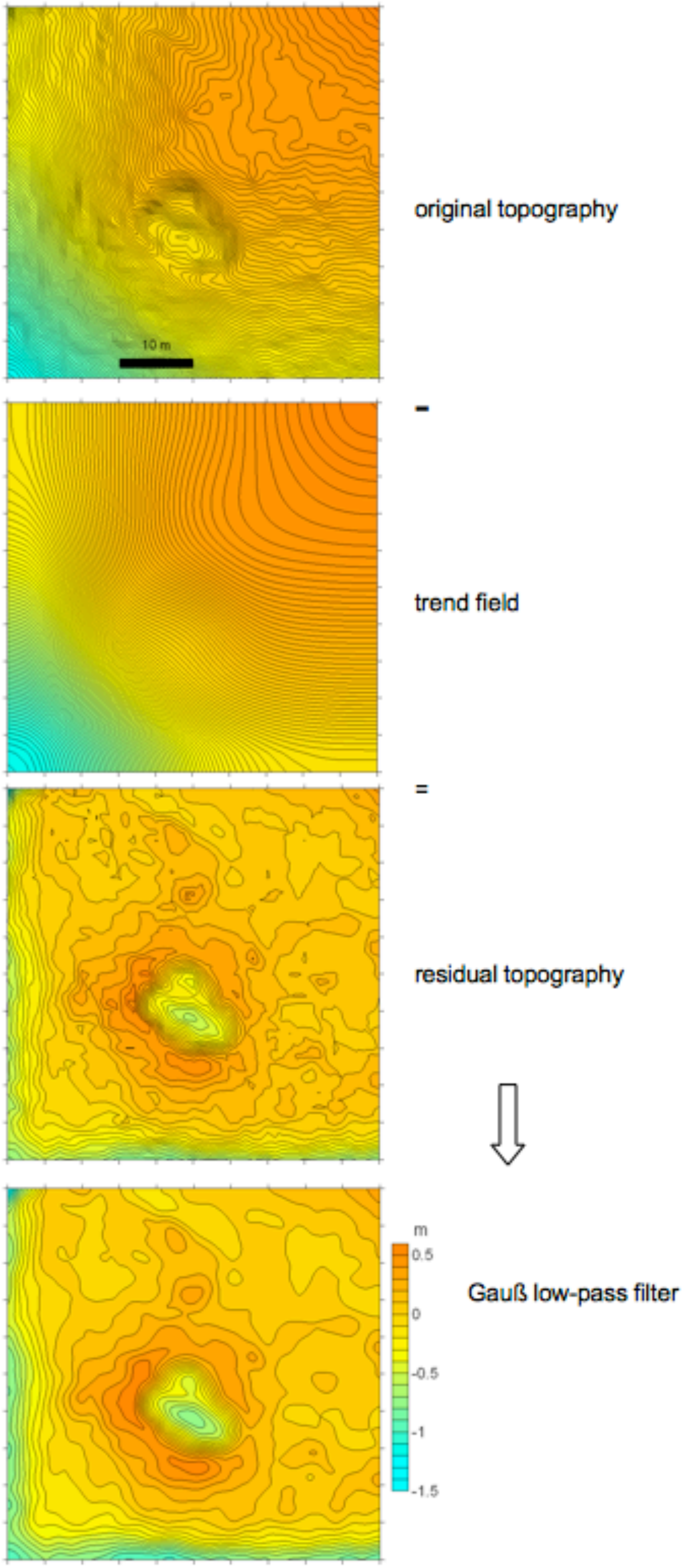


Fig. 9. Low-pass filters applied to the DTM of the Leonberg #012 crater. Explanation in the text. Contour interval is in all cases 0.1 m.

3.4 Cross sections

The high resolution of the DTM elevation data can usefully be applied to plot crater profiles providing not only very precise crater depths and diameters but also details of the geometry of the crater bowl, the in most cases existing distinct rim wall and the crater periphery. In Fig. 10A this is illustrated by typical cross sections for a few craters in the Chiemgau impact strewn field.

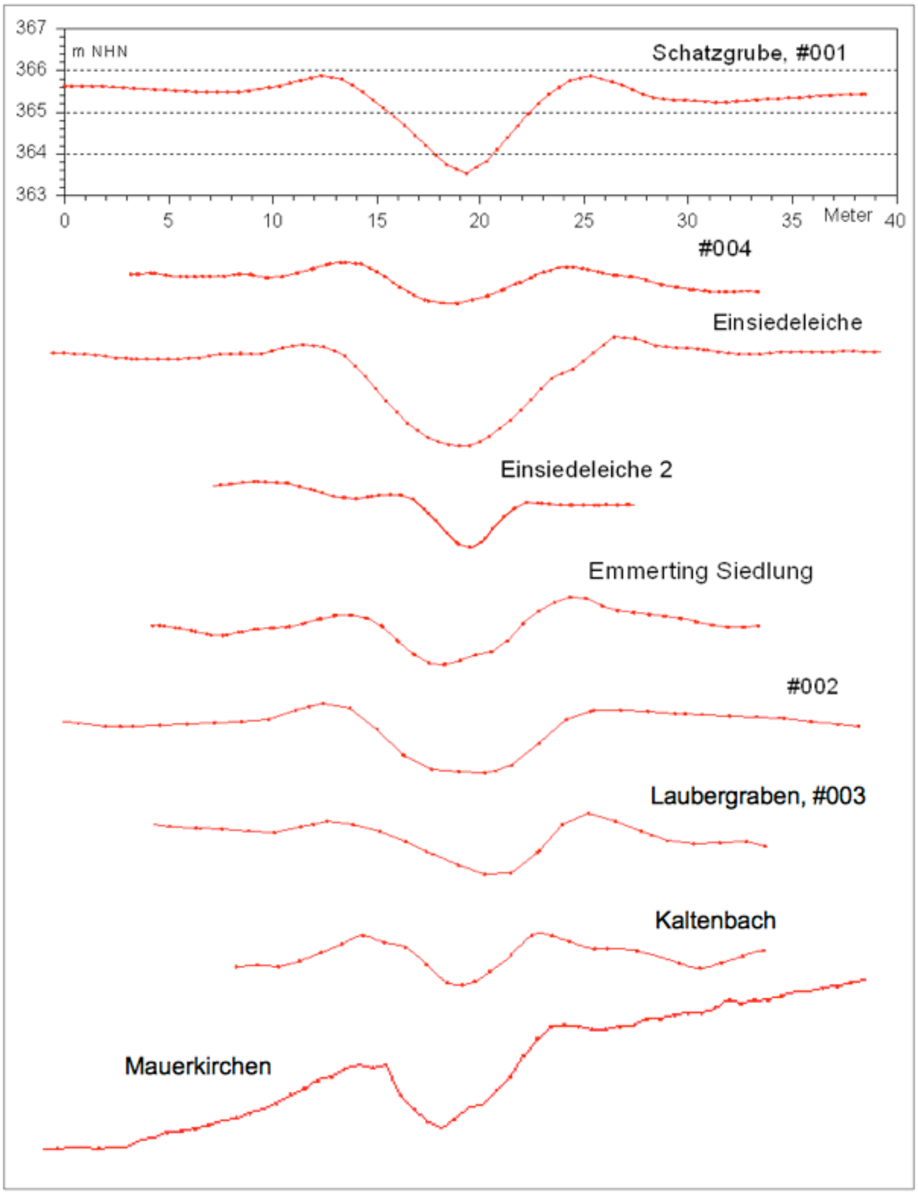


Fig. 10A. DTM diametrical cross sections for smaller craters in the Chiemgau meteorite impact strewn field. Except for the Einsiedeleiche 2 and Emmerting Siedlung craters the impact nature has been proven (shock metamorphism) or suggested (strong rock deformation, melt rocks, geophysical anomalies). For all cross sections the same scale applies.

As discussed for DTM contour maps (Fig. 8) horizontal gradients may be computed and plotted also for crater cross sections. This may be done either for profiles selected from the gradient contour maps or by mathematical differentiation of an already extracted elevation curve like those shown in Fig. 10A. The latter has been performed and is shown in Fig. 10B for one of the diametrical #001 crater cross sections. As emphasized for the gradient contour maps the profiles for the horizontal gradient distinguish by still higher resolution for particular crater shapes.

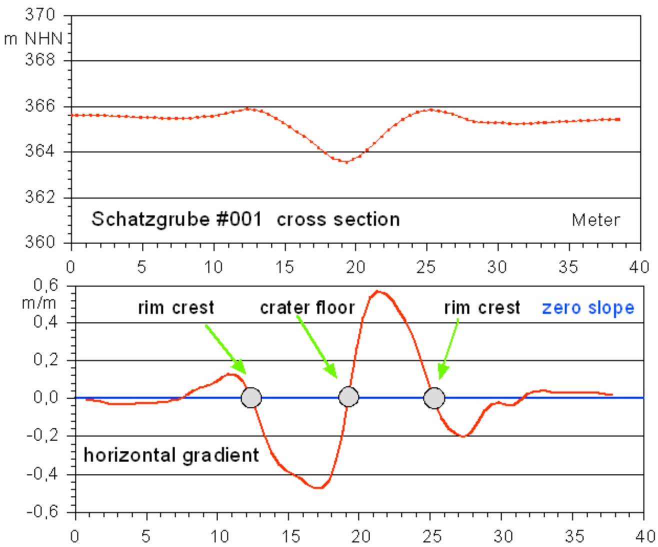


Fig. 10B. DTM crater profile and horizontal gradient curve. Inflection points and weaker amplitudes of the gradient curve point to details of the structure. Different from the gradient contour maps the line gradient dY/dX has positive and negative sign.

Undoubtedly, the today's crater topography and cross section reflect details of the formation process, which in particular holds true for very young structures. Likewise undoubtedly, there is not any morphological feature that enables the unambiguous diagnosis of the trigger mechanism. A bomb crater, a chemical explosion crater, a sand explosion crater from strong rock liquefaction (see e.g., Ernstson and Neumair 2011), or a meteorite impact crater, here of course in the foreground, may leave craters of the form shown in Fig. 10. The most intriguing potential of studying precise crater profiles is

a) to see close similarities suggesting common genesis,
b) to see differences suggesting common genesis under different constraints, and
c) to see basic differences suggesting that a certain formation process can be excluded.

Before respective examples will later be discussed for selected craters, a simple case a) is shown in Fig. 11. Diametrical cross sections for two craters roughly 2 km apart near the town of Emmerting have been stacked to reveal practically identical matching even in very detail, if a general small shift of only 50 cm is being neglected. Excluding a highly unlikely coincidence the same origin is obvious and at the same time a man-made construct irrelevant.

