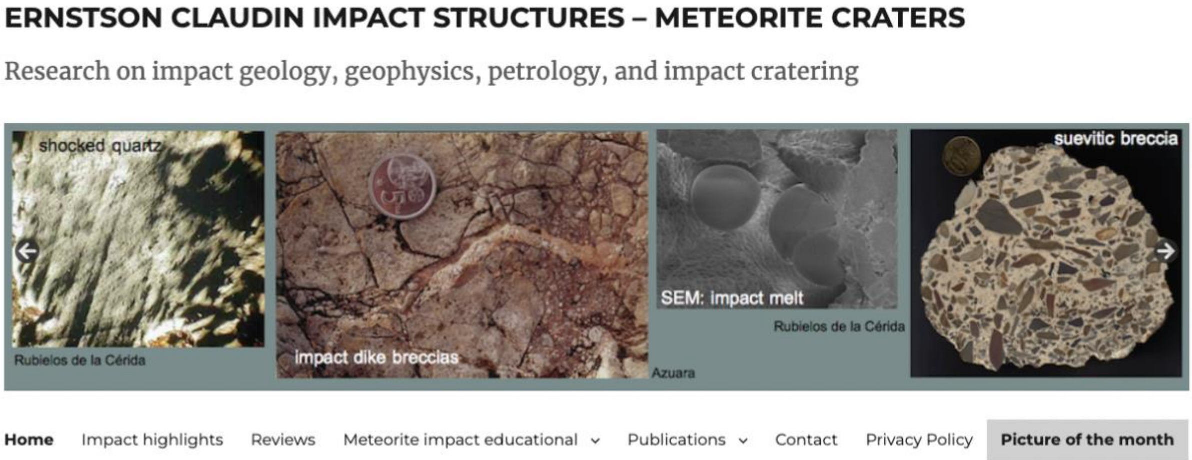

The Schlitzer Kauten (Hesse, Germany) and the high-resolution Digital Terrain Model DGM 1: a low-altitude airburst impact event with a crater strewn field

Kord Ernstson, Jens Poßekel and Rudolf Auth

August 2025

The Schlitzer Kauten (Hesse, Germany) and the high-resolution Digital Terrain Model DGM 1: a low-altitude airburst impact event with a crater strewn field

Kord Ernstson[1] , Jens Poßekel[2] and Rudolf Auth[3]

Abstract. - The three decameter-wide, kettle-shaped hollow formations of the Schlitzer Kauten in the Hessian Lower Triassic Buntsandstein field are a striking geological feature that has been interpreted in various ways in the past. A new exploration of the area using the enormous possibilities offered by the digital terrain model DGM 1 and its extreme resolution (down to the decimeter range horizontally and the centimeter range vertically) shows that the Kauten themselves are much more complex in structure than previously recorded and that they belong to an entire strewn field of impact features of various sizes and shapes. The interpretation of their formation involves a cosmic airburst near the Earth's surface with an extensive multiple impact ("low-altitude touchdown airburst impact"), which probably occurred in the Holocene. A connection to similar Holocene impact events in Germany and the Czech Republic is obvious. Previous models of the formation of the depressions, such as collapse structures (sink holes) or fossil pingos, can be ruled out.

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1 Introduction

The bowl-shaped hollow formations, known as "Schlitzer Kauten," are located in the Vogelsberg district of Hesse. The striking depressions, which are located in a forest area southwest of the village of Hemmen (Fig. 1), have diameters of approx. 90 m, 45 m, and 30 m and were measured in 1996 by M. Schütz in a special project called "Schlitzer Kauten" [0]. The word "Kaute" comes from Old High German and is a term for a depression or hollow. The Kauten have previously been interpreted as sinkholes [1] and as fossil structures of ice age pingos [2].

The discussion was revisited by Auth [3], who suggested that the Kauten were meteorite craters. He based his assumption on, among other things, their common location on a line, their successive increase in size from NW to SE, and the wall structure at Teufelskaute, the largest of the three kauten. Tiirma and Czegka [4] also interpreted them as possible Holocene impact structures.

In a thesis at the University of Würzburg in 2007 [5], the kauten were the subject of extensive geological, geophysical, and petrographic investigations with the aim of reviewing previous models of their formation. 's findings leave the question of a clear classification open and cite the occurrence of an increased frequency of fractures in thin sections of quartz from the sandstones inside the Teufelskaute as a possible indication of an impact, but also suggest a tectonic cause.

A revival of the impact hypothesis was published by Auth in 2022 [6].

With the new possibilities offered by extremely high-resolution digital terrain models, the complex of the three kaults is seen in a completely new light, which ties in with previous impact ideas but sees the events in a much broader context, as reported here.

2 Topography

The craters are located in the middle of Germany in the state of Hesse (Fig. 1), in the middle of a large forest area, which plays an important role in the enormous advantages of the digital terrain model.

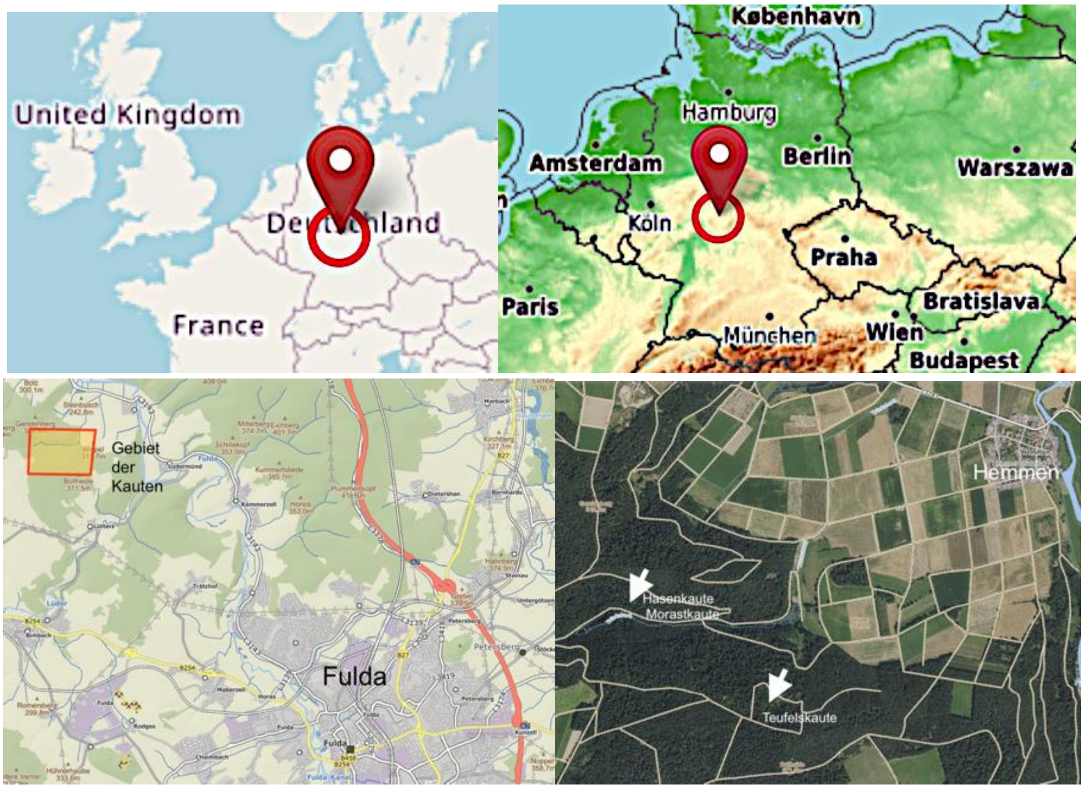


Fig. 1. Site plans for the study area. Google Maps and OpenTopoMap.

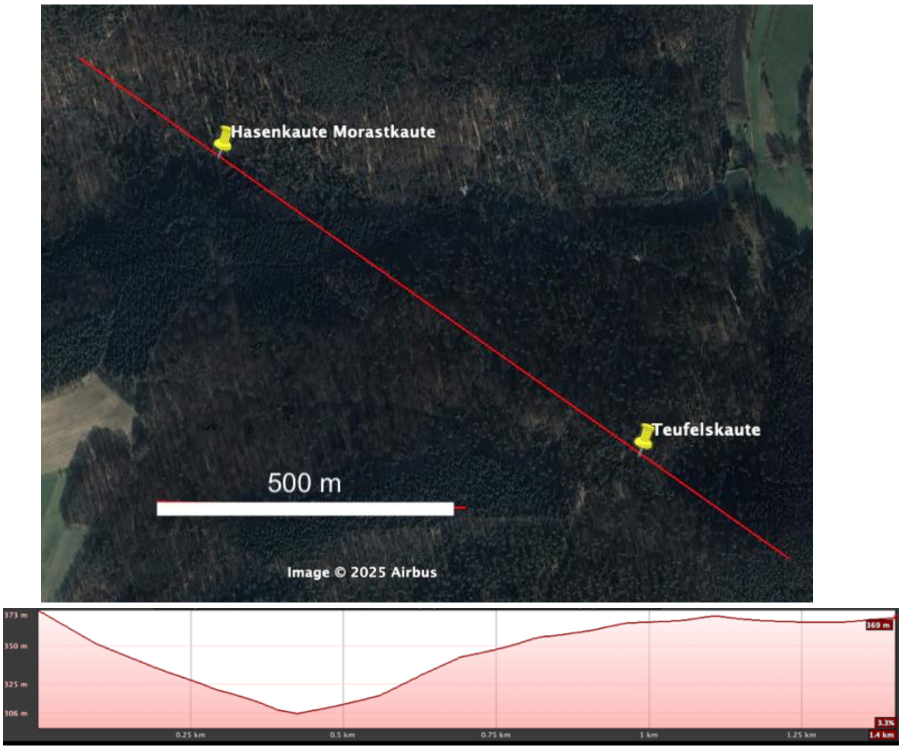


Fig. 2. Aerial view of the location of the Kauten with terrain profile; Google Earth.

3 Geology

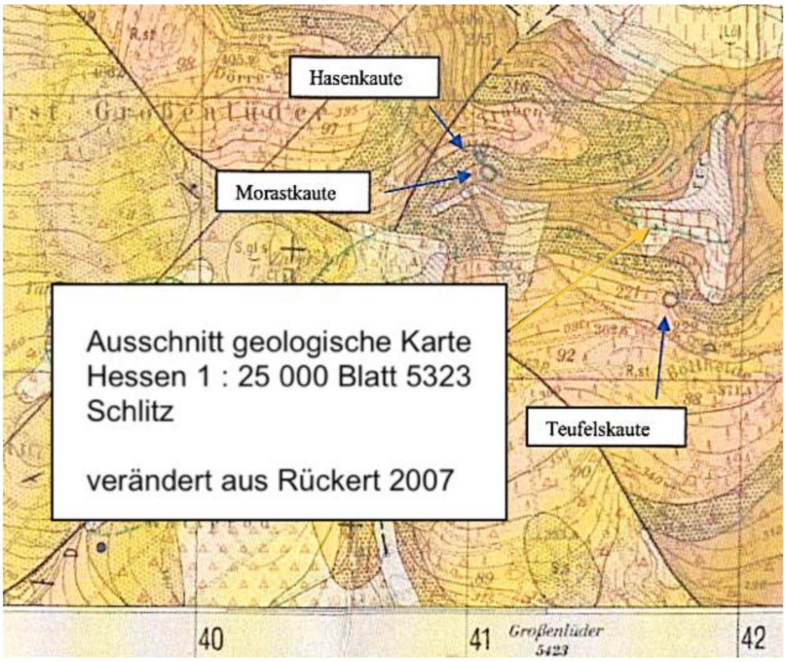


Fig. 3. The geological units in the Kauten area show exposed Middle Buntsandstein largely without recent overburden. The individual stratigraphic sections are described by Rückert [5] in relation to the Kauten, which is not necessary in this context. With regard to a tectonic connection between the formation of the kautes and deep-seated solution processes in the Zechstein salt dome, no connection with the mapped main faults can be established.

