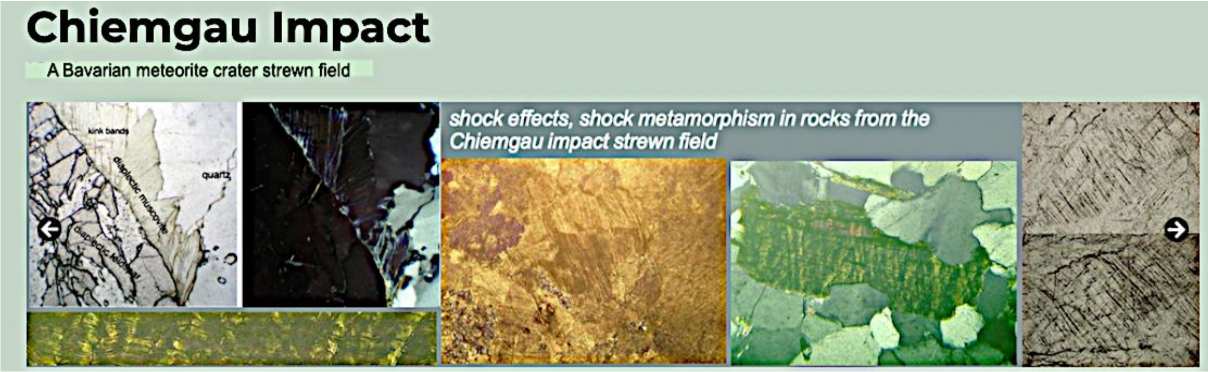
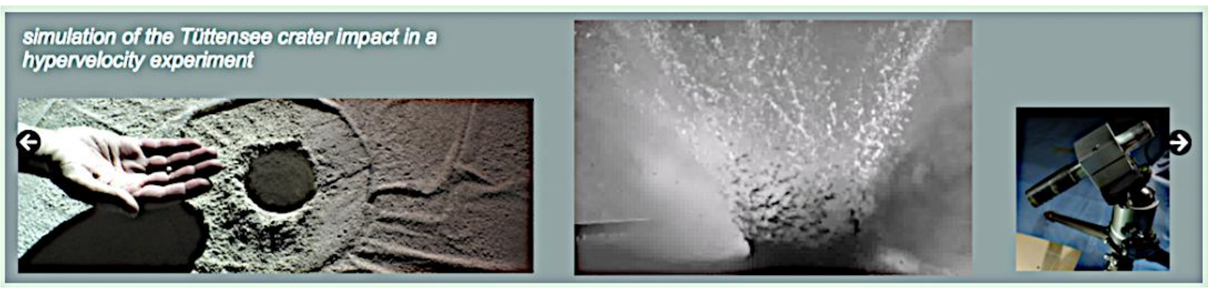


The Chiemgau Impact (Germany) meteorite crater strewn field and the role of high-resolution Digital Terrain Models. - Model craters, Part 3: the large craters

Kord Ernstson and Jens Poßekel

December 2025



The Chiemgau Impact (Germany) meteorite crater strewn field and the role of Digital Terrain Models. - Model craters, Part 3: the large craters

Lake Brunnensee/Griessee crater, Lake Obing crater, the Tittmoning (Asten, Leitgering) craters, Lake Chiemsee multiple crater, Eglsee crater, Lake Eschenau and Lake Laubensee craters, Lake Bärnsee crater, Lake Tüttensee crater ensemble

K. Ernstson[1] and J. Poßekel[2]

Abstract

As in Part 1 and Part 2, which dealt with the three most notable crater strewn fields of Emmerting 004, Kaltenbach, and Mauerkirchen, and the medium-sized craters, the focus here is again on the extremely high-resolution digital terrain models with horizontal resolution down to the meter and decimeter range and vertical resolution down to the decimeter and centimeter range, with larger multiple crater ensembles and individual craters with diameters up to 1,300 m. We repeat the statement from Parts 1 and 2 that this extreme resolution brings impact research close to a paradigm shift, which in turn is again a key aspect of this article. This is particularly relevant in the case of the Chiemgau impact, as the now documented low-altitude touchdown airburst impact is a matter of fact. The touchdown impact is also particularly relevant here, as in impact research, the physical processes of Rayleigh-Taylor instability and Kelvin-Helmholtz instability can play a significant role in the formation of very young craters in unconsolidated loose sediments, which is not the case with standard impacts in solid rock.