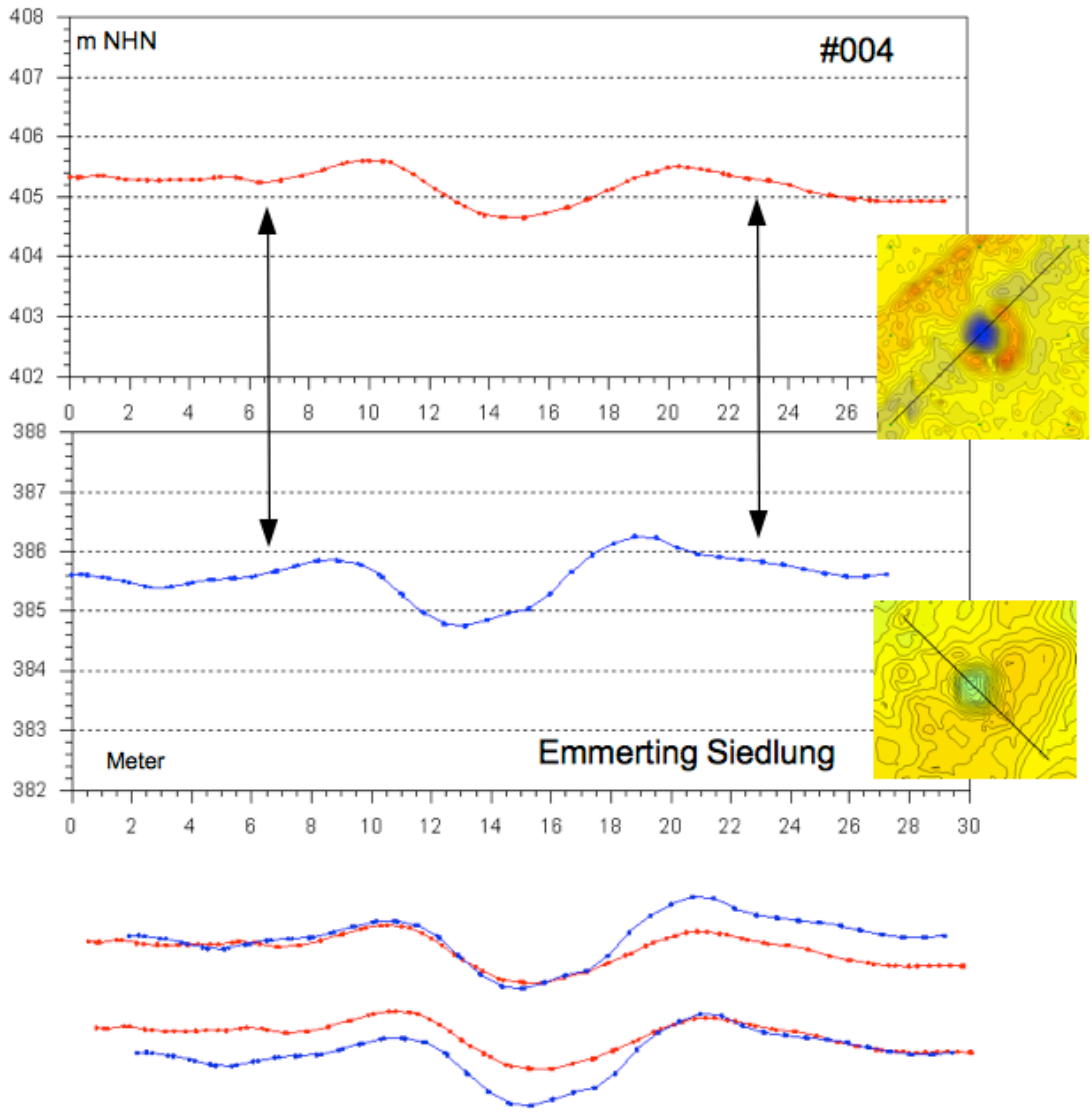


Fig. 11. Comparison of diametrical cross sections for the #004 and Emmerting Siedlung craters. Considering a slight shift of 0.5 m the crater profiles are practically congruent differing no more than 20 cm.

4 Examples

4.1 Small craters in the DTM

The Kaltenbach crater

The Kaltenbach crater located roughly 2 km north of the Lake Tüttensee so far most prominent crater in the strewn field (e.g., Ernstson et al 2010), is exemplary for a very small crater of only 8 m diameter that even overgrown in a forest area can clearly be identified by the DTM (Fig. 12, 13). It goes without saying that despite the nice rimmed crateriform shape the meteorite impact nature has to be verified in the field. In fact a geophysical survey (Fig. 13) showed typical magnetic anomalies already known from other small craters in the strewn field (Neumair and Ernstson 2011), and analyses of excavated rock samples proved a short-term, high-temperature overprint of the ground when the crater was formed, basically excluding an anthropogenic origin (Neumair and Ernstson 2011, Procházka and Kletetschka 2016).

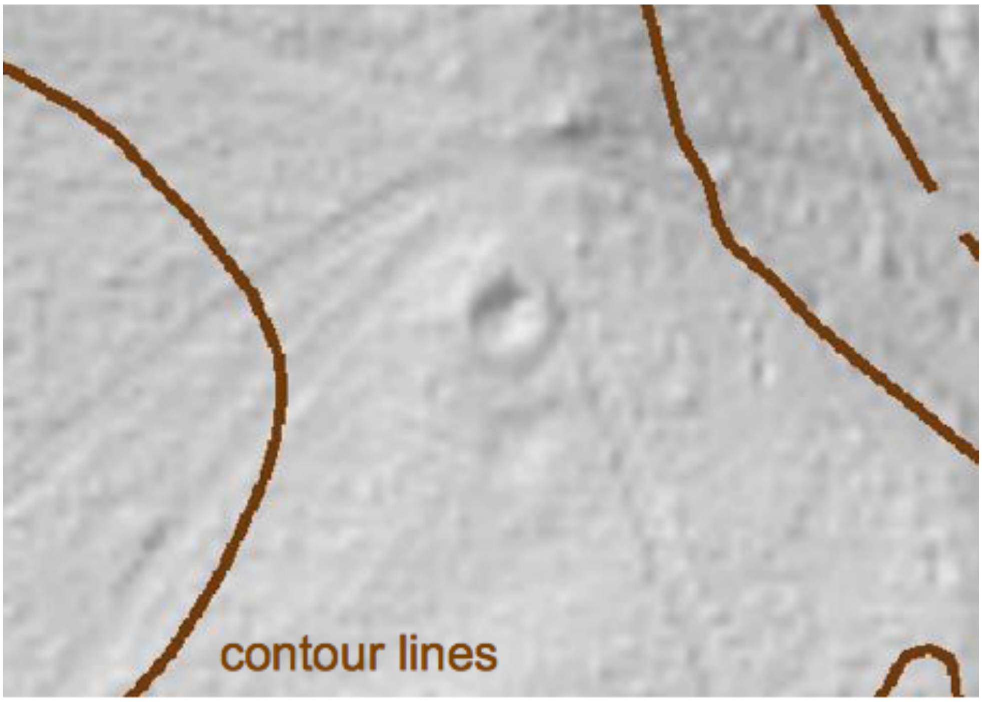


Fig. 12. DTM shaded relief of the 8 m-diameter Kaltenbach crater in a forest area (see Fig. 5). Crater diameter in all cases means rim crest diameter.

Fig. 13. The Kaltenbach crater in nature, overgrown by a tree and brushwood. Magnetometer survey.

The Schatzgrube (#001) crater

The somewhat larger Schatzgrube crater (also named #001 crater) in the northern part of the strewn field located also in a forest area is manifested by the DTM as a clear bowl-shaped depression with a distinct circular wall (Fig. 14, 15). Melt rocks and strong deformation of the target material and in particular diaplectic glass in a quartzite cobble as in proof of shock metamorphism (Ernstson 2012) give impact evidence.

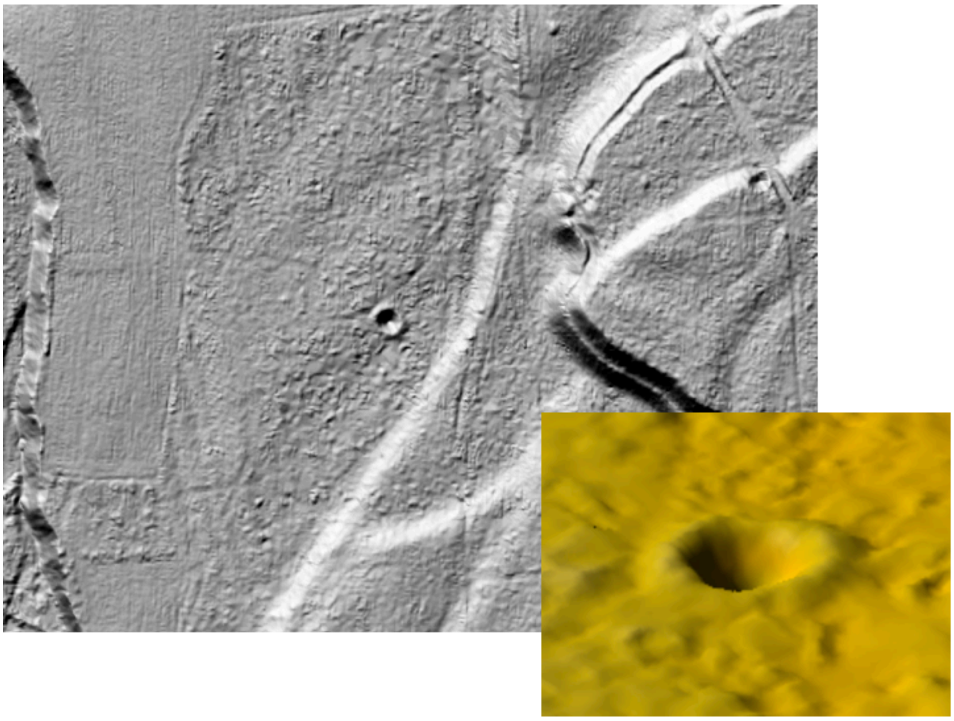


Fig. 14. DTM shaded relief and 3D surface of the 14 m-diameter Schatzgrube crater in a forest area.

The result of an earlier performed optical leveling on a diametrical profile provided an instructive comparison with the DTM data. As is shown in Fig. 15b the differences are minimal nowhere exceeding a few decimeters along the 40 m long profile, although the leveling yardstick had to be placed on the relatively soft forest floor.

Changing from the DTM two-dimensional topographic map in Fig. 15a to diametrical cross sections marked in that figure, a remarkable result is obtained for the crater structure ultimately due to the high DTM resolving power. In Fig. 15c the cross sections for the four profiles have been plotted from the DTM data, and by also plotting horizontally mirrored copies a stacking of in total eight radial cross sections could be performed. From Fig. 15c the amazingly nearly congruent shape along all eight radial profiles is evident. In the crater interior and along most part of the rim wall the height differences don't exceed 20 - 30 centimeters, and only outside the rim wall they reach a few decimeters more. Perhaps more impressively the horizontal gradient curves in Fig. 15 d show that even minor topographic features can be traced around the inner crater wall.

It is concluded that this 3D exact circularity with a diameter of nearly 20 m could have formed only by a more or less punctuate impact or/and explosion event. Particularly and reasonably it considers every man-made activities practically impossible.