4 The digital terrain model DGM 1 and data processing

The DGM 1 describes the terrain surface using data sets from a three-dimensional coordinate system with right (X) and elevation (Y) values from the UTM grid or geographical longitude and latitude, as well as the terrain elevation (Z) above NHN at regular grid points. The data is obtained from a flight using laser scanning (LiDAR, light detection and ranging), whereby all buildings and vegetation are calculated from the primary signals of the DOM (= digital surface model) through data processing, so that the DGM reproduces the surface of the ground very accurately, even in forest areas. The positional accuracy of the points in DGM 1 is approx.± 0.5 m with an elevation accuracy better than± 0.1 m, which can be further reduced by interpolation.

Fig. 4 shows the topographic map of DGM 1 for the four 1 km x 1 km tiles covering the study area. The distance between the contour lines is still quite rough at 5 m, allowing only a rough outline of the three hills to be seen.

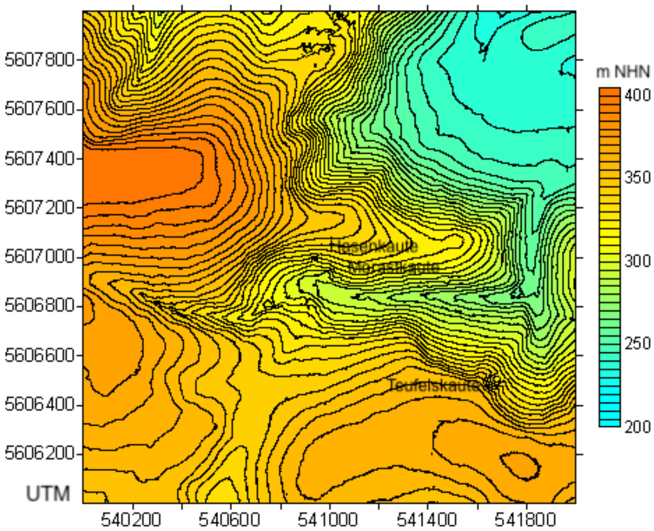


Fig. 4. The topographic map of DGM 1 covering the area under investigation.

4.1 Data processing

The terrain images for the Kauten logging area discussed here are all based on the German DTM (DGM 1) with a mesh size of 1 m and a height resolution of approx. 0.1–0.2 m in the UTM coordinate system. Simple data processing allows the standards to be reduced to the decimeter and centimeter range by interpolation. The best-known transfer of DTM data produces topographic maps based on arbitrary contour intervals. Fig. 4 shows such a topographic overview map with a contour interval of 5 m for the entire area under investigation, measuring 2 km x 2 km.

4.2 Data filtering

2D data filtering offers various options for DTM processing, based on the concept that the terrain consists of the superposition of different elevation wavelengths. Low-pass filters amplify general topographical trends, while high-pass filters emphasize smaller, local topographical features. Filtering does not create new field data, but certain terrain features can be made more visible to the eye. Small irregularities can often largely obscure general terrain trends that are of interest, and a simple low-pass filter can help here. A method borrowed from geophysics (e.g., gravity and geomagnetic fields) can also be useful in DTM data processing to separate local anomalies from a general trend in a field of contour lines. In gravimetry, for example, a regional trend field can be derived from the measurement data using various methods, and by subtracting the regional field from the measurement field, the local or residual field becomes the main object of interest. This method can be copied for DTM data processing if you want to separate local topographical features from a general trend in the terrain elevation. Two examples of crater evaluation are shown in Figs. 5 and 6.

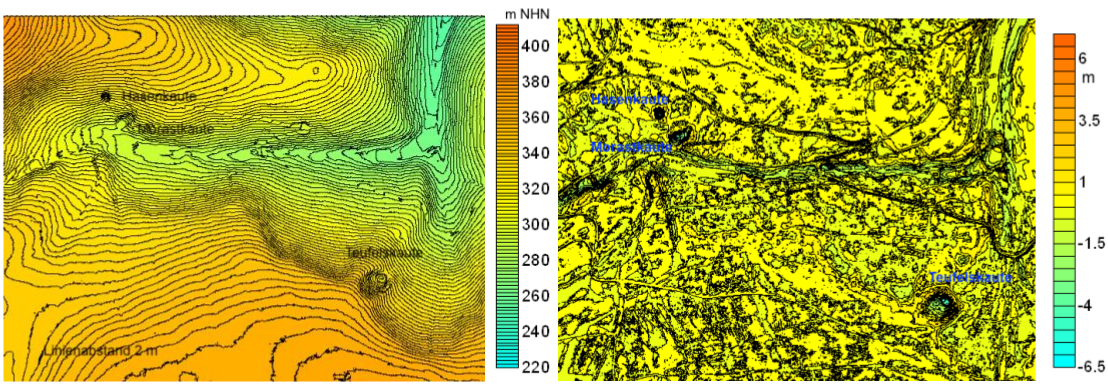


Fig. 5. Section of the original topographic map of DGM 1 focusing on the three craters. Right: the topographic residual field after subtracting a trend field (2D low-pass filter, moving average).

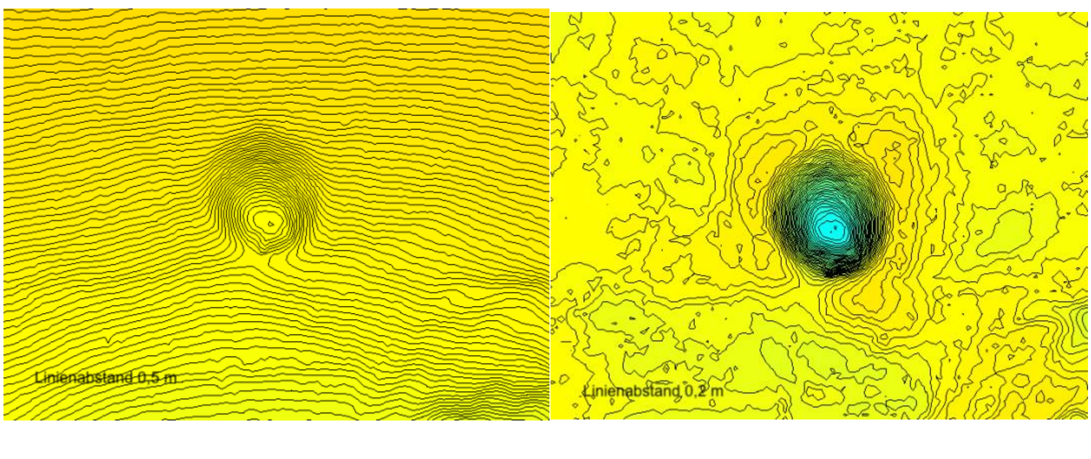


Fig. 6. The Hasenkaute in DGM 1: on the left, the original topography; on the right, the DGM 1 residual field. After subtracting the terrain trend field, the surrounding ring wall becomes clearly visible.

4.3 3D block representations of the terrain surface; shaded relief maps

The creation of a 3D surface from the digital data provides a clearer representation of the terrain, especially for the visualization of more complex craters, as shown in Fig. 8 for the Hasenkaute crater. In suitable data processing programs, any colors and gradations can be selected and a height grid can be superimposed or omitted.

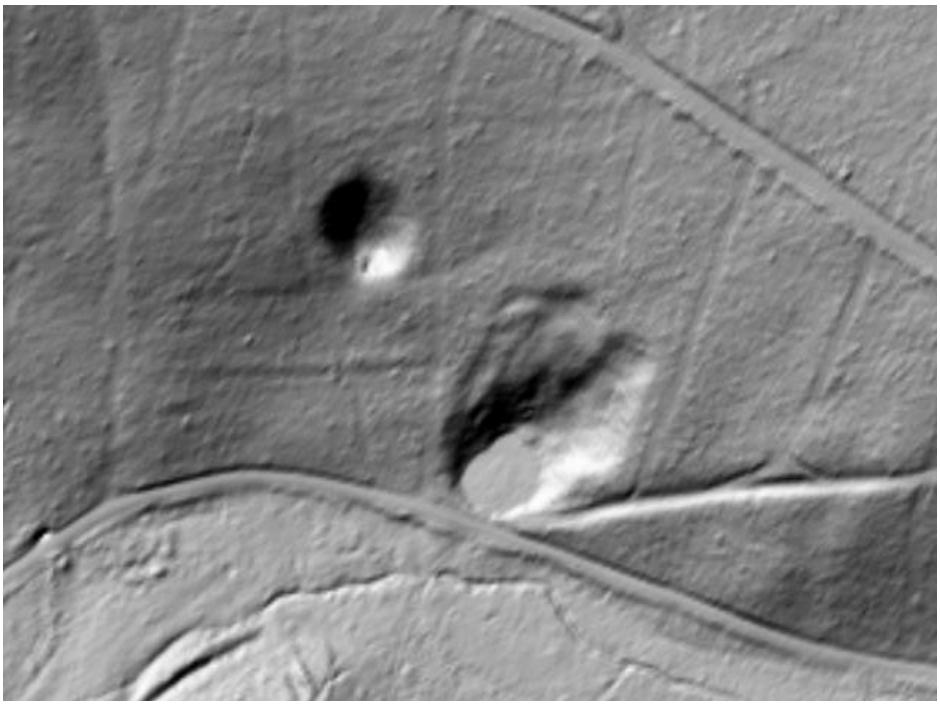


Fig. 7. Shaded relief map of the two northern kautes.

Shaded relief maps, which can be digitally brightened from different directions and at different angles of incidence, highlight any topographical features and provide a similar 3D visualization of the terrain surface. The shaded relief map in Fig. 7 shows the craters of Hasenkaute and Morastkaute in their slightly larger surroundings as a clear anomaly, but not as impressive as in the 3D surface map (Fig. 8). The particular significance of shaded relief maps lies in their ability to provide a quick overview of selected features, even over larger areas.

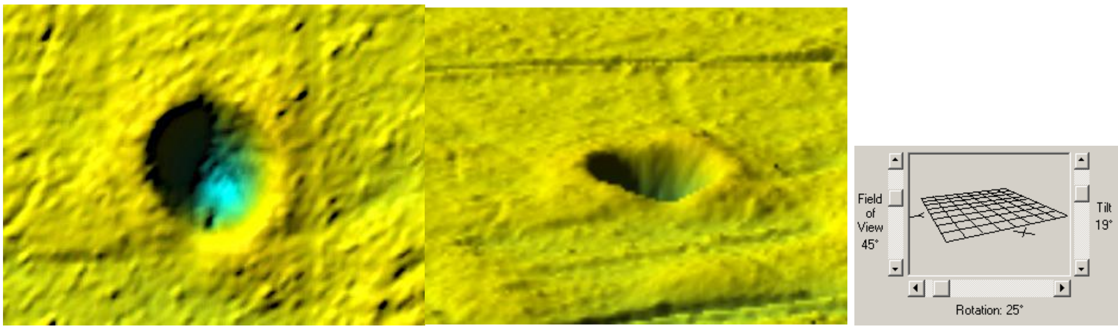


Fig. 8. The Hasenkaute in the DGM 1 residual field map; view centered from above and oblique view to the northeast. Note the strong elevation in the maps.