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1 Introduction

For readers who do not have quick access to Parts 1/2 with the study of the areas of the small and medium-sized craters, here is first a copy of the introduction with the most important current knowledge about the Chiemgau impact.

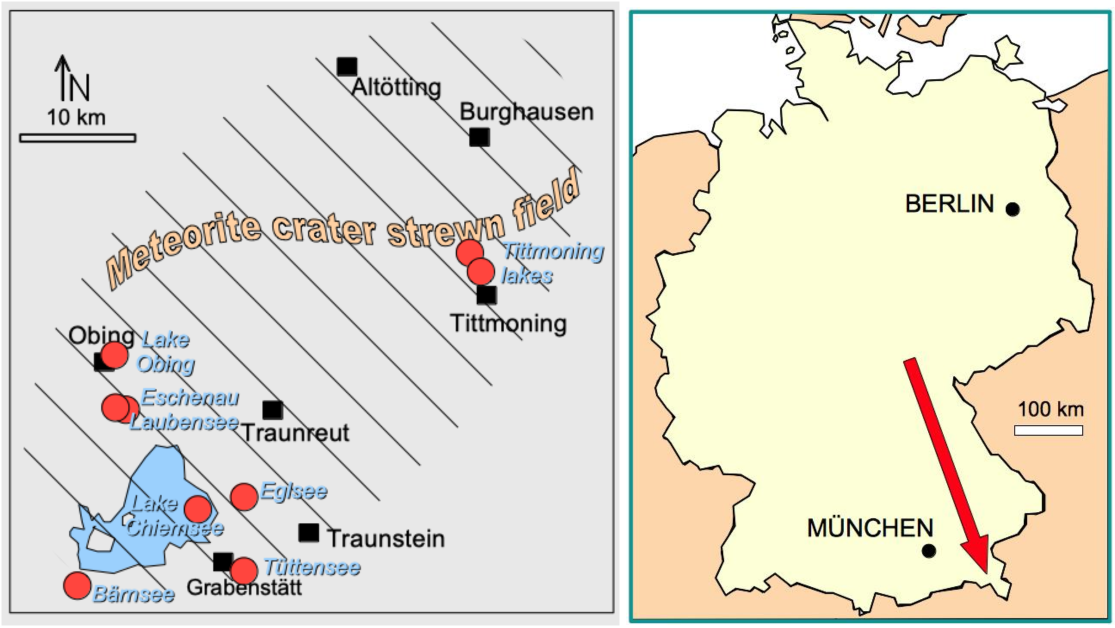
The Chiemgau strewn field discovered and established in the early new millennium (Schryvers and Raeymaekers, 2004; Schüssler et al., 2005; Rösler et al. 2005, Rappenglück, M. et al., 2005,Hoffmann et al., 2005, 2006; Yang et al 2008), extensively investigated in the following decade until today (Ernstson et al. 2010, 2011, 2012, 2013, 2014, 2017, 2020, 2023, 2024, Hiltl et al. 2011, Isaenko et al. 2012, Rappenglück, B. et al. 2010, 2020 a, b, c, 2021, Rappenglück M.A, et al. 2013,2014, Bauer et al. 2013, 2019, 2020, Shumilova et al. 2018, Ernstson and Poßekel 2017, 2020 a, b,2024, Ernstson and Shumilova 2020, Poßekel and Ernstson 2019, 2020), and dated to 900-600 BC in the Bronze Age/Iron Age (Rappenglück, B. et al. 2023) comprises far more than 100 mostly rimmed craters scattered in a region of about 60 km length and ca. 30 km width in the very south-east of Germany. The crater diameters range between a few meters and 1,300 m. The doublet impact at the bottom of Lake Chiemsee is considered to have triggered a giant tsunami evident in widespread tsunami deposits around the lake (Liritzis et al. 2010, Ernstson 2016). Geologically, the2