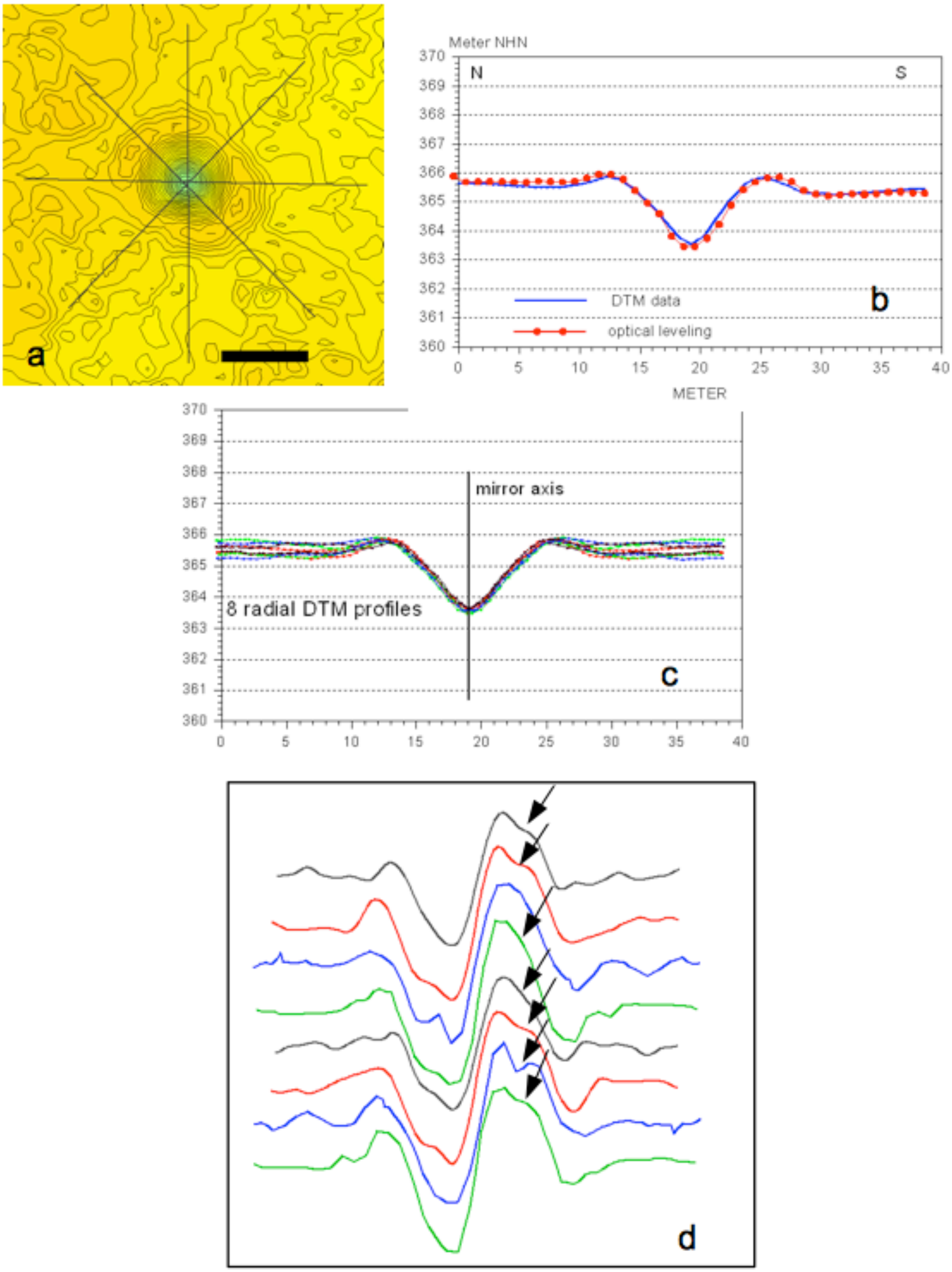


Fig. 15. The Schatzgrube crater. a: DTM, contour interval 0.2 m. b: DTM cross section along a north - south profile compared with ground optical leveling with 1 m spacing. c: DTM cross sections for four diametrical profiles (see a) which have additionally been mirrored to show the stacking of eight radial cross sections. d: Horizontal gradient profiles for the cross sections in c (compare Fig. 10B). Please note that even minor elevation features along the eight radial profiles can be traced around the crater (arrows).

The crater is of particular importance because of its nearly identical size and shape when compared with the recently (2007) formed Carancas meteorite crater in Peru (e.g., Tancredi et al. 2009, Kenkmann et al. 2008, 2009) (Fig. 16). The Carancas crater featured something totally unexpected because according to the till then established "laws of impact" such a crater created by a hypervelocity impact of an estimated 0.5-1 m stony meteorite seemed completely impossible (as claimed by e.g., Reimold 2006, 2007). And consequently Schultz et al. (2008) in their LPSC abstract article on the Carancas impact are beginning their text with the nice statement: "The Carancas impact crater (just before noon on September 15, 2007) should not have happened." We need not especially emphasize that this statement concerns the arguments earlier formulated with unshakeable conviction that the Chiemgau impact with lots of small craters (among them the Schatzgrube crater) cannot exist (e.g., Reimold 2006, 2007, Wünnemann et al. 2007).

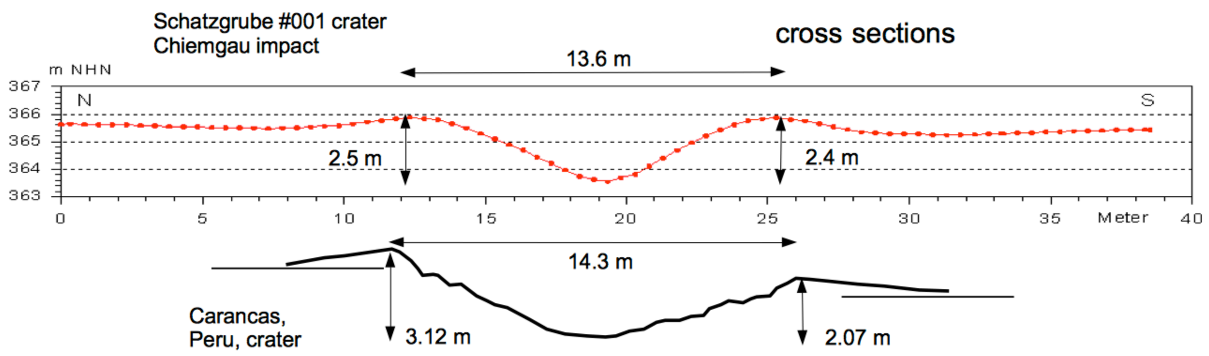


Fig. 16. Cross section of the Schatzgrube crater in comparison with the nearly identical cross section of the Carancas meteorite crater. Carancas section and data redrawn from Kenkmann et al. 2009).

4.2 Peripheral depressions around small craters

The enormous resolution of the DTM points to a possibly impact-specific peculiarity. As is marked in Fig. 17, the in each case clearly visible rim wall for four smaller craters is surrounded by a roughly concentric ring depression a few decimeters deep only, giving the structures a total size of more than 30 m. Similar ring-like depressions are found also for several other small craters, but because of general rough terrain conditions they often lack the exemplary geometry seen in Fig. 17.

In the meteorite impact terminology one would speak of a peak-ring crater as a typical exponent of large complex impact structures, and the formation is largely understood to be the result of transient crater collapse and elastic rebound (e.g., Melosh 1989). This cratering process is of course a long way from being a model for the small craters under discussion here although at least the #004 and Schatzgrube #001 structures because of strong shock metamorphism are established meteorite craters. Although for the time being a reasonable explanation is lacking, the mere existence of this peculiar crater structure highlights once more the enormous potential of the DTM terrain evaluation.

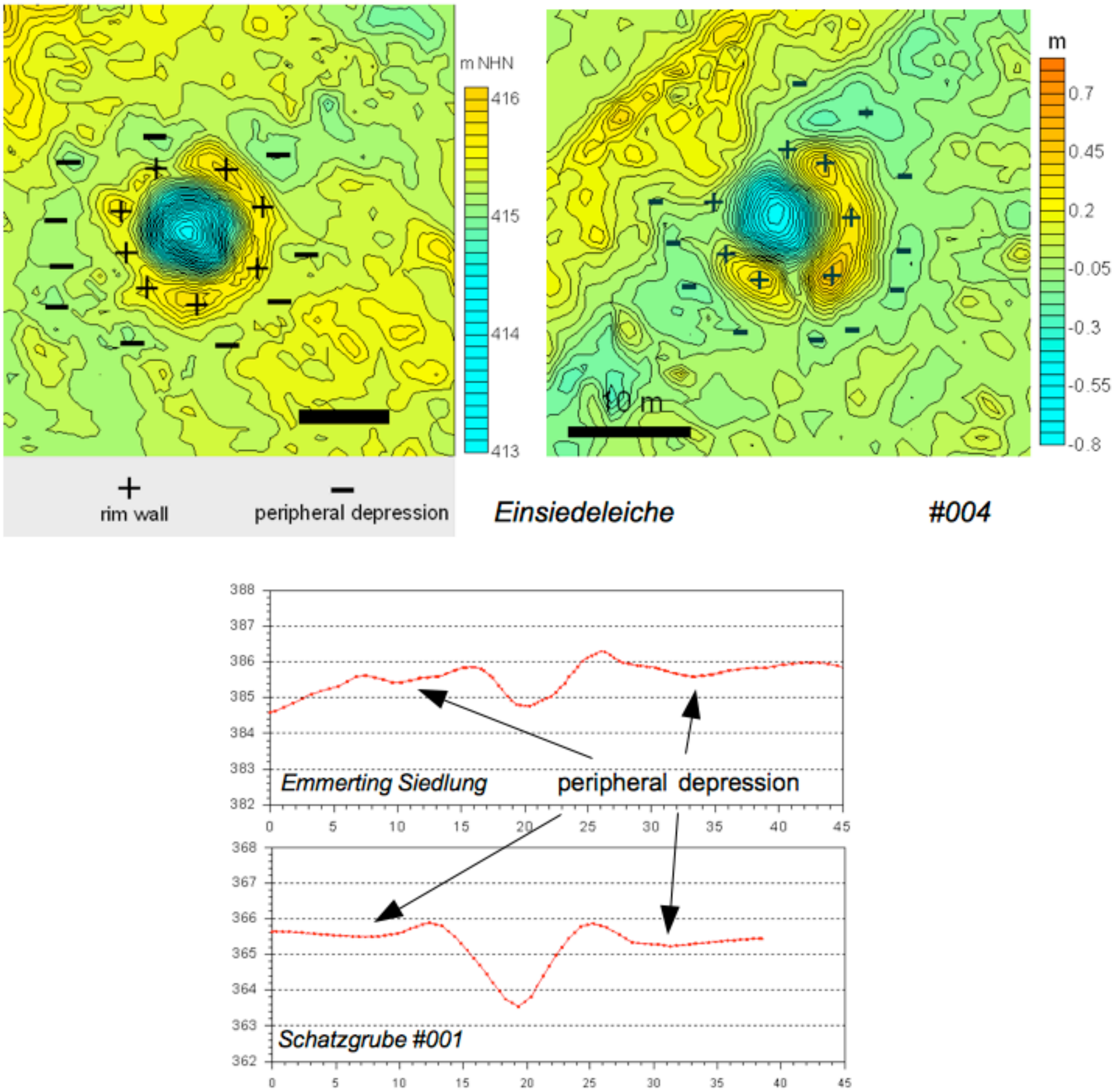


Fig. 17. Peripheral depressions around small crater seen in contour maps and on diametrical cross sections.

4.3 Medium-sized craters in the DTM

The Purkering crater

The Purkering 75 m-diameter crater (photo in Fig. 19) is a paragon and owes its first impact recognition when T. Marx (pers. comm.) saw the structure rather accidentally during his studies of the freely in the web available DTM shaded relief map (Fig. 18, left) in the east of the town of Trostberg. Later a complete digital data set (DGM 1) was acquired for a more detailed data processing (Figs. 17, to the right; 20, 21 and 22).

Meanwhile, the impact nature is substantiated not only by the circular wall hardly compatible with another origin but also by geophysical measurements (ground penetrating radar GPR, geomagnetics) only recently performed, and by a curtain of ejected gravelly material (Fig. 22).