5 Results

The investigations with the DGM 1 have yielded a wealth of results, and it seems important that these are not lost in the compilation. For this reason, we have decided not to integrate the accumulation of illustrations into a connecting text. Instead, the relevant illustrations are simply listed one after the other, each accompanied by a caption of varying length. All illustrations without scale references are in meters.

5.1 The Teufelskaute

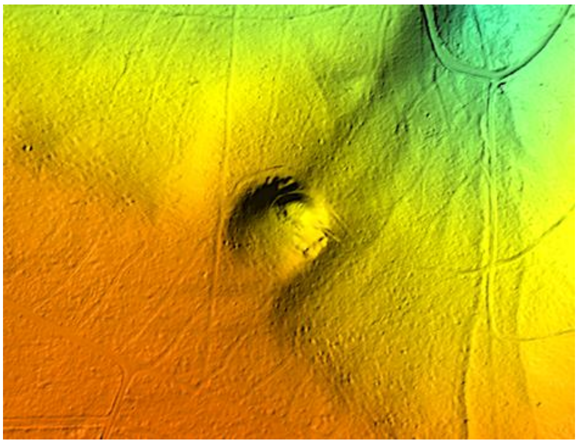


Fig. 9. The Teufelskaute in the original DGM1 map of the terrain surface. The ring wall of the Kaute with the belt of ejecta is clearly visible.

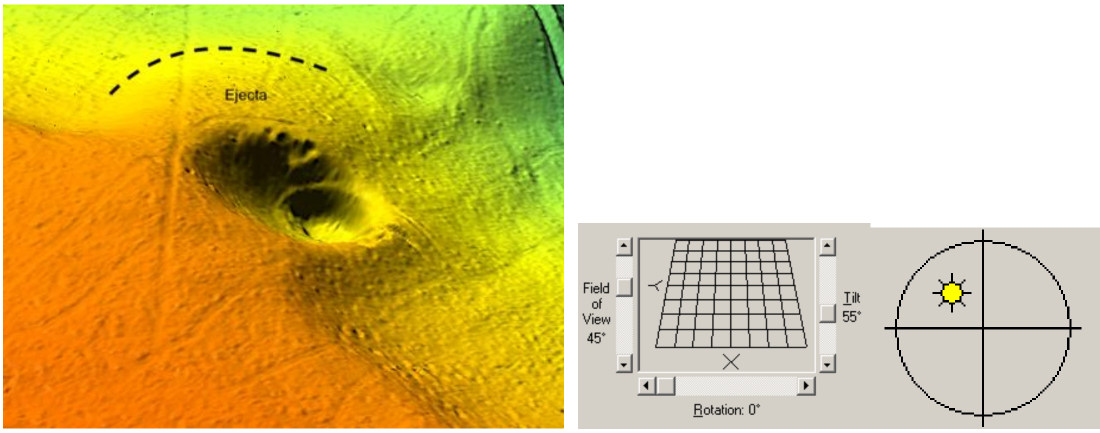


Fig. 10. The same surface map of the Teufelskaute with a diagonal view to the north and illumination from the northwest. This unmodified map clearly shows that the Kaute is in fact a double crater, which will be discussed later. The wider belt of ejecta is also particularly highlighted here.

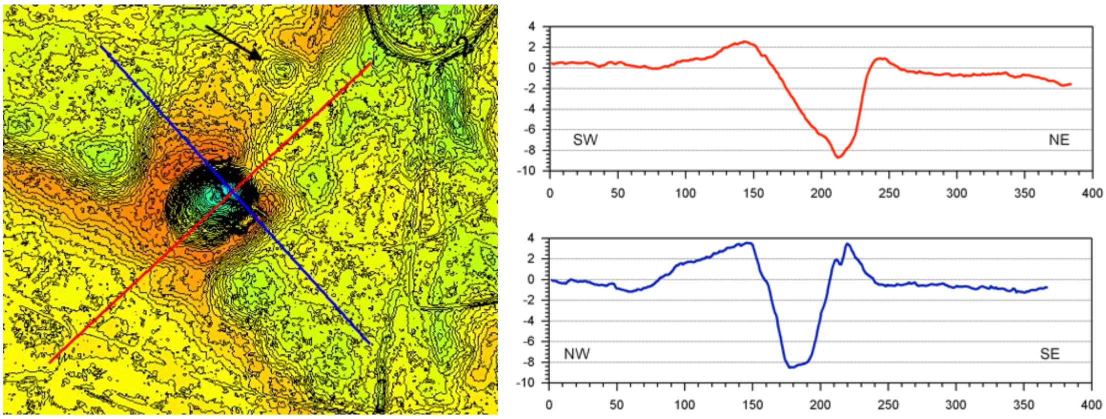


Fig. 11. The dimensions of the Teufelskaute in longitudinal and transverse profiles with a length of 100 m and a width of approx. 80 m, each as usual relative to the wall crown. The longitudinal profile also shows the double crater from Fig. 10 in the gradation of the basin to the northeast.

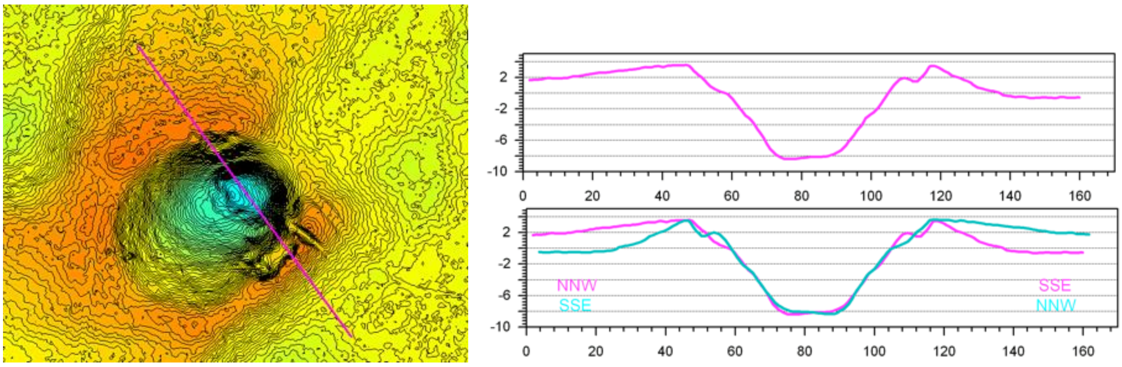


Fig. 12. The DGM 1 elevation profile over the smaller structure of the double crater in Fig. 10. Noteworthy is the practically identical overlap of the NNW-SSE profile (pink) with the mirrored SSE-NNW profile (turquoise). The almost perfect symmetry of the ring walls over a length of 80 m, with height deviations in the decimeter range up to a maximum of 1 m, rules out endogenous geological processes in the formation of the Teufelskaute.

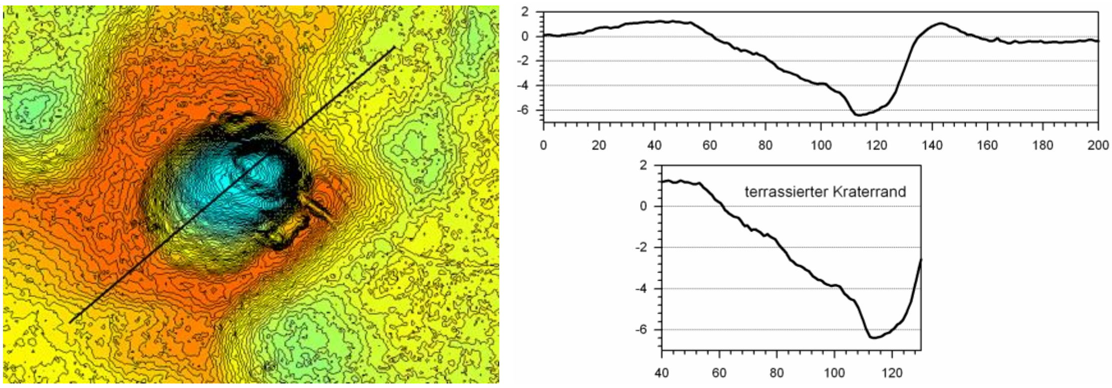


Fig. 13. The longitudinal profile across the Teufelskaute crater rim with clear terracing is likely related to the excavation of the crater and a reaction to the layered red sandstone subsoil of varying strength.

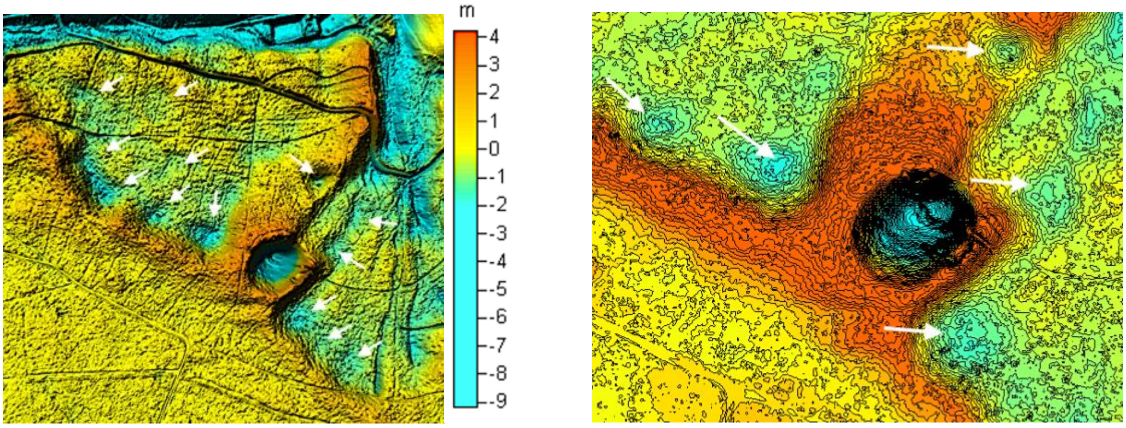


Fig. 14. The Teufelskaute in the residual field of DGM 1 as part of a whole group of accompanying smaller crater structures. An enlarged section is shown on the right.

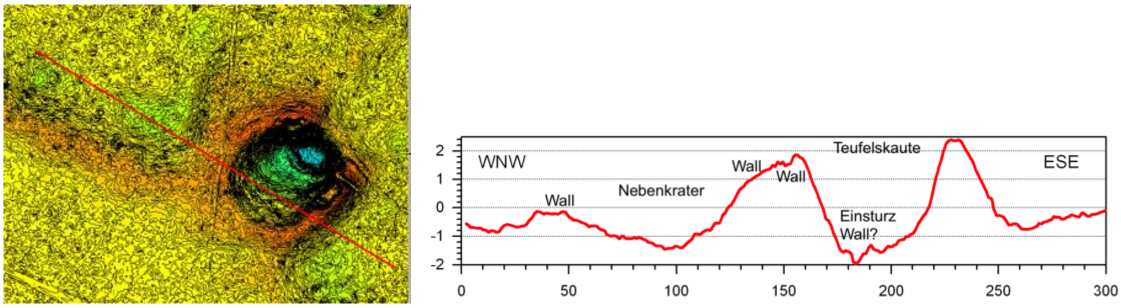


Fig. 15. The Teufelskaute and an immediately adjacent secondary crater. In the course of the profile, I obviously intersect the walls of the two craters, which led to collapse masses in the Teufelskaute.