Craters occur in Pleistocene moraine and fluvio-glacial sediments. The craters and surrounding areas feature heavy deformations of Quaternary cobbles and boulders, impact melt rocks and various glasses, strong shock-metamorphic effects, and multiple geophysical (gravity, geomagnetic, electromagnetic, GPR, and seismic) evidence. Impact ejecta deposits in a catastrophic mixture contain polymictic breccias, strongly shocked rocks, melt rocks, and artifacts from Bronze Age/Iron Age people. The impact is substantiated by the abundant occurrence of metallic, glass, and carbonaceous spherules, accretionary lapilli, microtektites and of strange, probably meteoritic matter in the form of iron silicides like gupeiite, xifengite, hapkeite, naquite and linzhite, various carbides like, e.g., moissanite SiC and khamrabaevite (Ti,V,Fe)C, and calcium-aluminum-rich inclusions (CAI), minerals krotite and dicalcium dialuminate. The impactor is suggested to have been a roughly 1,000 m sized low-density disintegrated, loosely bound asteroid or a disintegrated comet to account for the extensive strewn field. A touch-down airburst is currently being discussed for the Chiemgau impact event (Ernstson et al. 2020, 2024).

A new situation for impact research on the Chiemgau impact has arisen in recent years in that the Digital Terrain Model DGM 1 is available online free of charge for the whole of Bavaria and thus for the entire Chiemgau impact field in the form of tiles measuring 1 km x 1 km, which can be downloaded in a matter of minutes as ASCII (x, y, z) files. The mesh size of the DGM 1 is 1 m with a vertical resolution of the terrain surface of 0.1 m, which can be interpolated into the decimeter and centimeter range using the SURFER program. SURFER data processing can be used to generate topographic maps with isolines of any density, shaded relief maps, and pseudo 3D models of the surface in any view orientation and color scaling (Fig. 1). In the same extremely high resolution, profiles of any orientation can be extracted from the generated maps, which enables a completely new approach to the analysis of crater morphologies.

A further step towards a completely new approach to impact crater research is made possible by the DGM 1, which eliminates buildings and all vegetation, including the densest forests, in the LASER processing of the digital terrain model, so that only the bare ground is registered and included in the data. These new possibilities for impact research have led to the gradual systematic examination of the tiles for promising morphological signatures. While the original documentation of the discoverers of the Chiemgau impact around 20 years ago already included around 80 craters, the number has been multiplied several times up, with the help of DGM 1 and the "thinning out" of the widespread forests and inaccessible swamp areas.

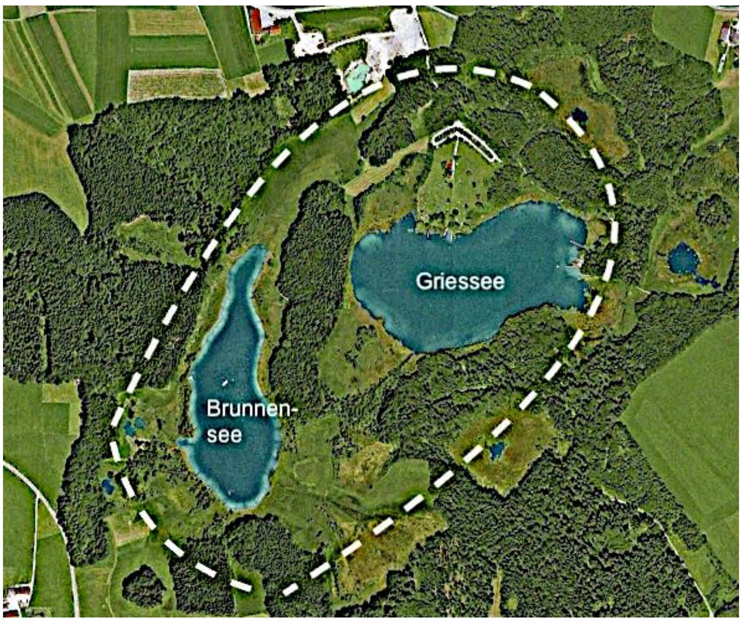
In this third part, we report on a summary of our research on a selection of the group of large-sized craters of the Chiemgau impact (Fig. 1), and we would like to highlight the impressive possibilities of data processing and graphical representations as the basis for the new approaches in impact research mentioned above.