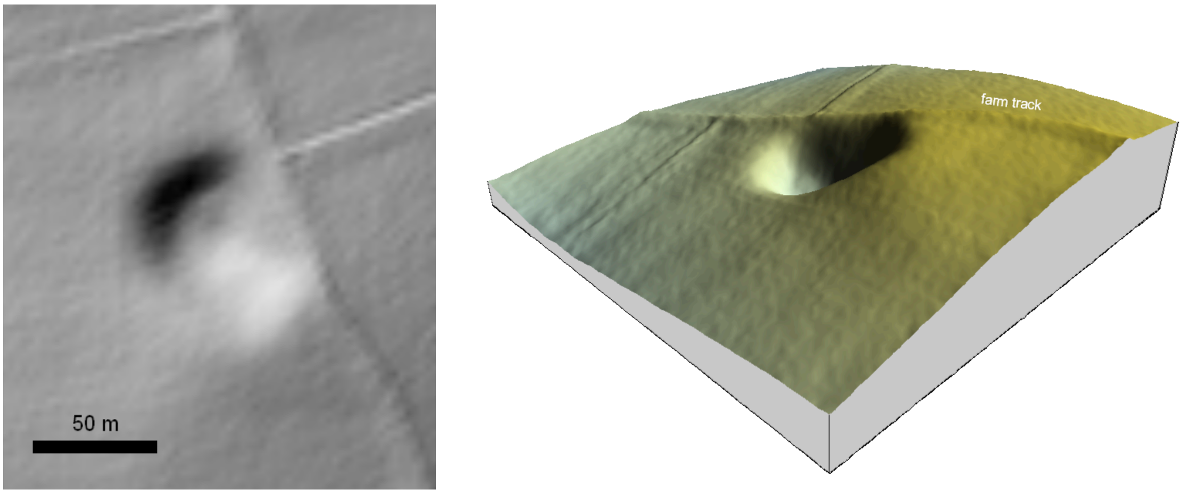


Fig. 18. DTM: shaded relief (to the left) and 3D surface of the 75 m-diameter Purkering crater.

Fig. 19. In the field: the 75 m-diameter Purkering crater with a slight rampart. The Alpine foothills in the background.

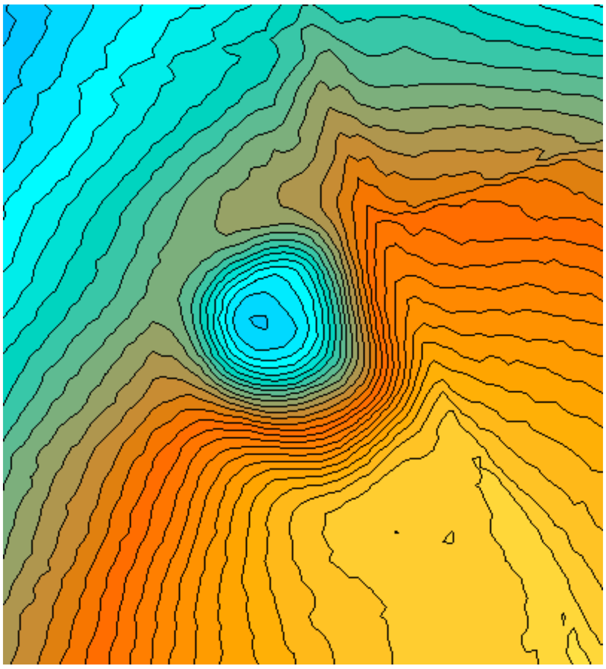


Fig. 20. DTM contour map of the Purkering crater. Contour interval 20 cm.

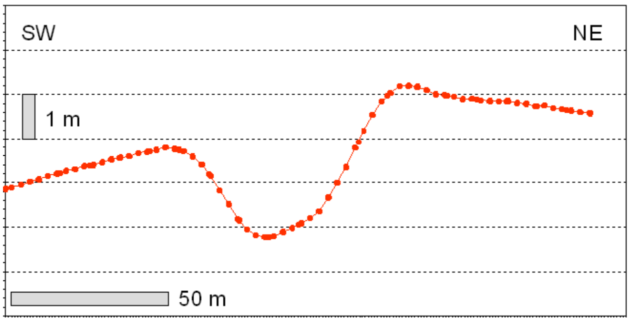


Fig. 21. Cross section of the Purkering crater from DTM data.

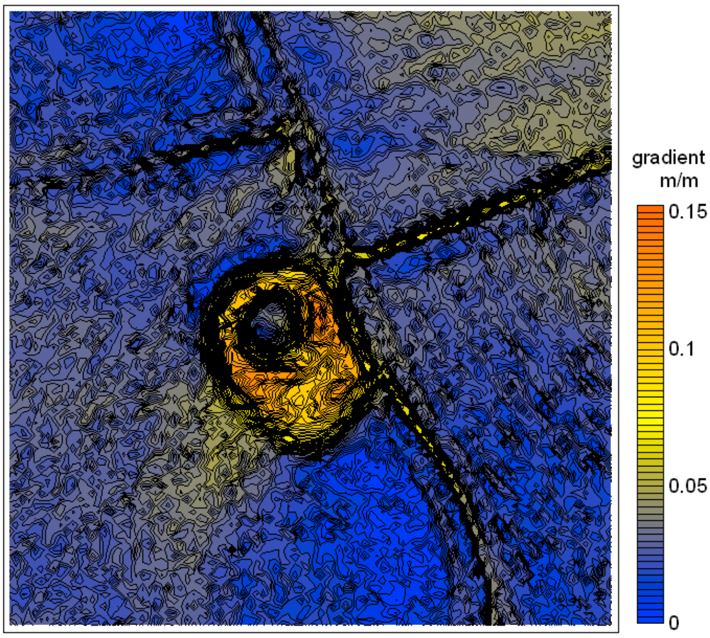


Fig. 22. Purkering crater: Horizontal gradient map from DTM data indicating a smaller companion structure at the southeastern rim.

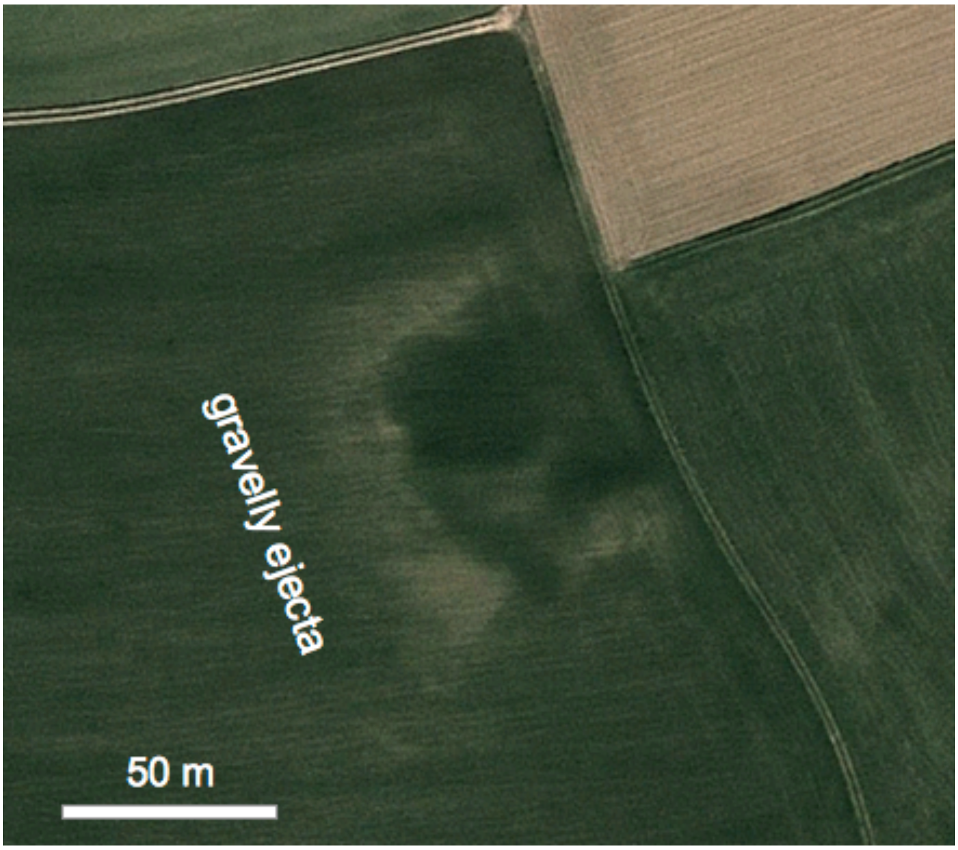


Fig. 23. The Purkering crater and its curtain of impact-ejected gravelly material. Google Earth 2011.

The enormous possibilities of the DTM data processing become evident when the map of the computed horizontal gradient for the Purkering crater is taken as an example (Fig. 22). More than all others DTM images the gradient on the one hand outlines the absolute circularity of the main depression and, on the other hand, points to an additional morphological anomaly at the southeastern rim that may have resulted from the synchronous impact of a smaller separate companion projectile. This impressively fits the distinctly asymmetric distribution of the ejected gravelly material (Fig. 23).

The Hochfelln crater

So far, the Hochfelln crater (Fig. 24 - 26) has been recognized by non-geologists' hiking tours only and needs verification by geologic and geophysical field work. It is the first established probable meteorite crater with a characteristic rim wall in the Alpine foothills (see Fig. 10), after a Chiemgau impact overprint of the mountainous region had long before been predicted. This is based on an in part very peculiar landscape, unusually widely scattered fractured rocks and the occurrence of microtektites in the upper soil layers chemically reflecting the local rocks (Ruhpolding Fm.) (Ernstson et al. 2014).

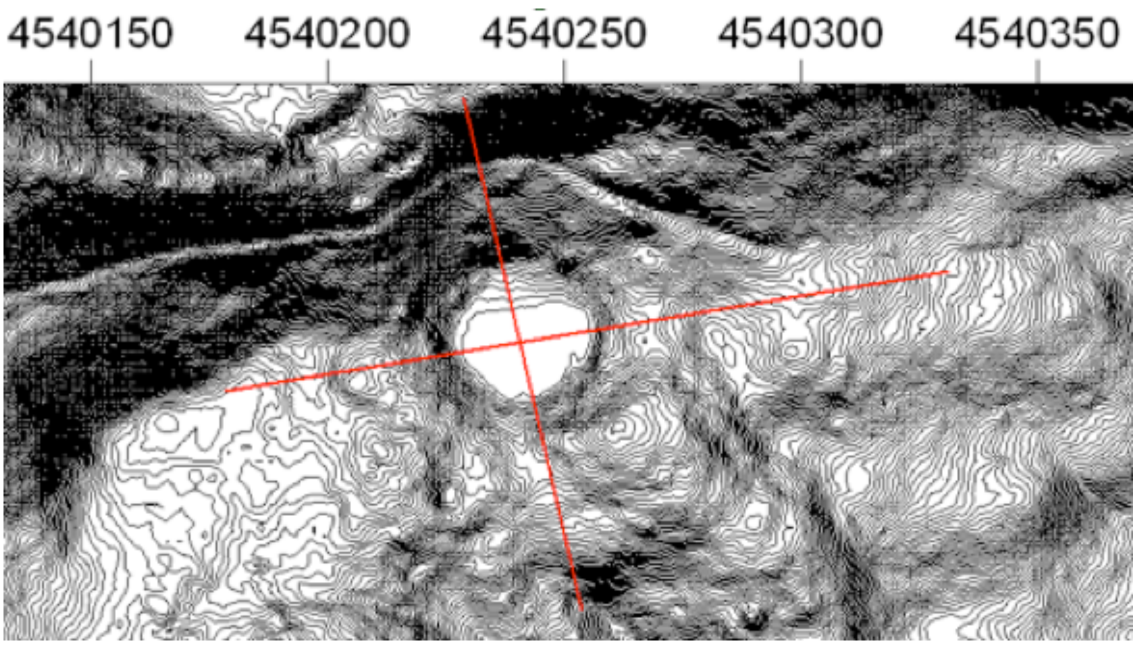


Fig. 24. The Hochfelln 55 m-diameter crater. DTM contour map; counter interval 0.2 m. Red: cross section profiles in Fig. 25.