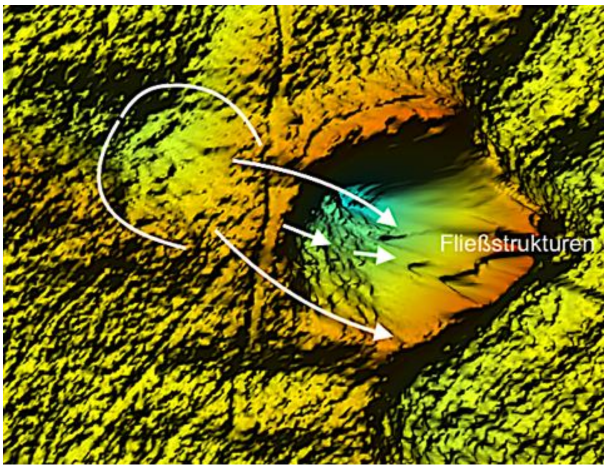


Fig. 16. Teufelskaute and secondary crater in the DGM 1 3D surface model. The more or less simultaneous impact probably led to instability in the contact between the two ring walls during their formation and to a mass flow into the Kaute. The block-like surroundings of the craters (here morphologically extremely exaggerated) probably mark the ejecta from the impact.

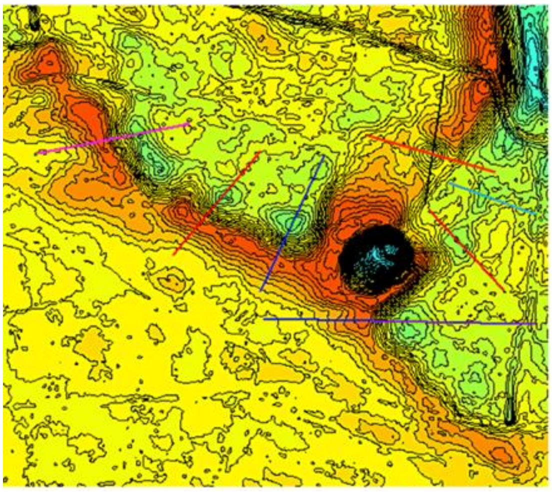


Fig. 17. DGM 1 topographic profile extracts for companion craters of the Teufelskaute. The profile colors correspond to the colors of the profiles in the following figures.

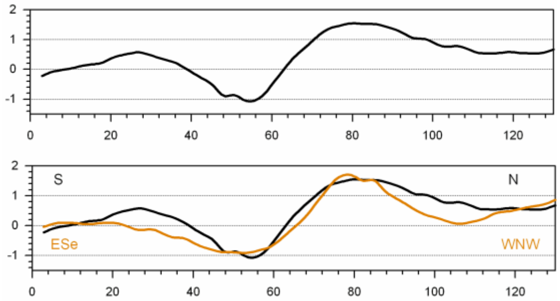


Fig. 18. The two intersecting profiles (black and red) above the isolated crater nne' of the Teufelskaute. The almost exact overlap illustrates the circular symmetry of the walled structure.

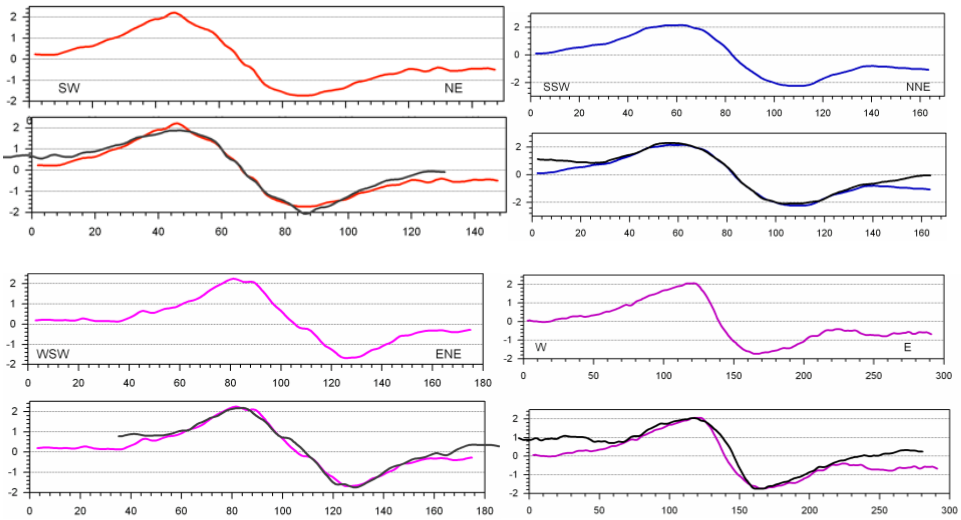


Fig. 19. The compilation of the four DGM 1 profiles shows a remarkable feature. All four profiles in the respective upper figure show a bipolar morphological plus-minus anomaly. If the profiles are mirrored both horizontally and vertically, the superimposition of all four profiles reveals virtually identical patterns for the centers of the structures, as illustrated again in Fig. 20.

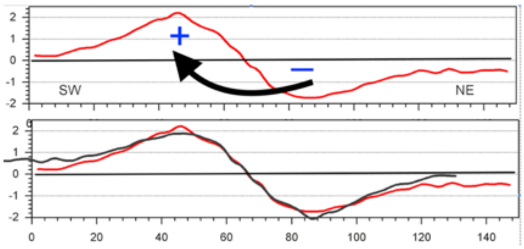


Fig. 20. The superimposition of the horizontally and vertically mirrored profiles makes it clear that, in terms of volume, the material excavated from the roughly 50 m large pit was piled up in the directly adjacent wall of identical geometry during the formation of the bipolar structures. This is obviously not a random isolated finding, but a systematic process, as will be discussed further.

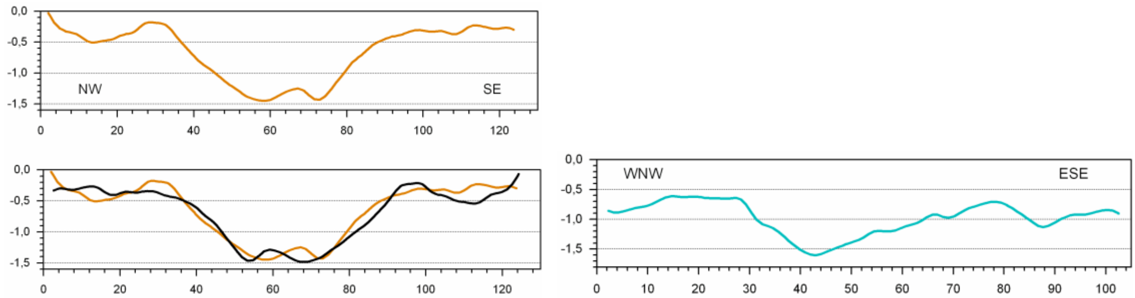


Fig. 21. Other crater shapes. Left: The crater directly east of the Kaute (red) with a superimposed mirrored profile showing almost perfect symmetry. The central elevation is well known from the other airburst crater fields as a water drop model. Right: Asymmetrically elongated crater (turquoise), north of the previous crater.

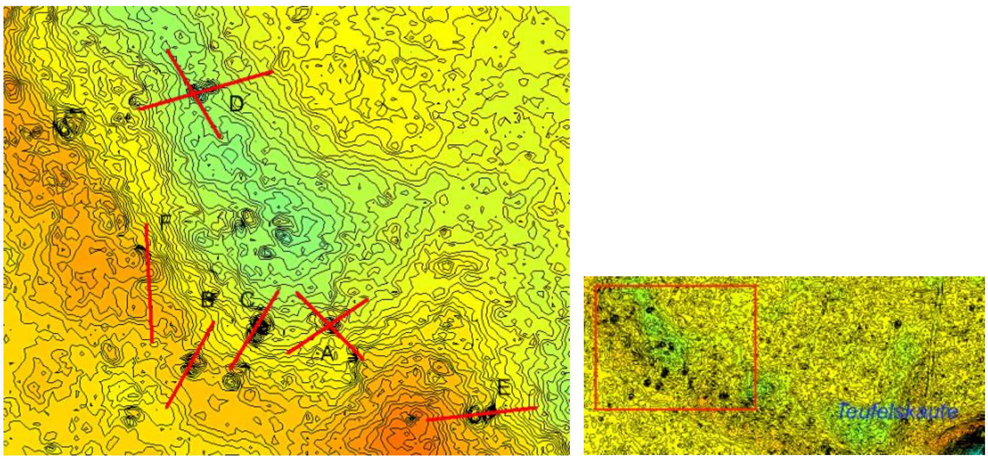


Fig. 22. Cluster of roughly equal-sized smaller structures of various shapes in a strip between the Teufelskaute and the two other craters with the marked DGM 1 profiles.

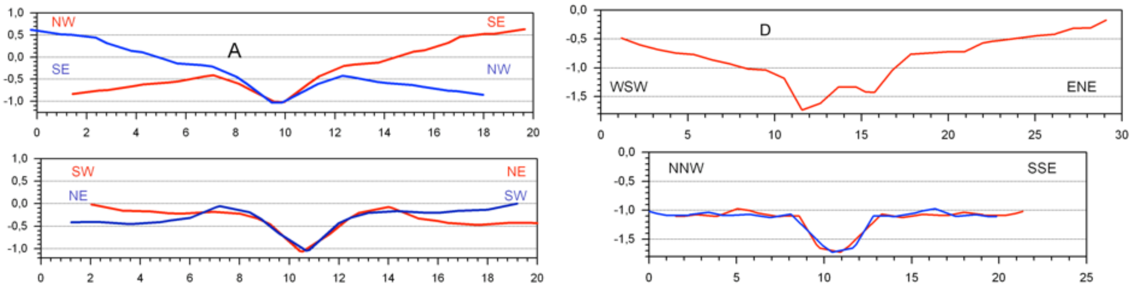


Fig. 23. Left: The intersecting diametrical profiles with their superimposed mirror images. Right: Profile above the double crater (top) and cross-section with superimposed mirror image (bottom). The perfect symmetry is striking.

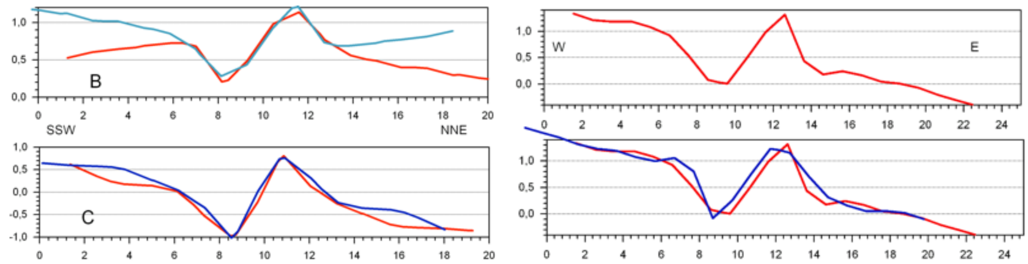


Fig. 24. Bipolar structures with superimposed horizontally and vertically mirrored profiles. As in Fig. 19, the almost perfect geometric correspondence in volume between the excavated material and the wall deposits is remarkable. Right: Profile E.