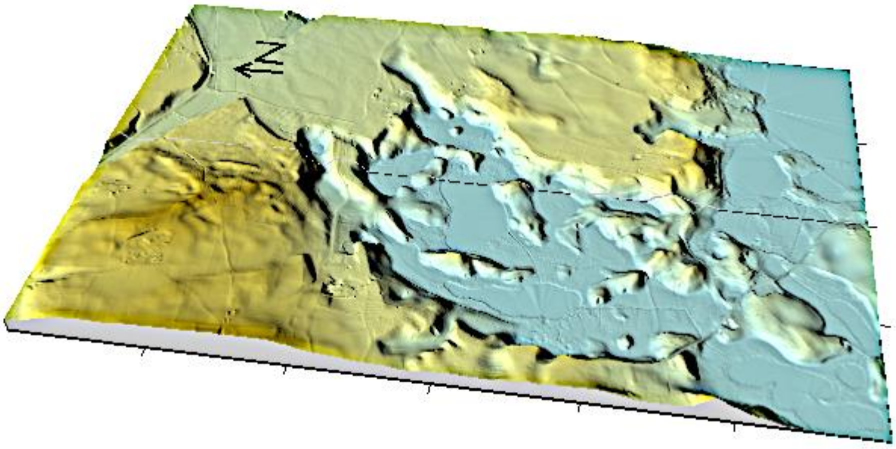
Location map: The selected large craters in the Chiemgau impact crater strewn field.

2 Lake Brunnensee/Griesseee crater

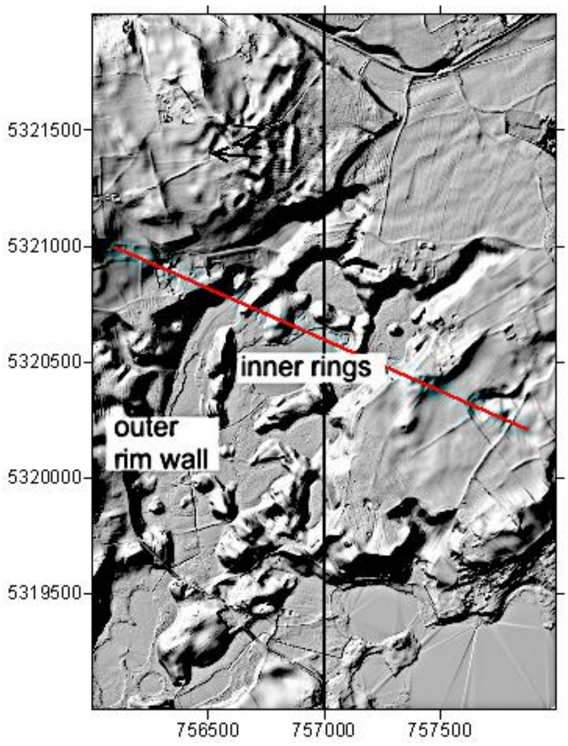
Lake Brunnensee and Lake Griessee are commonly regarded as parts of the ice age decay landscape of the Seeon lakes and formed from dead ice blocks. Ice age geologists and geomorphologists have understandably been unable to come to any other conclusions so far. However, with the data from the Digital Terrain Model DTM 1 and the newly recognized morphology, which unites both lakes into a uniform complex exhibiting the typical characteristics of an impact formation with rim walls and inner rings, a rethinking must take place in Bavarian ice age research.



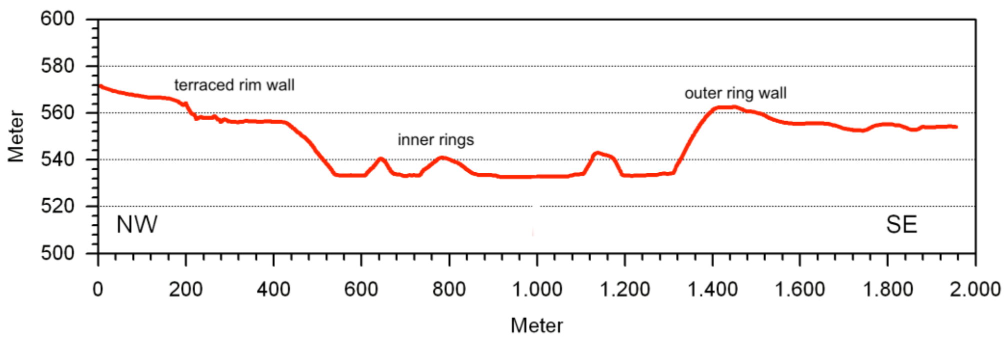
Rough outline of the Brunnensee/Griessees crater. Google Earth.