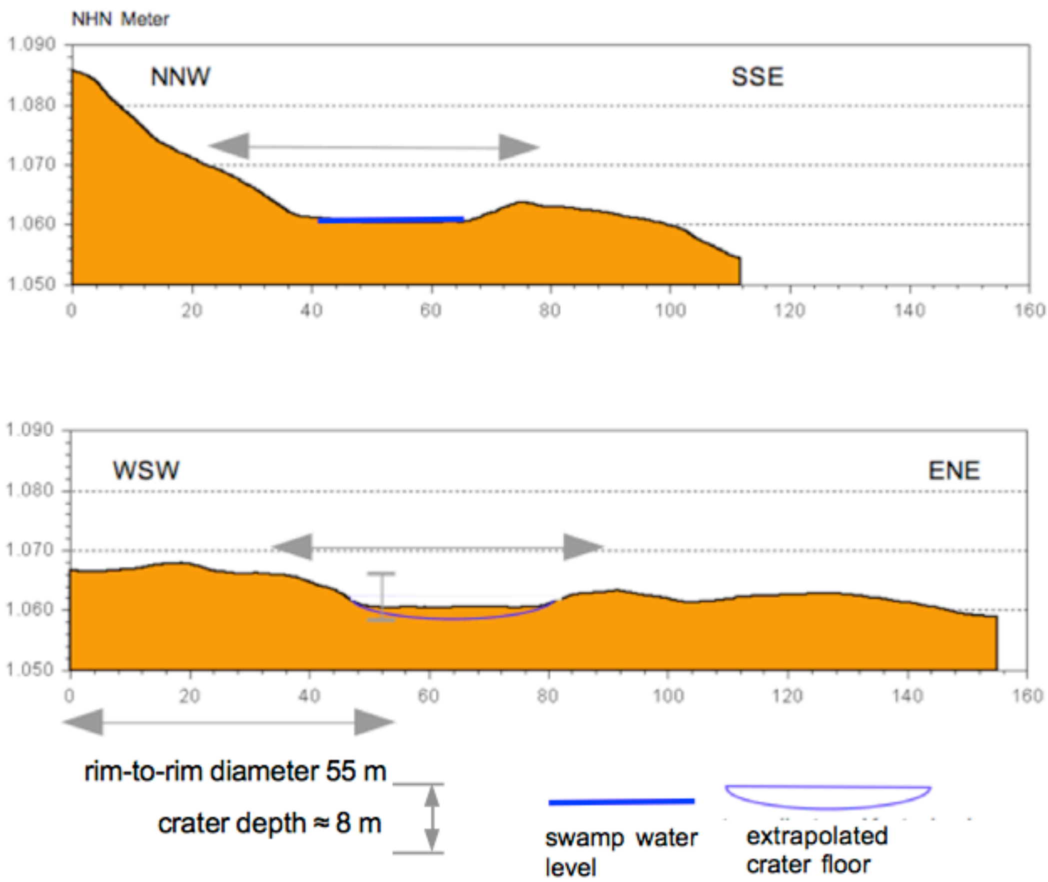


Fig. 25. Cross sections of the Hochfelln crater from DTM data. Profiles in Fig. 24.

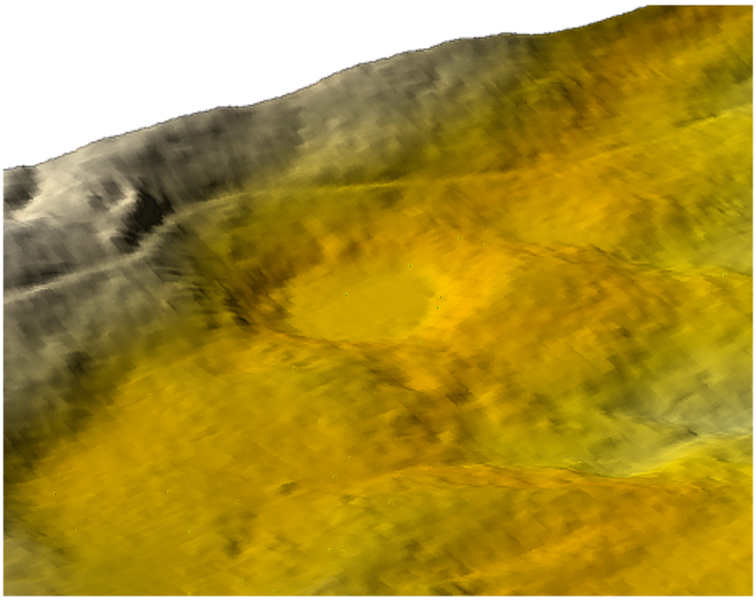


Fig. 26. DTM 3D surface of the Hochfelln crater revealing a distinct crater wall obviously merging into a curtain of flow structures downhill, which in the case of an impact crater may be attributed to ejecta.

As mentioned before, the crater needs verification by geologic field work, which will have to focus also on the peculiar morphological signature crater downhill (Fig. 26), which in highest DTM 3D surface resolution may trace excavated and ejected target rock material.

Likewise eye-catching in the DTM 3D surface map of the crater environment (Fig. 27), one big landslide and a few smaller suspected ones may be considered a possible result of nearby impact cratering and related seismic shattering in the Chiemgau impact event.

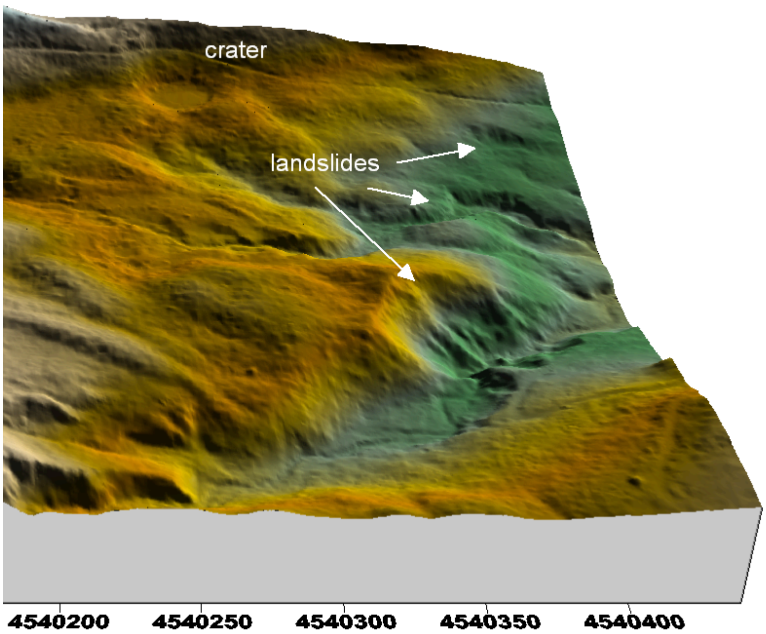


Fig. 27 Landslides possibly impact-induced in the Chiemgau event. DTM 3D surface.

The doublet (? triplet) Punzenpoint crater

One more impressive example for the efficiency of the DTM data processing is given by the Punzenpoint structure (Fig. 28), which has only recently been discovered some kilometers to the northwest of the town of Obing and still lacks a geologic-geophysical verification. In the official topographic map, 1 : 25,000 scale (Fig. 29), one cannot even guess the existence of such a special feature. There are strong points for an impact crater given by the distinct circularity of both the depression and the obvious wall belonging to it, which excludes any sinkhole formation, also by virtue of its size alone. The distinct bulge in the southeastern rim wall is without doubt related with the neighboring 50 m-diameter rimmed depression, and a synchronous formation of both structures to feature a possible impact doublet crater seems obvious. Moreover, a third depression may possibly contribute to a triplet crater with overlapping rim wall crests (Fig. 28).

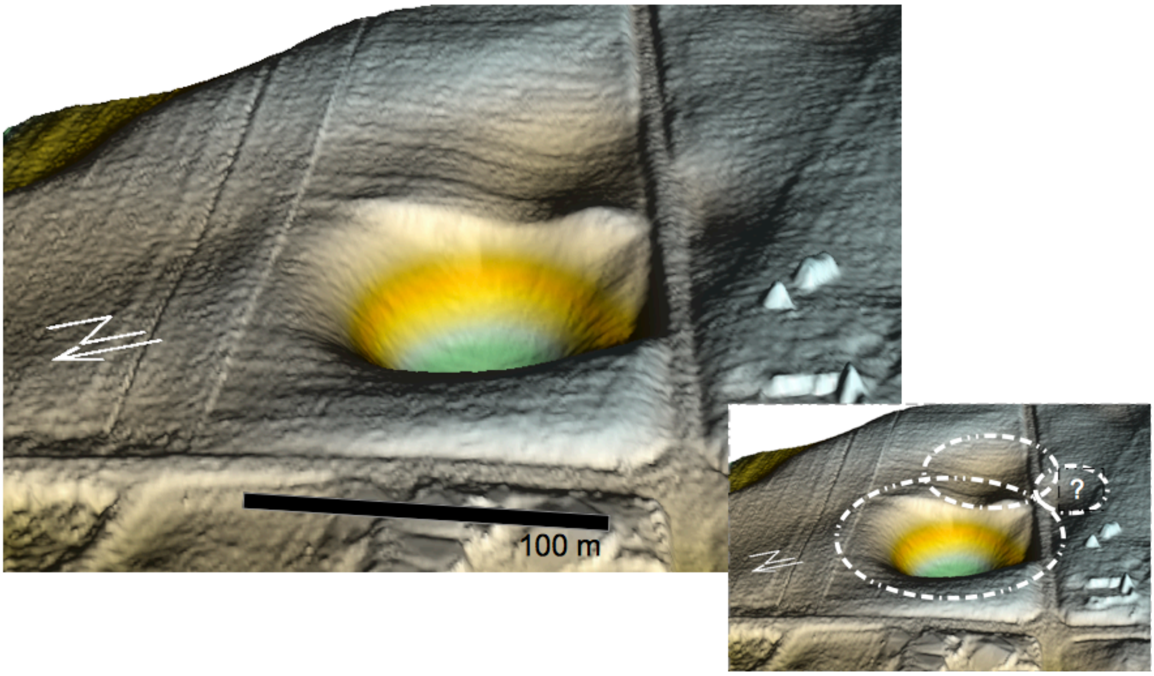


Fig. 28. DTM 3D surface of the 120 m-diameter Punzenpoint main crater, an about 50 m-diameter companion crater and a possible third 20 m-diameter crater. The dotted lines are delineating the particular rim crests.

Fig. 29. The Location of the Punzenpoint crater on the official topographic map 1 : 25,000. Source TOP10.