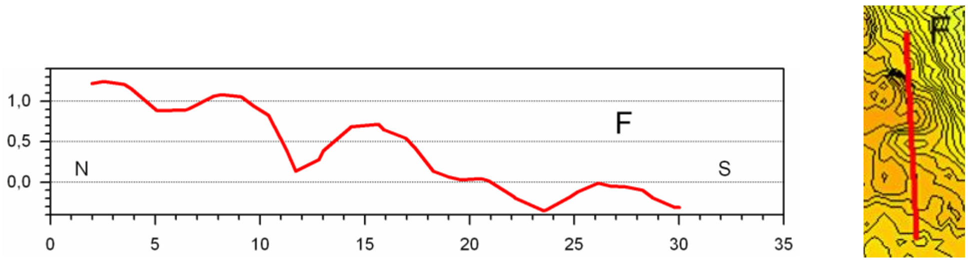


Fig. 26. Wave-like series of humps and hollows.

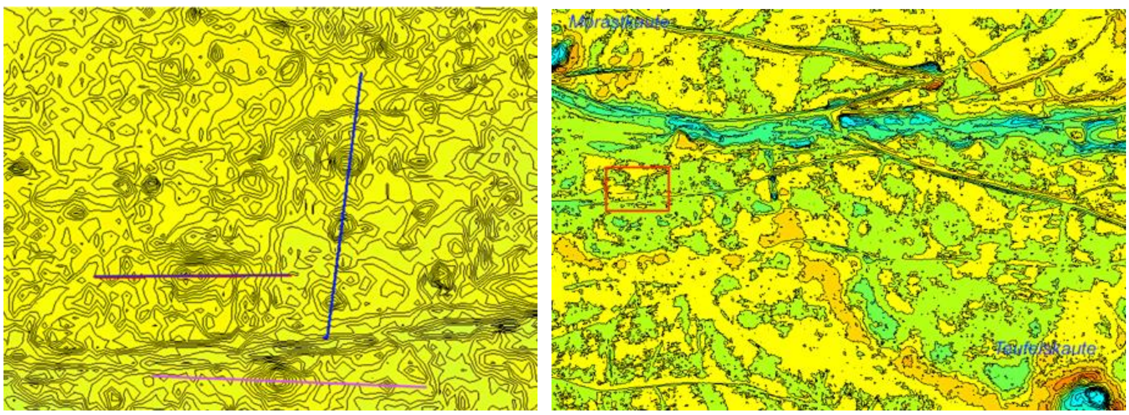


Fig. 27. Cluster of hump-shaped structures between Teufelskaute and the two other kaute with some height profiles in Fig. 28. Scaling according to Fig. 28. Distance between contour lines on the left: 5 cm.

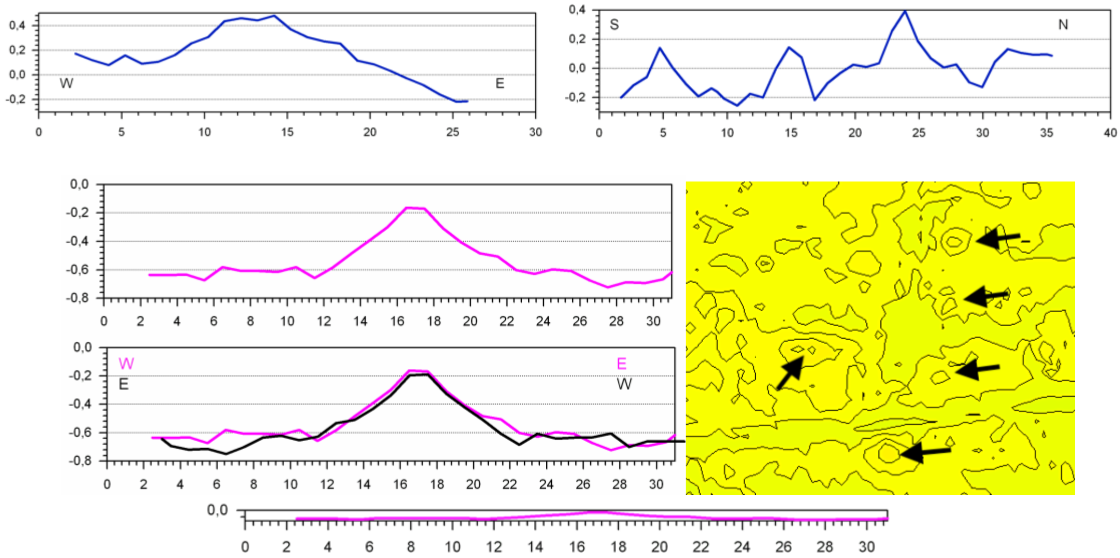
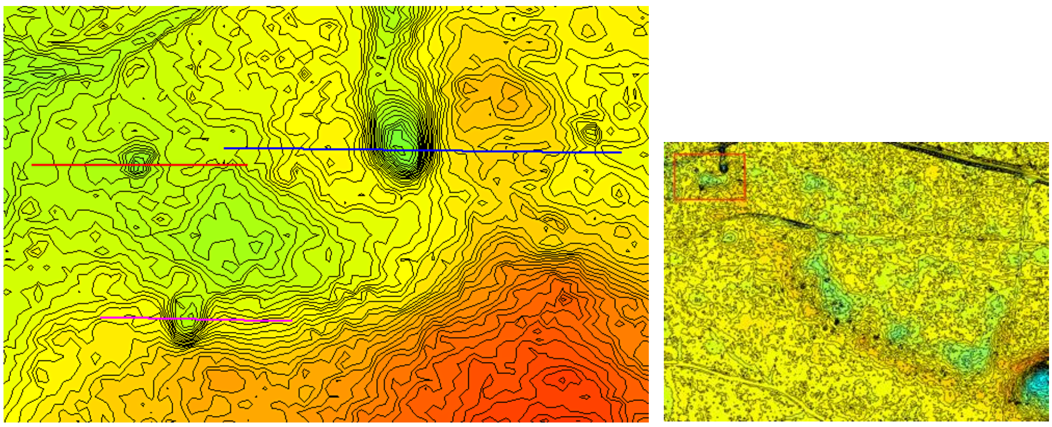


Fig. 28. Selection of profiles over hump structures. Bottom left (pink): Almost perfect symmetry in the superimposition with the diametrically mirrored profile. The shape of inverted funnels is apparently characteristic. - Compared to Fig. 27, the distance between the contour lines in the bottom right of the map is 20 cm. This is an important observation, as it indicates that these significant hump structures remain morphologically hidden from view, especially within the partially dense vegetation of the forest. The DGM 1 elevation profile below, without elevation, underscores this.



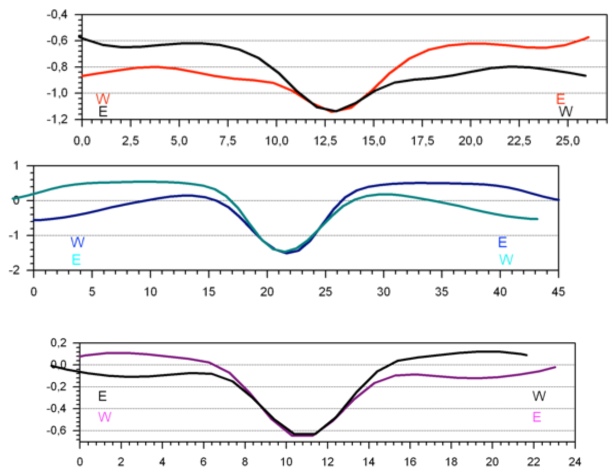


Fig. 29. Three elliptical elongated simple craters with perfectly symmetrical internal crater structure on the cross-sections.

5.2 The Morastkaute

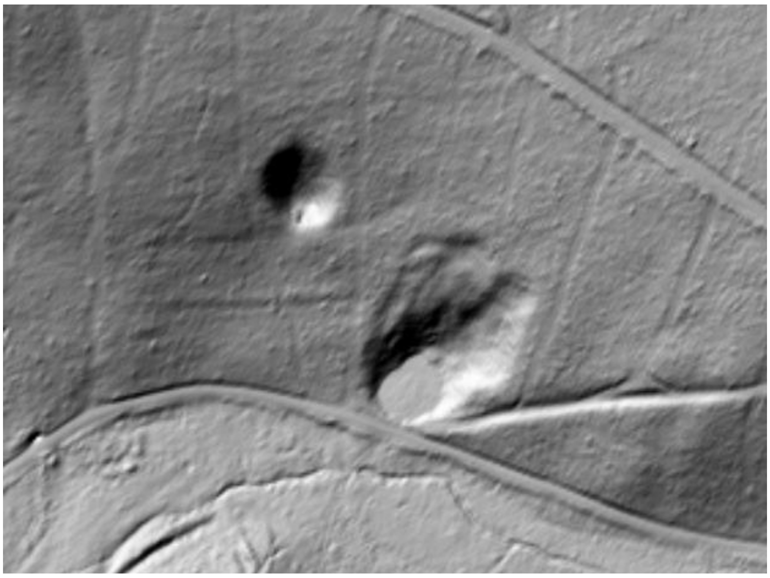


Fig. 30. The Morastkaute together with the Hasenkaute on the shaded relief map. Illumination from the northwest.

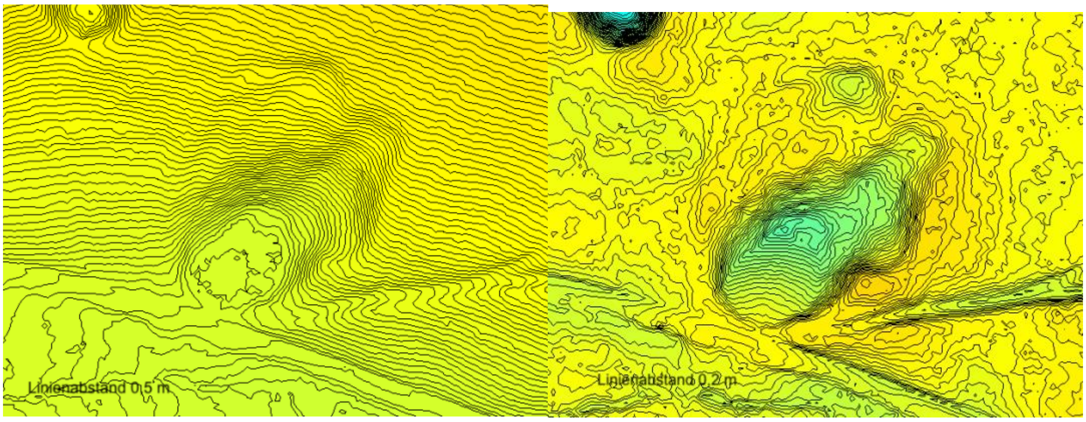


Fig. 31. The Morastkaute in the original topographic elevation map of the DGM 1 and after deduction of a trend field with centering on a zero level. The complex structure of a multiple impact with a small external crater in the NW is evident. The residual field after deduction of a trend field also highlights the ring wall surrounding the entire structure.