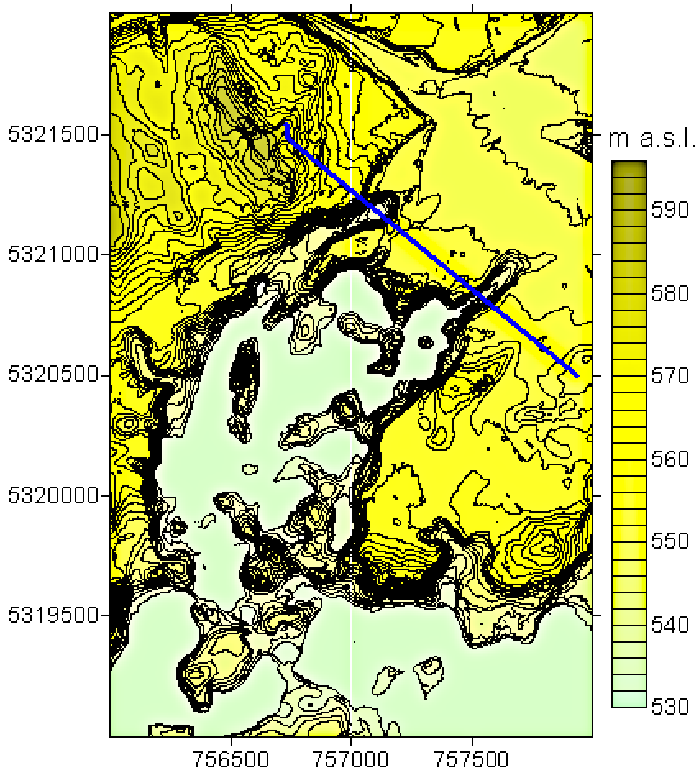
DGM 1 of the crater structure, terrain surface. Origin from dead-ice blocks can be excluded.



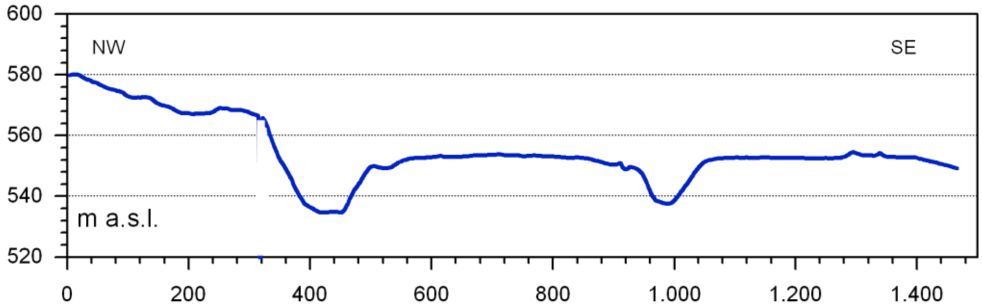
DGM 1 shadowed relief. Red profile below.



DGM 1 profile exhibits a complex multi-ring crater.