The Aiching semi crater

The Aiching crater near the town of Marktl, marked number #024 in the original list of the discoverers, is not easily recognized in the field (Fig. 30) and not at all on the official topographic map. The early discoverers became aware of it by making a photo from a plane in wintertime when the trees were free of leaves. The meteorite impact nature of this semi crater was substantiated by abundant finds of the strange iron silicide matter (Ernstson et al. 2010) in the field adjacent to the semi crater.

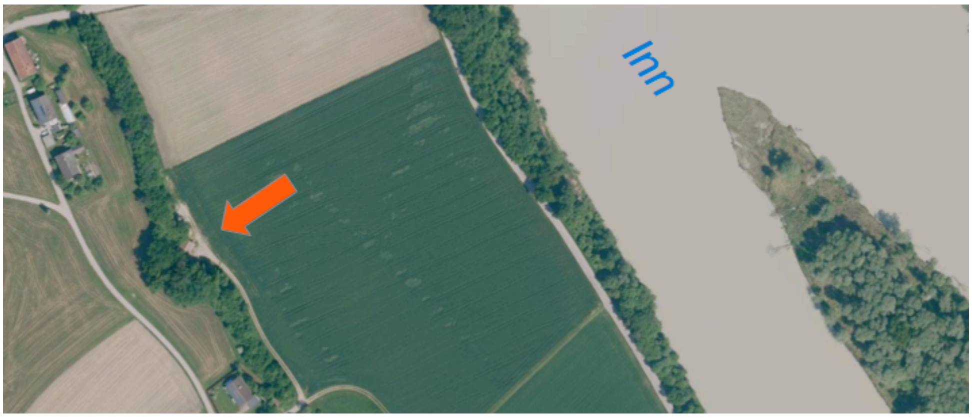


Fig. 30. The Aiching semi crater (arrow) located in the steep bank of the Inn River near the town of Marktl. Dense tree growth and a big stable right in the middle of the crater are largely masking its impressive shape that becomes evident in the DTM data (Fig. 31 -34).

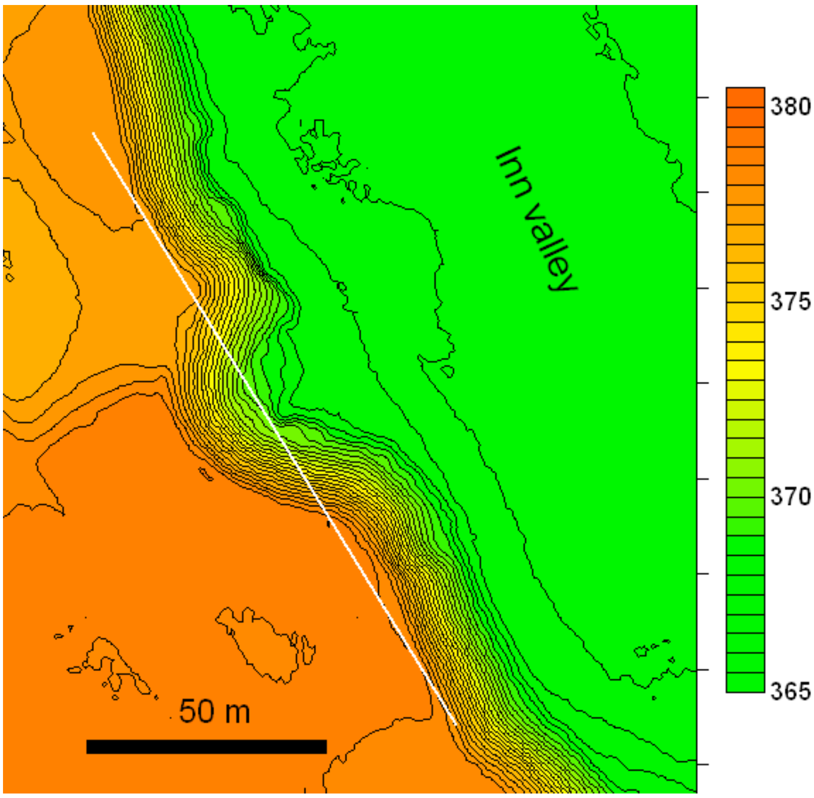


Fig. 31. Aiching semi crater in the DTM; 1 m grid and 0.5 m contour interval. The crater was punched in the steep valley border and today is conserved at half only because of the destruction by the nearby Inn River erosion. The white line traces the cross section of the crater in Fig. 32.

Today, with the aid of the high resolution of the pure DTM digital topographic data (Fig. 31, 33) details of this remarkable crater have become evident. For the first time, precise depth and diameter data were attained, and a (semi) circular rim wall of no more than 1 m height (Fig. 32, 34) could be established. In the very beginning a seemingly lacking rim wall had been attributed to a radical leveling by the farmers.

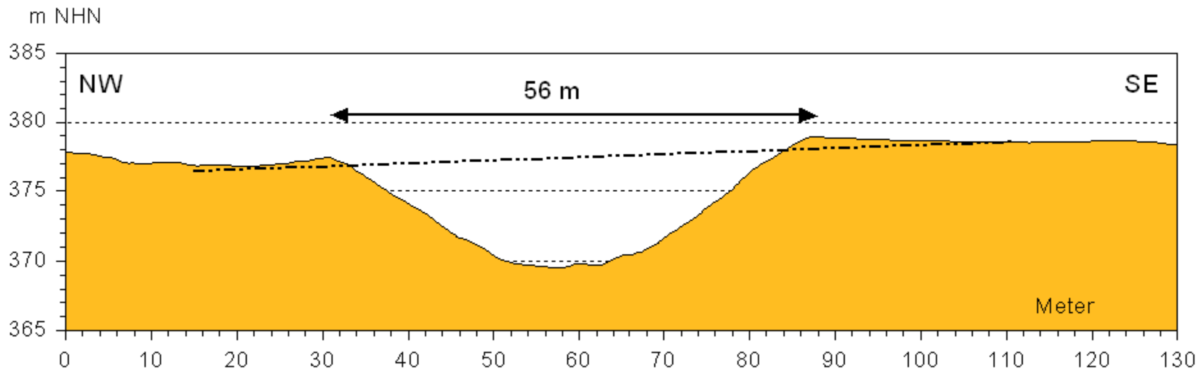


Fig. 32. Cross section of the semi crater along the white line in Fig. 22. From the eccentric course of profile the rim crest distance brings about a crater diameter of at least 56 m and a depth of more than 7 m.

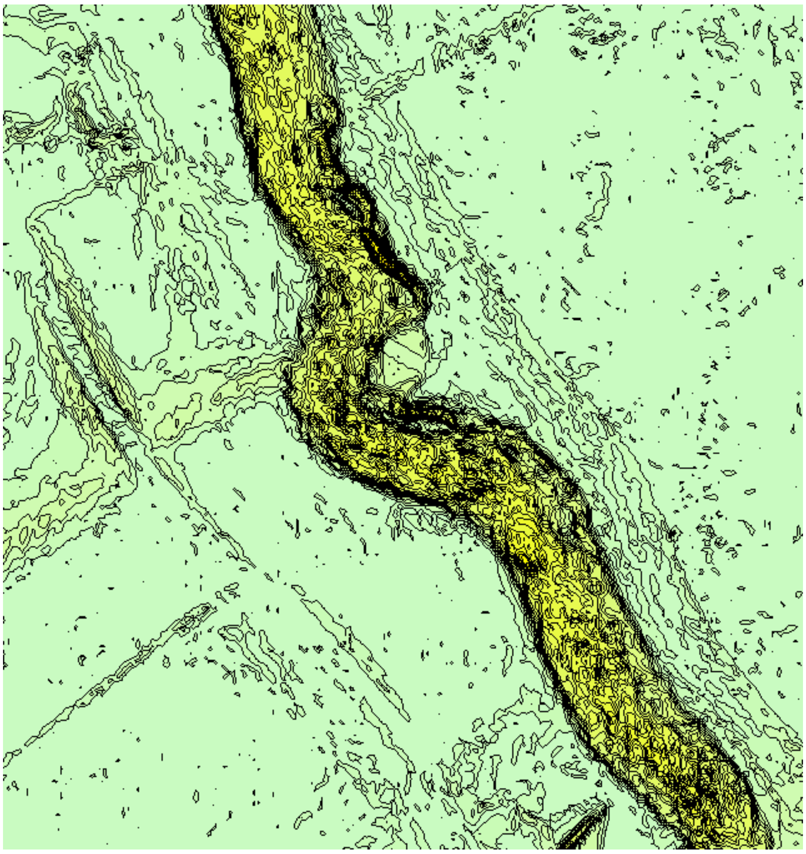


Fig. 33. The map of the horizontal gradient computed from the DTM data in particular highlights the crater to be a foreign body in the Inn River landscape.

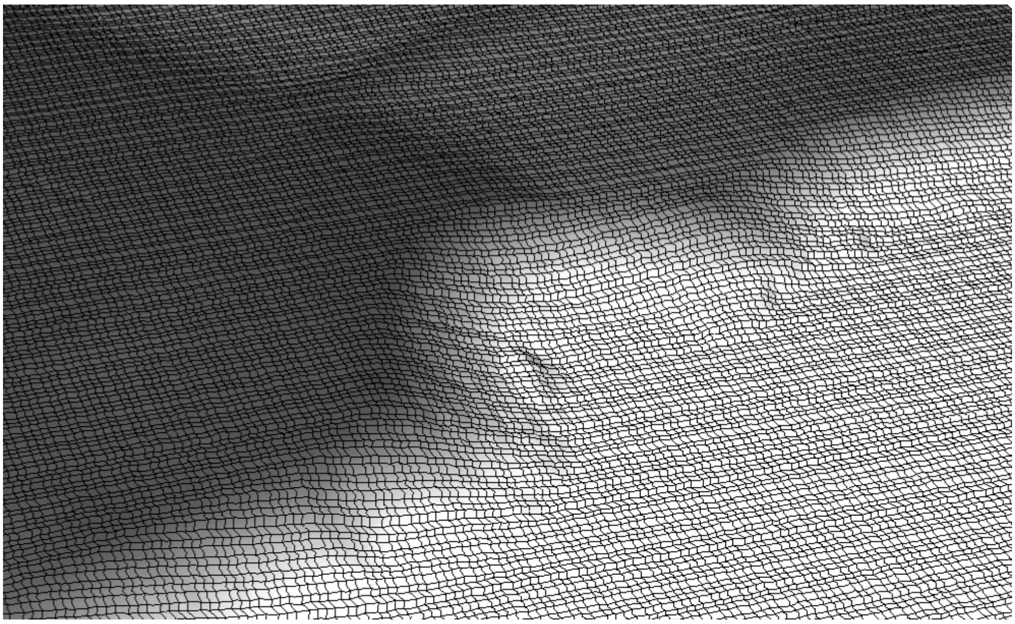


Fig. 34. The Aiching semi crater in a DTM 3D meshed surface image. It accentuates a rimmed crater as a discrete, originally circular object that stands out against the scarp of the riverbank.

4.4 Mistaken structures

So far, the DTM data processing has been used to evaluate known craters in the Chiemgau strewn field and to look for promising new structures. On the other hand, the potential of the DTM should not be underestimated to bring doubtful candidates into question or to even eliminate them. An interesting example is shown in Fig. 35 focusing on two distinctly circular structures of some 30 - 50 m diameter that about 15 years ago in the early phase of the Chiemgau impact research were discovered in satellite imagery and considered probable impact points, and they got the numbers #52 and #53 in the original crater list.