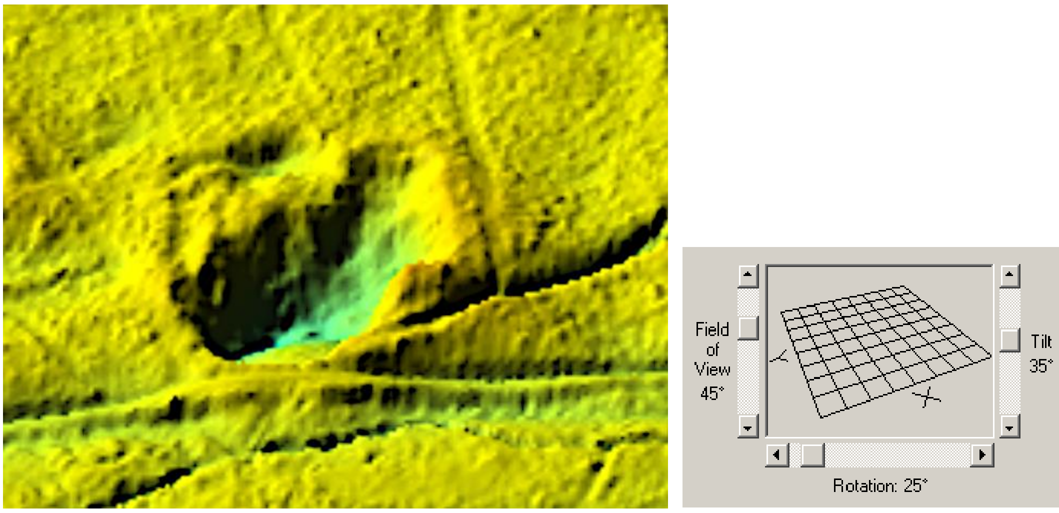


Fig. 32. The Morastkaute in a 3D representation with an oblique view conveys the complex multiple impact structure, which has not been realized in this way before.

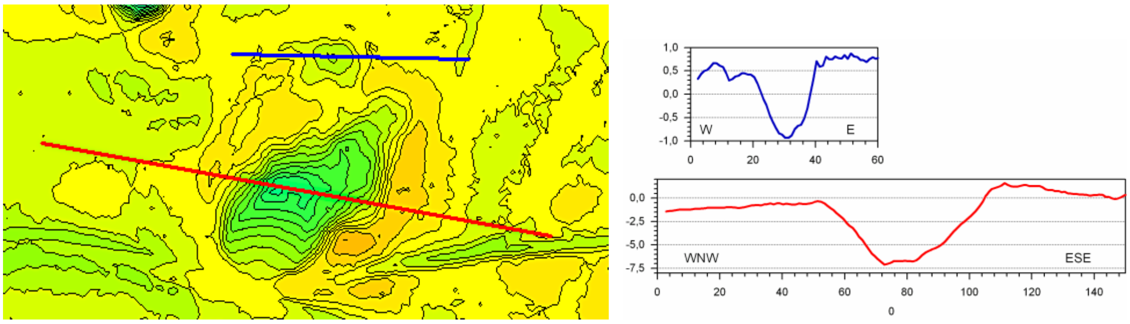


Fig. 33. The main structure, approximately 60 m wide, and the accompanying crater, measuring approximately 25 m (each wall crown).

5.3 The Hasenkaute

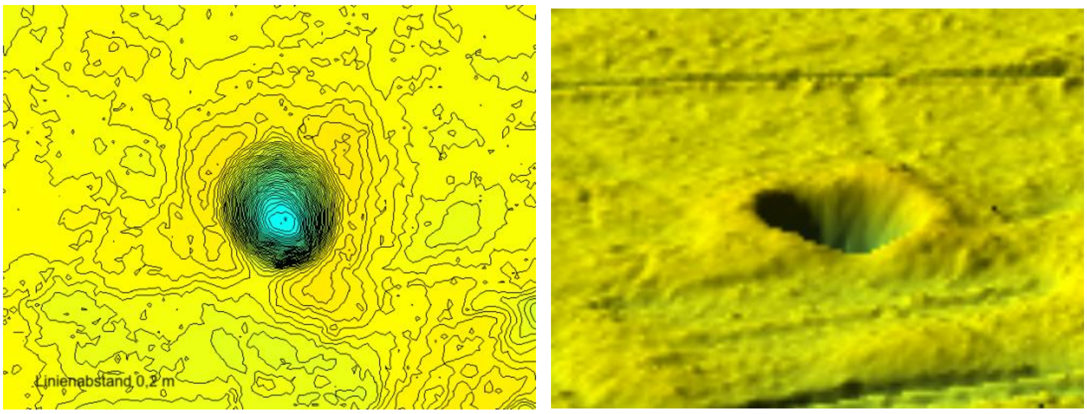


Fig. 34. The relatively simple shape of the Hasenkaute crater on the DGM 1 topographic map and in an oblique view of the (greatly exaggerated) terrain surface with the exposed ring wall.

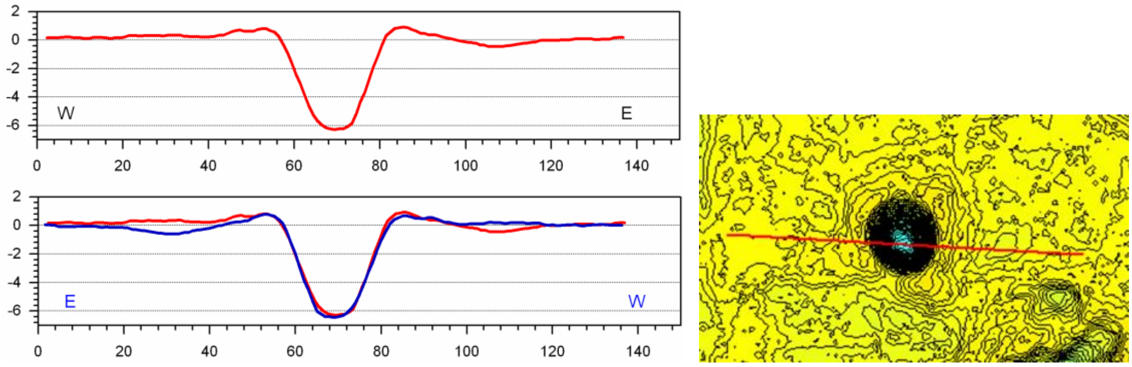


Fig. 35. The 35 m crater of the Hasenkaute shows almost perfect symmetry in its diametrical elevation profile. An outer flat ring depression around the wall is clearly visible.

5.4 Accompanying craters

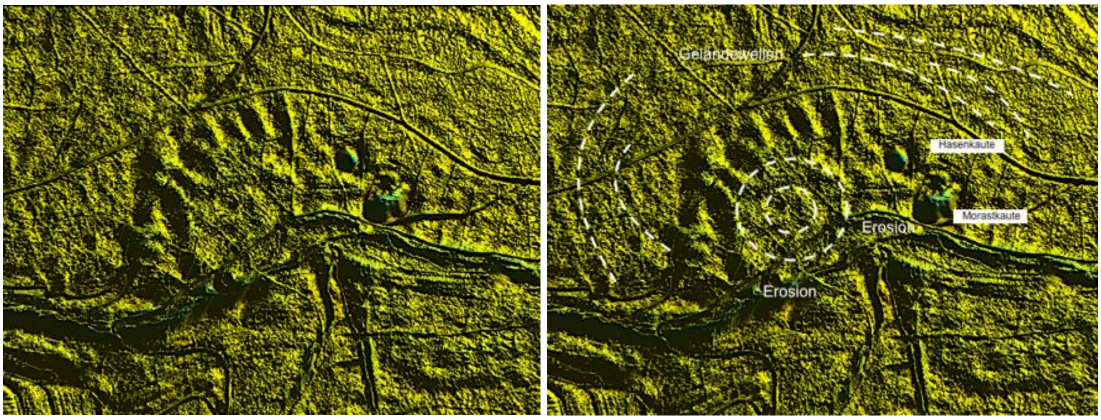


Fig. 36. In the immediate vicinity of Hasenkaute and Morastkaute, the DGM 1 shows an unusual ring structure with a partial, roughly radially arranged morphological ribbed rim (DGM 1 terrain surface, greatly exaggerated).

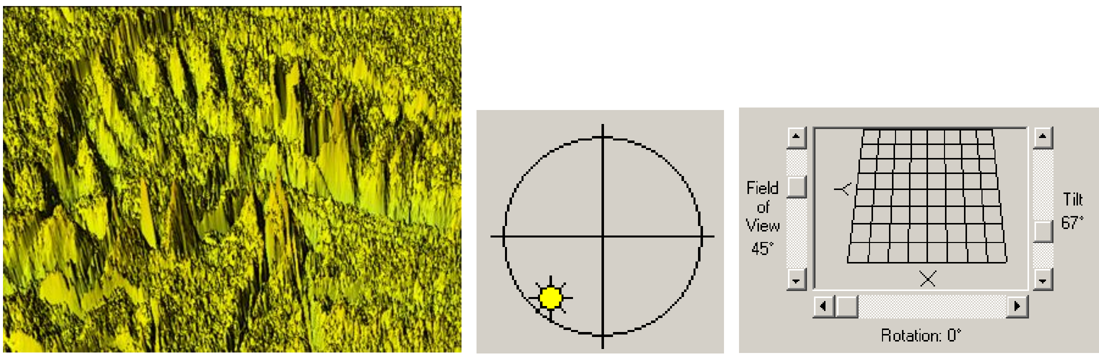


Fig. 37. The capabilities of the DGM 1 enable a precise, high-resolution image of the rib structure. Illumination of the surface and slight oblique view.

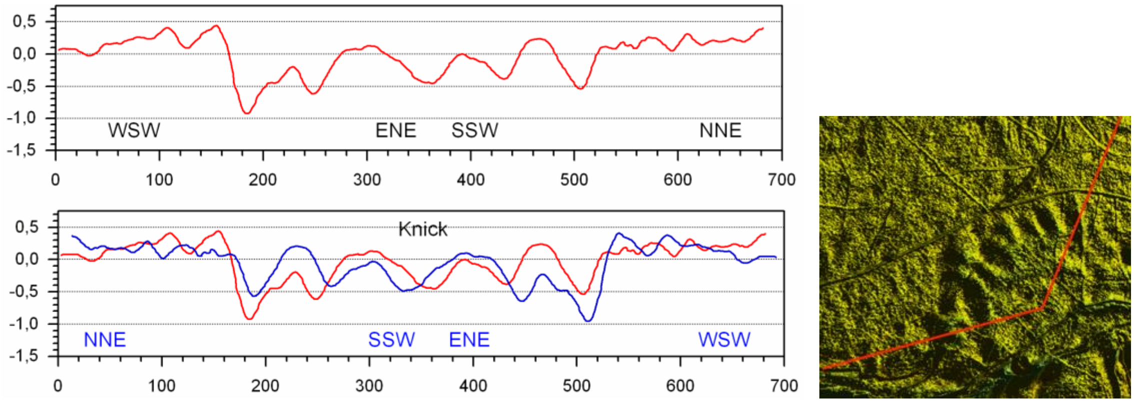


Fig. 38. The bent radial profile indicates a multiple ring structure measuring roughly 400 m.