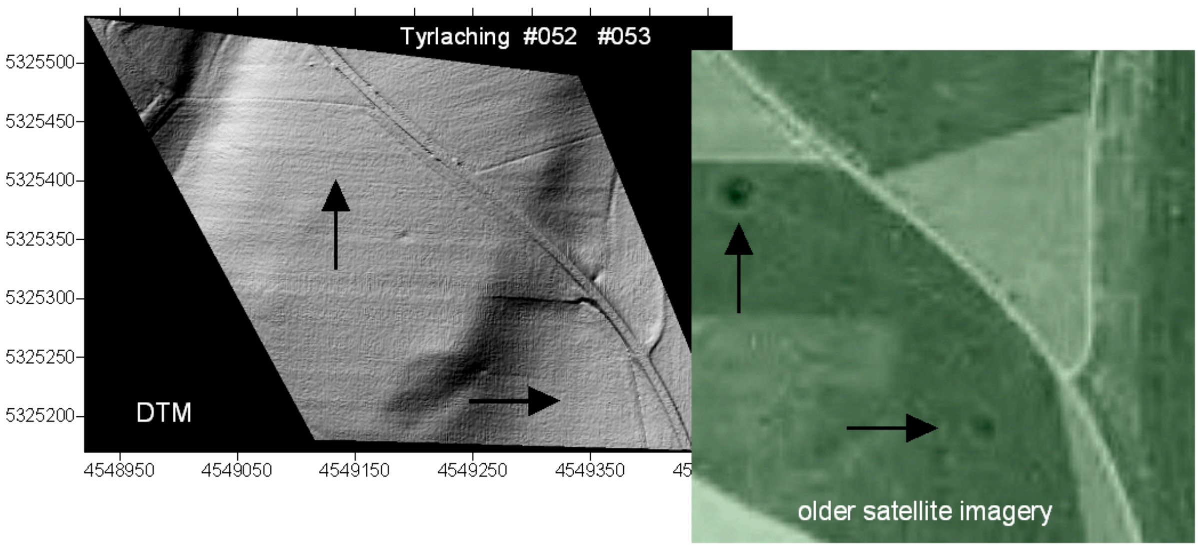


Fig. 35. Suspected craters from satellite imagery (to the right) lack any indication on the ground (DTM shaded relief, to the left).

Today, with the aid of the high-resolution DTM (Fig. 35, to the left), both suspected sites amazingly are completely unidentifiable in the shaded relief map. Hence, Nos. #52 and #53 lack any indication on the ground, and the original circular ground features remain enigmatic.

The case shown in Fig. 36 is different. Near the Lake Tüttensee crater a group of three or four bowl-shaped depressions in the ground have been considered possible candidates for the Chiemgau meteorite crater strewn field, and different from Fig. 35 the holes are reality. Selected DTM sections, in each case forming a cross over the depressions, don't however speak in favor of such an origin. This corresponds with the result of a geomagnetic survey revealing not any noteworthy anomalies otherwise regularly found with the typical proven or suspected impact craters. The origin of the holes is obscure, but because of their location very near to the 600 m-diameter Tüttensee crater a formation in the course of strong impact rock liquefaction leading to local sand explosions (see Ernstson et al. 2011) could be a reasonable explanation.

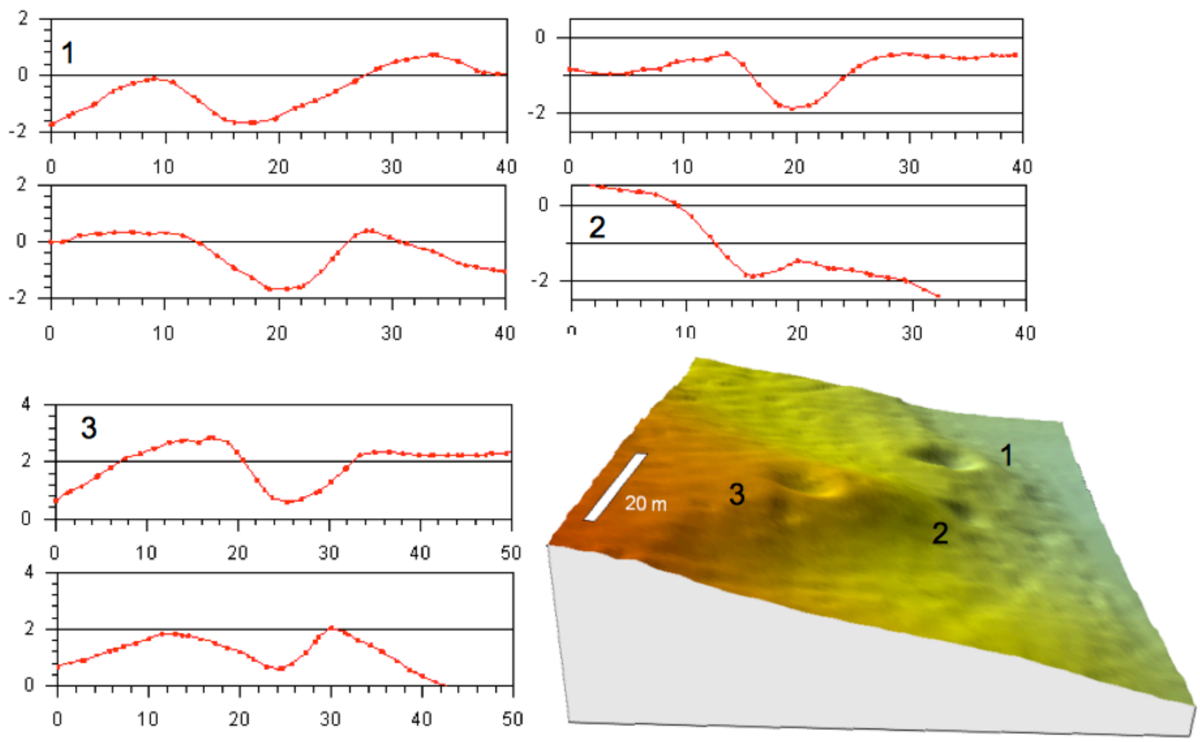


Fig. 36. DTM 3D surface map and cross sections of three roundish depressions near the Lake Tüttensee crater: Probably no impact craters but possibly rock liquefaction sand explosion blowouts.

5 A possible large-sized crater in the DTM

The Eglsee structure

It is said that some astronomers after having visited the Chiemgau impact crater strewn field pointed to a suspicious near-circular structure with a diameter of about 1 km located not far from Lake Chiemsee, which they had studied from satellite imagery. The in fact casual hint to a possible further crater in the strewn field swiftly fell into oblivion until the DTM high-resolution maps and data processing enabled a closer view and study of that structure. First fieldwork revealed abundant finds of deformed rocks well known from e.g., the Tüttensee meteorite crater. Also the extremely steep flanks of the impressive rim wall encircling a peculiar large circular depression attracted our attention and caused serious problems to relate them to a glacial moraine deposition more than 10,000 years ago. In fact this Eglsee structure so far had simply been incorporated in the ridge of terminal moraines around Lake Chiemsee attributed to the Inn-Chiemsee glacier (Darga 2009, Doppler et al. 2011) without giving it further particular consideration.

From the high-resolution DTM contour map in Fig. 37 a terminal-moraine origin for the Eglsee structure would make no sense with regard to the three-quarter nearly perfect rim circle and the contouring of the rim wall with a few sharp offsets. Hence, the original idea of the astronomers about a meteorite impact structure revived the discussion and initiated geophysical gravimetry and ground penetration radar (GPR) surveys currently under data evaluation.

Tentatively, the idea of a meteorite crater is also illuminated by contrasting it with the famous, nearly equally sized Barringer (or Meteor) crater in Arizona (Fig. 38, 39). In particular the amazingly similar cross section of both rim walls is striking (Fig. 39), although the markedly different depth has to be considered. The latter may possibly the result of the basically different target rocks, which are solid rock in the case of the Barringer crater and unconsolidated soft rock in the case of the Eglsee structure.

Meanwhile a competing formation of the Eglsee structure has been considered possible with regard to impressive tsunami deposits (Ernstson 2016) that have been shown to be related with the earlier established impact and impact doublet crater at the bottom of Lake Chiemsee only 2.5 km apart (Ernstson et al. 2010). This powerful tsunami could possibly have piled up the Eglsee structure rim wall, but at the same time it does not exclude a meteorite crater that immediately was formed before the tsunami that carried huge masses of rock material arrived. Such a coupled event may perhaps explain both the rim wall gap in the direction of Lake Chiemsee (see Fig. 37) and the less deep Eglsee crater compared with the Barringer crater. In particular the results of the geophysical measurements are expected to clarify the true formation of this peculiar topographic anomaly.

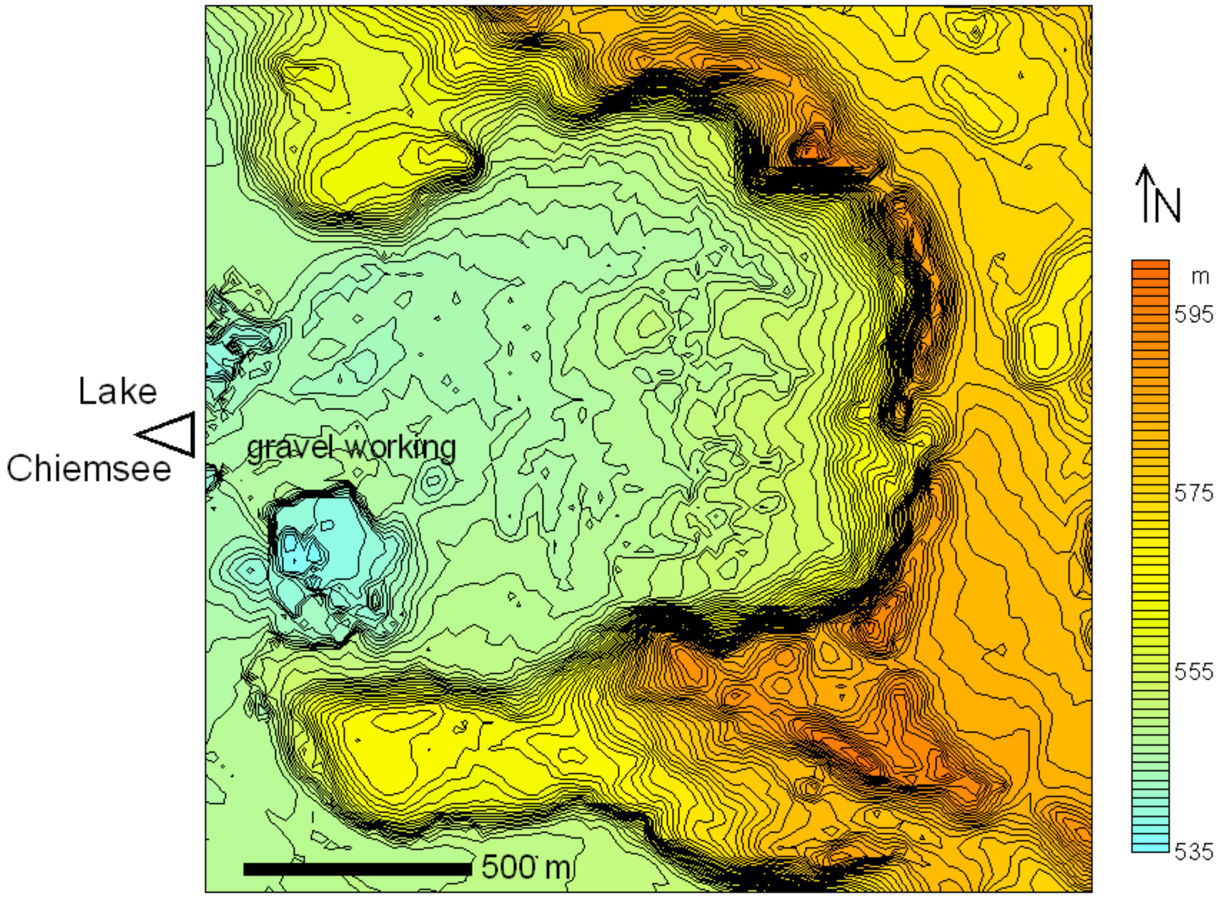
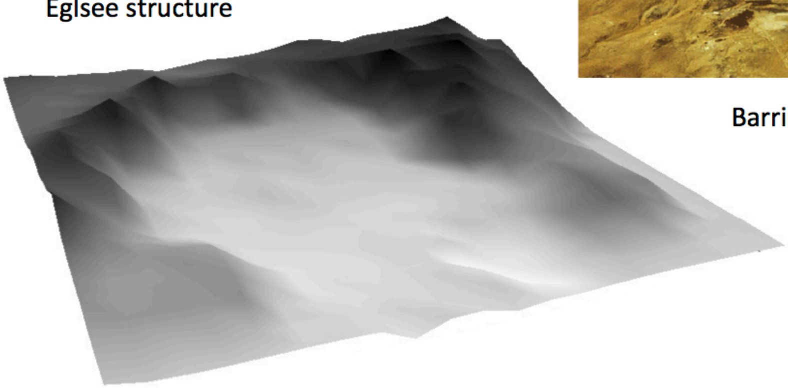