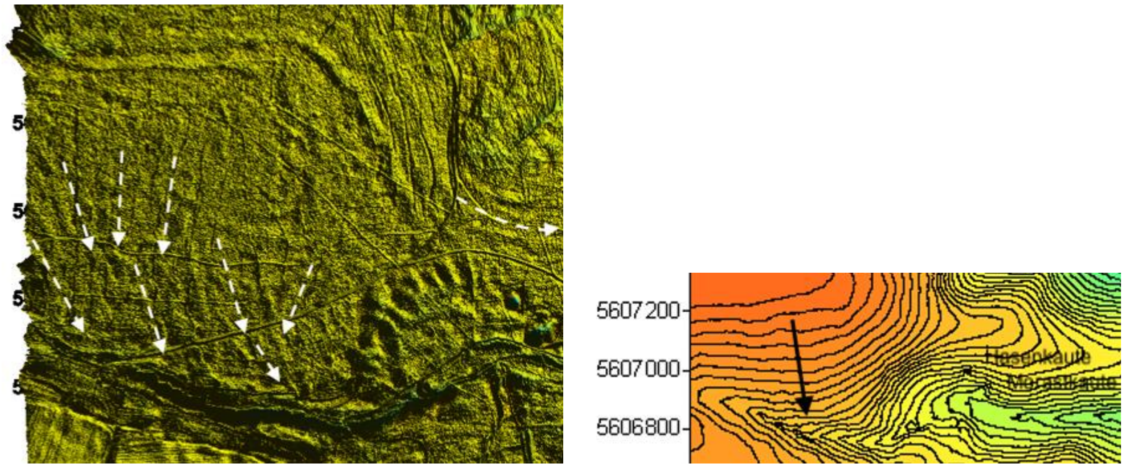


Fig. 39. The DGM 1 detects further rib structures a little further to the west. As their strike direction runs down the slope (see right), these are not erosively exposed layers in the red sandstone. This rib formation will be discussed later.

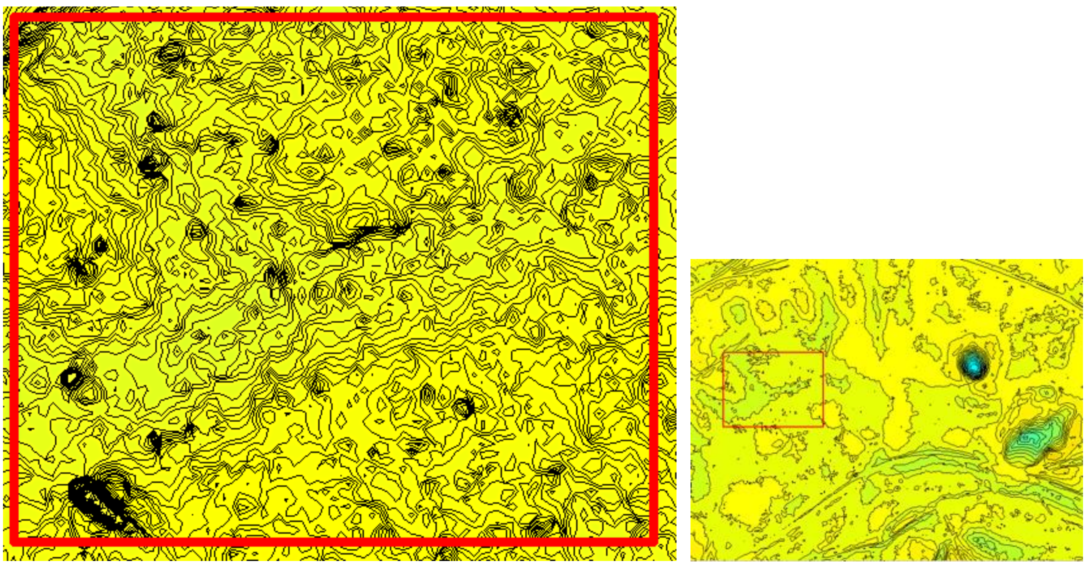


Fig. 40. Clusters of more complex small crater structures also exist in the western continuation of the kaus, with two examples shown in Fig. 41 and Fig. 42.

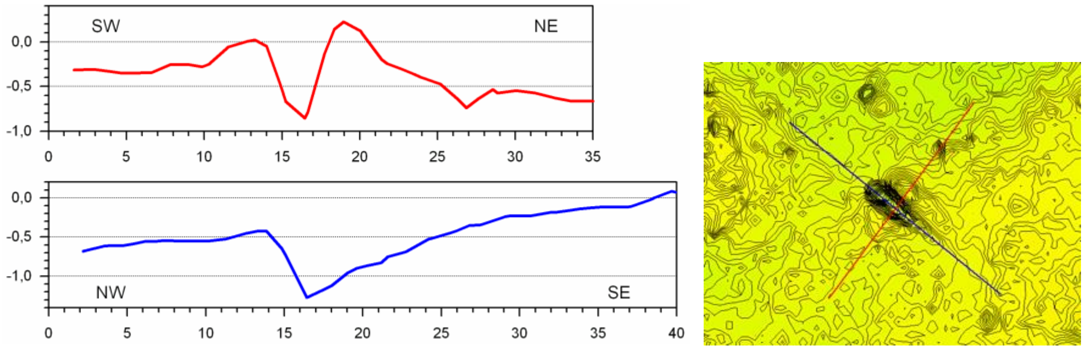


Fig. 41. A small walled crater chain of multiple impacts with apparently systematically decreasing energy.

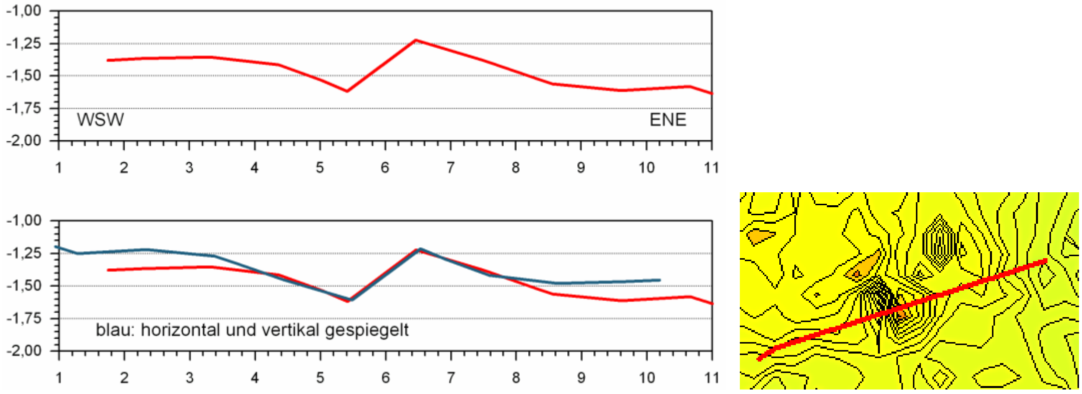


Fig. 42. Here, too, craters with an almost perfect bipolar structure.

7 Discussion

-- The craters, which were already mentioned in the 17th century as landmarks, have since been regarded mostly as collapse structures (large sinkholes).

-- Ice age research at the University of Würzburg suggested that the kauten were post-glacial fossil pingos, without presenting any convincing geological evidence.

-- The kauten were first interpreted as possible meteorite craters by the author R.A., who revisited the hypothesis in the late 1990s. However, the cosmic explanation remained controversial, and even a more extensive investigation in a thesis did not change this.

-- With the free acquisition of extremely high-resolution elevation data from the Digital Terrain Model DGM 1 from the Geoportal Hessen, research into the kauten received an unexpected boost.

-- Until then, it had been unthinkable to record terrain structures down to the decimeter and centimeter range without time-consuming and expensive optical leveling, even in the dense forest of the kauten, and to display and interpret them using suitable evaluation software.

-- This new picture of impact research has led to the rediscovery of several impact strewn fields in Germany and the Czech Republic in recent years [7-15]. Observations and computer modeling have contributed greatly to our understanding of impact processes and impact frequencies, especially in connection with airburst impacts caused by exploding asteroids and comets near the Earth's surface [e.g., 16].

-- This brings together new ideas about impacts and high-resolution digital terrain models. In contrast to "conventional" impacts of large bodies with large, deep craters, airburst impacts at low altitudes or near the Earth's surface tend to produce strewn fields of many smaller and shallow to very shallow craters with extensive other ground changes, which are more familiar from severe earthquakes. It is precisely these many small and very shallow impact structures that can be recorded very precisely in terms of their morphology, which makes it possible to distinguish them from anthropogenic structures and "normal" geological formations.

The individual new findings can be discussed as follows:

-- The three known devil's, morass, and hare's dens are only part of a larger impact strewn field that extends over the 4 $^{km^2}$area investigated so far.

-- Clearly identifiable structures occur in clusters and are roughly estimated to be in the order of 100.

-- The structures can be roughly divided into simple craters, multiple craters, crater chains, bipolar structures, and hump structures. These types are also known from the other airburst impact fields mentioned in Germany and the Czech Republic.

-- The Teufelskaute and Morastkaute prove to be more complex in terms of structural morphology in DGM 1 than previous studies have shown. The Teufelskaute is a double structure consisting of a larger and a smaller crater that overlapped during a simultaneous impact. The Morastkaute is a multiple irregularly structured impact form accompanied by a smaller external simple crater. The Hasenkaute appears as a simple walled crater hollow with a strictly symmetrical diametrical cross-section.

-- A key feature of the new model of the extensive impact strewn field at the Schlitzer Kauten is the numerous crater structures with a perfectly symmetrical diametrical cross-section of the hollow shape. Even the Hasenkaute crater, with a diameter of 35 m, displays this perfect symmetry (Fig. 35), and the smaller crater of the Teufelskaute double crater even shows perfect symmetry over a diametrical cross-section of approximately 80 m in DGM 1 (Fig. 12). However, the perfect symmetry of the hollow shape of many smaller craters, down to the centimeter range, also supports the conclusion that their formation cannot have a geological endogenous or anthropogenic origin and, from a geological point of view, is not very old. This is demonstrated with unprecedented precision by DGM 1 alone and proves at the same time that these craters were indisputably formed by a roughly point-shaped explosion at a height above them, from which a spherical shock wave emanated, naturally producing a flat circular deformation on the ground. Ice ages (pingos) or other geological processes or humans cannot have done this.

-- The bipolar structures consisting of a depression and directly associated swelling, which show exact correspondence in shape and volume on diametrically opposite profiles, are to be regarded as special features. The largely uniform orientation of the bipolar structures, which are approximately the same size, suggests a uniform, simultaneous formation process that has not yet been fully clarified. The perfect superimposition with the horizontally and vertically mirrored profiles illustrates the closed process of mass displacement. In earthquakes, this occurs through soil liquefaction caused by earthquake waves (Fig. 43); analogously, this is likely to also occur during impact.

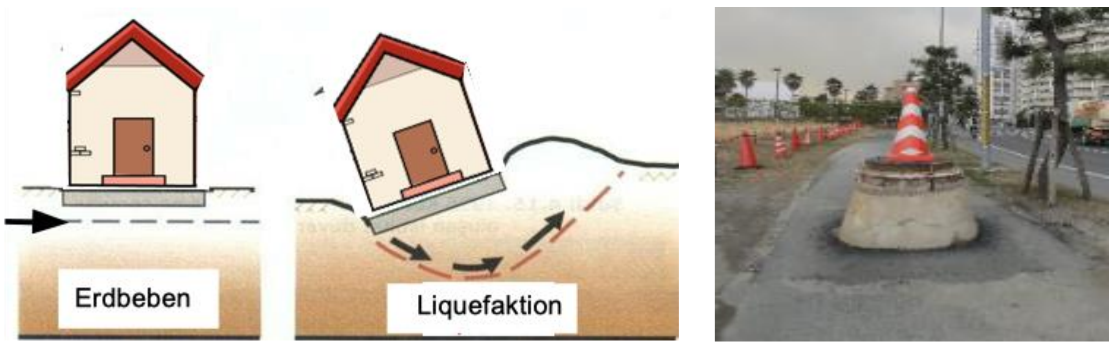


Fig. 43. Liquefaction: Formation of bipolar impact structures (modified after Bakir and Baran Karasin (2016)) and formation of impact hump structures (earthquake in Japan).