Fig. 37. The Eglsee structure from DTM data. Contour interval 1 m.

Eglsee structure



Barringer (Meteor) crater

Abb. 38. DTM 3D surface of the Eglsee structure and photo (NASA) of the equally sized Barringer crater.

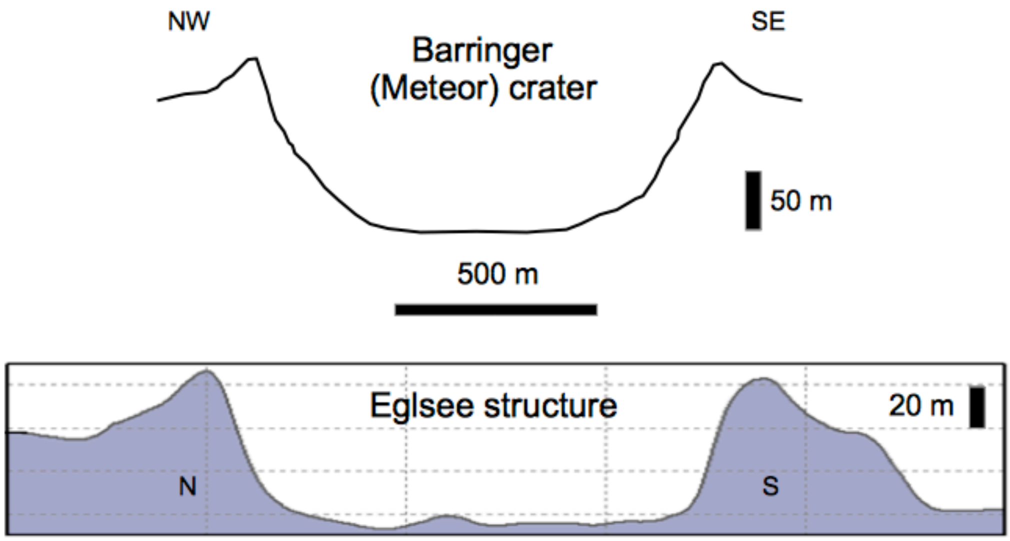


Abb. 39. Cross sections of the Barringer crater and the Eglsee structure. Same scale of length, but note the different height scales. Barringer profile redrawn from LPI.

6 Discussion and conclusions

Astonishingly enough the use of digital LiDAR data in the form of the Digital Terrain Model DTM has in the past only very hesitantly if at all found its way into the world of geologists, engineers and geophysicists, which at least holds true for Germany (here the corresponding *Digitales Geländemodell DGM*), although one can enormously profit from the various possibilities the data processing is offering for many purposes. This article deals with the applicability and efficiency of the DTM for a special field of research, the exploration of meteorite craters and related phenomena. Established craters as well as presumptive craters in the area of the Chiemgau impact served as test objects to show how impact research may recognize interesting morphological details adding to mineralogical-petrographic, geochemical, geologic and geophysical insight. The basic advantage of the DTM is that it sees and measures the "naked" crater morphology with an unbelievably high precision and resolution with mesh sizes, if desired, down to 1 m and contour resolution down to 20 cm. This holds true at least for the DGM 1 in Germany (Bavaria). The significance of the DTM meets well the very young age of roughly 2,500 - 3,000 B.P. of the craters, which means that the structures have comparably well been preserved. But also some later overprints of e.g., agriculture and young erosion did not blur characteristic features like crater rim walls which is exemplarily shown for the Aiching semi crater.

Morphological similarities or dissimilarities, for example depth-diameter ratios, which are much more precise to be evaluated by the DTM, asymmetric ejecta distribution, prior unseen details of the crater structures (e.g., the ring-like depressions around several craters), are typical subjects making the DTM an essential tool. A particular merit of the DTM data processing can be attributed to the recognition of multiple, doublet or even triplet, structures. If they were produced by meteorite impact they could point to a fragmented projectile and collective impact. These morphological peculiarities shown for the Punzenpoint and Purkering sites but unsupported by any field evidence or topographic maps, benefit solely from the DTM. Even processes like the Hochfelln landslides may make an alternate explanation of their formation available to geologists if a possible connection with an impact can be revealed by studying the processed DTM high-resolution maps.

When the unmissable merit of the DTM processing for the study of impact craters is pointed out here it is likewise emphasized that it also facilitates to debunk or to query at least previously suspected meteorite craters as could be shown for the Chiemgau strewn field. On the other hand, it cannot be repeated often enough that in impact research the morphology of a structure alone is not sufficient criterion for establishing a meteorite impact crater. Generally accepted criteria are, apart from the direct observation of the impact (Carancas!) and remnants of the projectile (macroscopic or geochemically measurable) diverse shock-metamorphic effects.

This sheds some light on a strange notice. Early and a few remaining critics and deniers of the Chiemgau impact event (Reimold 2006, 2007a,b, Wünnemann et al. 2007, Koeberl 2008, Doppler and Geiss 2005, Reimold & Koeberl 2014, Reimold et al. 2014, Doppler et al. 2011, Schmieder et al. 2011) have apart from ignoring all impact evidence like shock metamorphism, impact melt rocks, impact ejecta, geophysical anomalies, and more, always claimed the ice age, glacial processes and the glacial landscape, as well as anthropogenic activities as unmistakably being behind all proposed impact features. In their paper on "Impact structures in Africa: A review" Reimold and Koeberl (2014) are renewing their attack against the Chiemgau impact research and claim that when discussing possible new impact craters also the regional-geologic setting has to be taken into consideration. At that they in particular accentuate a glacial overprint obviously aiming at the Chiemgau impact strewn field that in their opinion is a cluster of glacially produced “holes”. In doing so they do not at all realize that they are questioning their own and always propagated postulate – shock as prerequisite for the acceptance of impact – and putting the case for all those regional geologists who deny the existence of impact structures because these are incompatible with the regional-geologic setting. Reimold and Koeberl are encouraged to take a look at the "cluster of glacially produced holes" in the Digital Terrain Model DTM from which they may possibly learn a lot for their own impact research.

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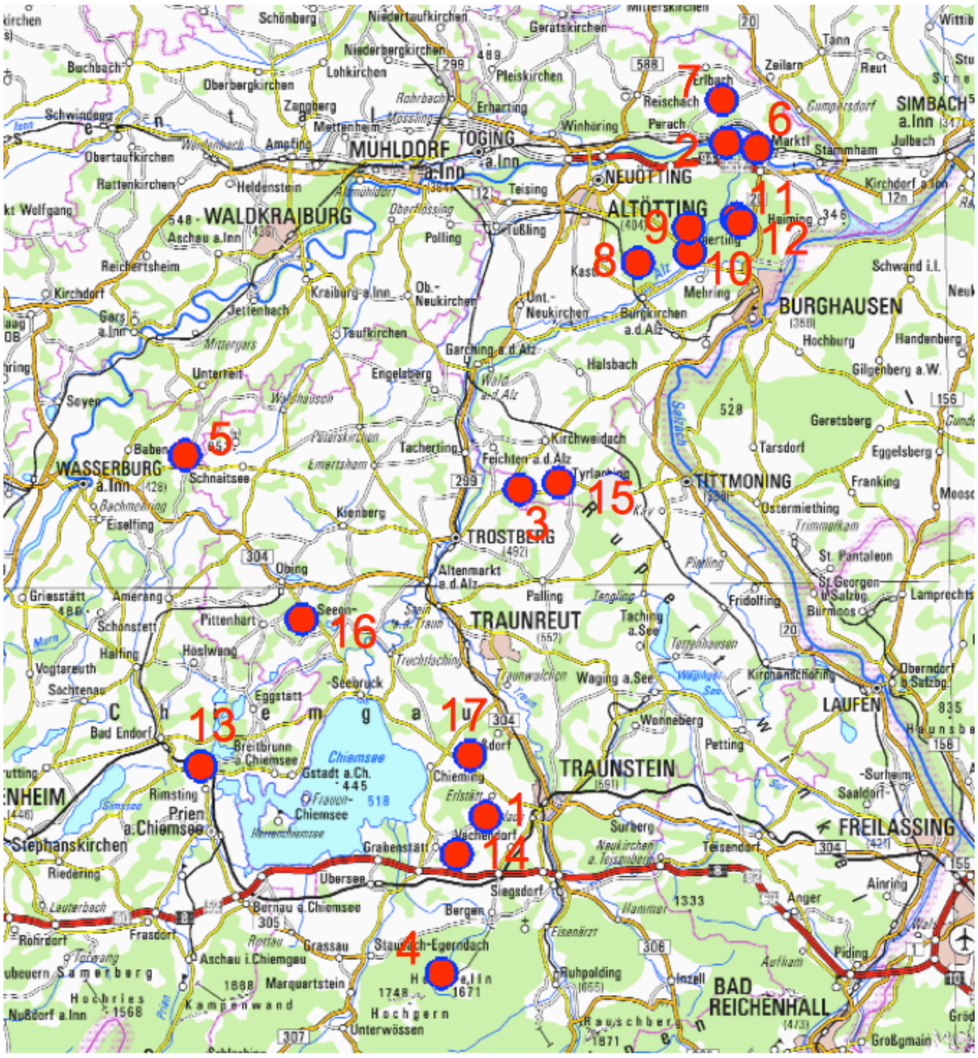
Appendix



The location map for the sites discussed in this article: 1 = Kaltenbach, 2 = Schatzgrube, 3 = Purkering, 4 = Hochfelln, 5 = Punzenpoint, 6 = Aiching, 7 = Leonberg, 8 = Einsiedeleiche, 9 = #004, 10 = Emmerting Siedlung, 11 = #002, 12 = Laubergraben, 13 = Mauerkirchen, 14 = Burgstall, 15 = Tyrlaching, 16 = Thalham, 17 = Eglsee.