-- The hump structures, which usually occur in clusters, are well known from all other airburst impact strewn fields in comparable formations. In the Chiemgau impact, they are even marked on geological maps as hummocky meadows on the northern foothills of the Alps. There are said to be more than a dozen different hypotheses in the literature about their formation, including seismic forces such as those involved in the Mima Mounds or the Pimple Mounds in the USA. Their regular occurrence in airburst impact areas also suggests an impact-seismic connection, whereby the strong shock waves emanating from the impacts lead to soil liquefaction, which discharges upwards at weak points (e.g., in fracture zones) with hump formation. Such models exist for the thunder holes resulting from collapsed impact humps in the Chiemgau impact event. Soil liquefaction and point-like pressure discharge upwards at weak points during an earthquake in Japan are shown in Fig. 43. Hump structures could also form in this way during an airburst impact.

-- A special feature of the impact process in the vicinity of the kautes with their impact-related structures are systems of rib-shaped ground deformations, some of which are associated with larger crater structures, but also cover more extensive areas (Fig. 44), which is explained in comparison with other impacts in Fig. 44.

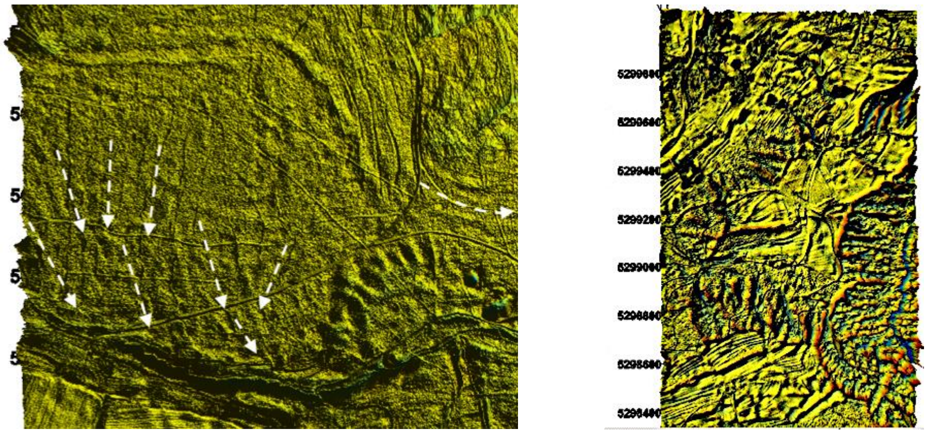


Fig. 44. DGM 1, terrain surface: rib structures at the craters (Fig. 39) and at the Bärnsee crater in the Chiemgau impact strewn field with striking similarities. The irregular overlaps of the rib systems in this model can arise from the fact that an airburst causes many neighboring impacts, from which the "earthquake waves" radiate outwards and overlap to form the ground rib systems.

-- Models of the formation of the ridges are shown in Fig. 45 and Fig. 46.

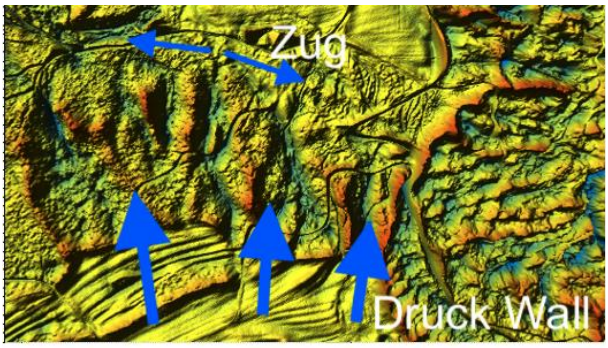


Fig. 45. Model of the formation of ribs as pressure-tension structures (transpression-transtension) at the crater rim.

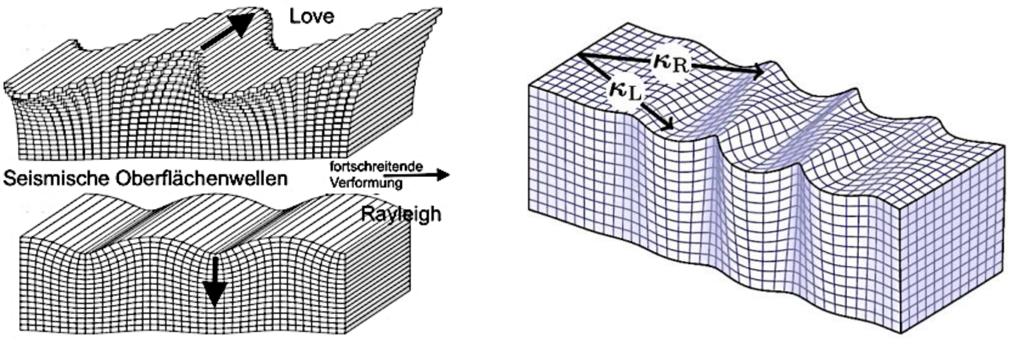


Fig. 46. Models of seismic surface waves and superposition with ridge formation. (heavily modified after Shearer 2009, left), Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License, Stefano Maranò (right). A model for ridge formation during impact "earthquakes" suggests itself.

-- The comparison already shown earlier between impact craters on the Moon and Mars and strikingly similar structures on Earth [7] is also significant in two examples in the Kauten crater field with the Teufelskaute (Fig. 47, Fig. 48).

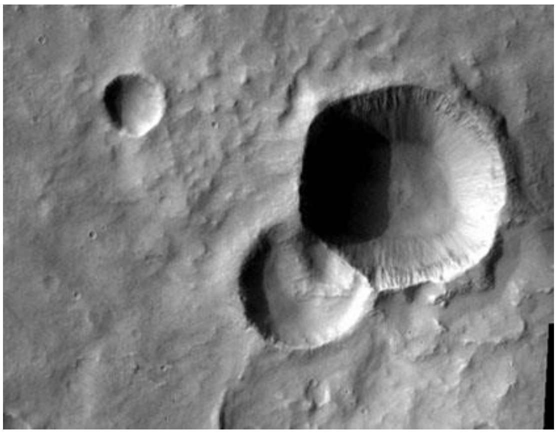
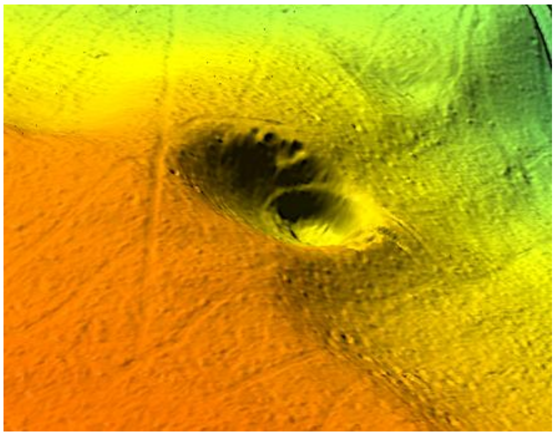
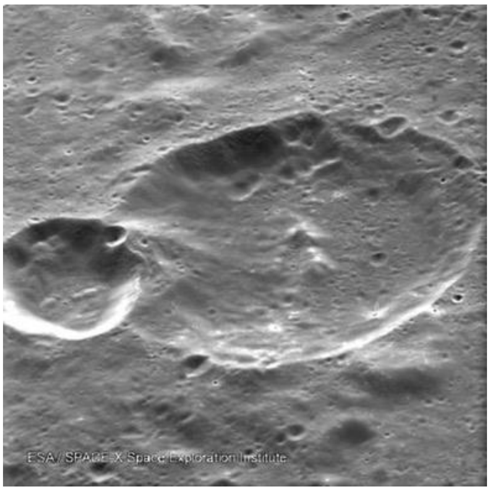



Fig. 47. An instructive comparison: a double impact crater on Mars and the double impact of the Teufelskaute (from Fig. 10). Photo: NASA space probe Odyssey.



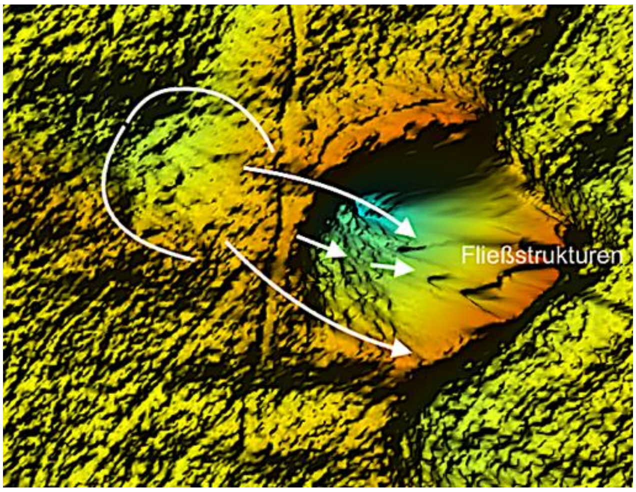


Fig. 48. Here is another impressive comparison: the Moon impact and the Teufelskaute impact (Fig. 16). The more or less simultaneous impact with the partial collapse of the contacting ring walls and the mass flow into the larger crater. ESA/SPACE-X (Space Exploration Institute).

6 Conclusions

The use of the extremely high-resolution digital terrain model DGM 1, whose data can now be downloaded online without any problems and fed into suitable evaluation programs, has opened up completely new avenues for impact research. Triggered by the impressive results of the newly addressed impact strewn fields in Germany and the Czech Republic, among which the Saarland impact and the Chiemgau impact stand out in particular, the impact strewn field of the Schlitzer Kauten has impressively joined their ranks. All other explanations for the formation of the Kauten that have been put forward to date are now invalid, although the original and initial hypothesis of the author R.A. about meteorite craters was already on the right track.

In impact research, the written rule generally applies that a meteorite impact and an impact structure are verified if the mineralogical findings prove clear shock effects or remnants of the projectile. In the case of the Saarland impact and the Chiemgau impact mentioned above, these criteria are more than adequately and convincingly fulfilled. The fact that these clear criteria are not yet met in the case of the Schlitzer Kauten impact can be attributed to the strict focus on the individual structures of the three kauten. Rückert's very detailed discussion in his thesis [5] of the various possibilities for the formation of the Kauten is commendable, although it should be borne in mind that the meteorite hypothesis was (naturally) based on the classical ideas of crater formation. A completely new picture of a wide-ranging airburst impact with small and shallow craters caused by explosive debris and earthquake-like soil liquefaction without the extremely high-energy shock processes was not even conceivable.

If the expected critics of a Kauten impact now point to the lack of mineralogical evidence, it can be countered that the morphological signature identified with DGM 1 is equally indicative of an impact due to a point source of deformation at a height above the Earth's surface. When classical impact mineralogy is used to argue that shock effects such as planar deformation structures (PDF) or diaplectic glasses or shatter cones do not occur in any other geological process and are therefore proof of impact, this must also apply without restriction to the perfectly symmetrical impact morphologies, for which there is no other geological process. In addition, it is very important to note that in an airburst impact above the Earth's surface, the energy of the shock fronts hitting the ground can vary greatly. Although this energy is capable of creating relatively shallow craters and enormous deformations through liquefaction, it does not necessarily generate the gigapascal-high pressures required for the shock effects mentioned above. This is also the difference between the airburst impacts in Saarland and Chiemgau, for example, where, in addition to significant shock effects, accompanying craters measuring kilometers in size were formed [12, 13, 15].

It has already been articulated that a paradigm shift in impact research is ultimately necessary [8].

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