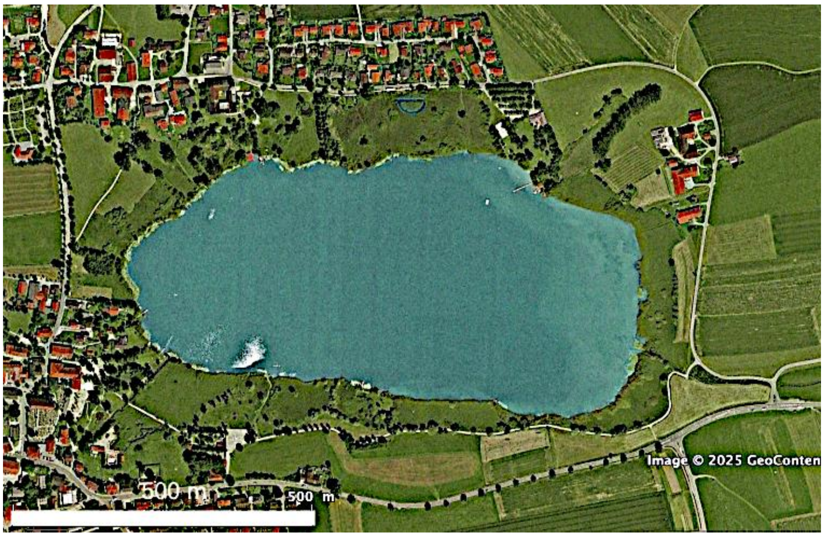
DGM 1 contour map, contour line interval 2 m.



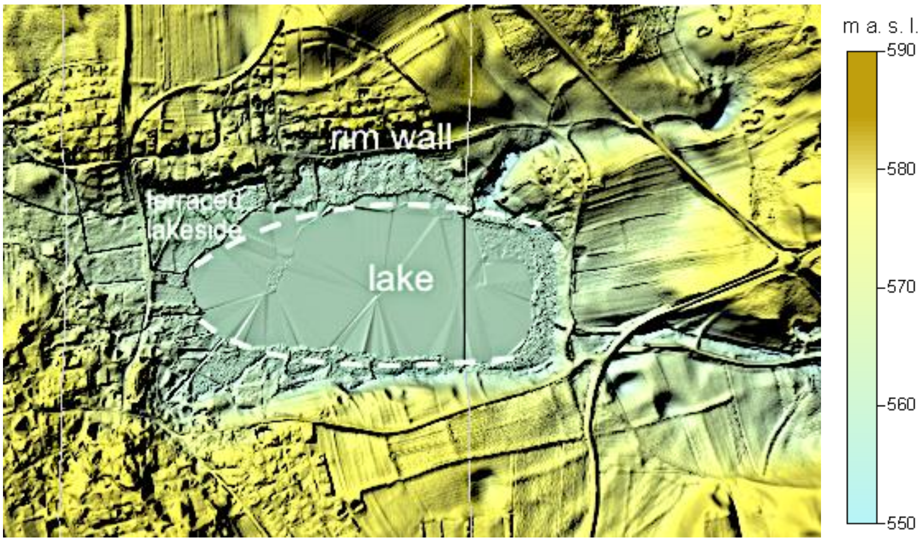
DGM 1 profile; the touchdown impact process remains enigmatic.

3 Lake Obing crater

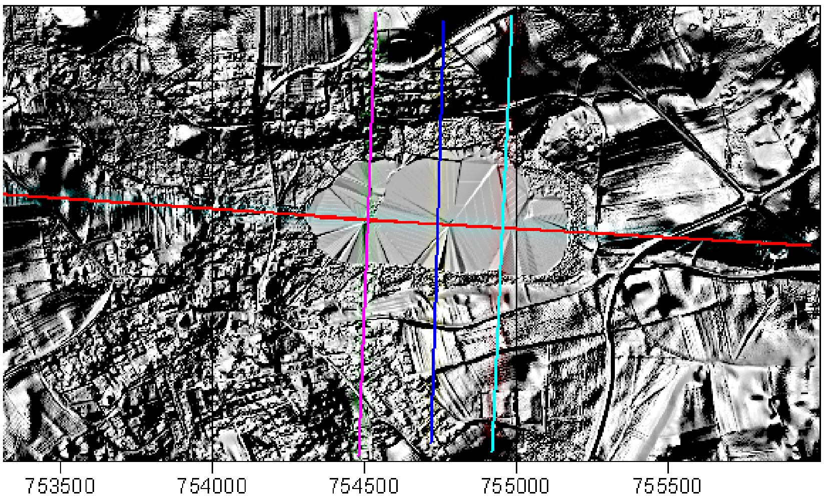
Lake Obing is generally considered to be a depression carved out by glacial ice during the Würm glaciation, with a maximum depth of 15-18 m, and therefore not a dead ice relic.



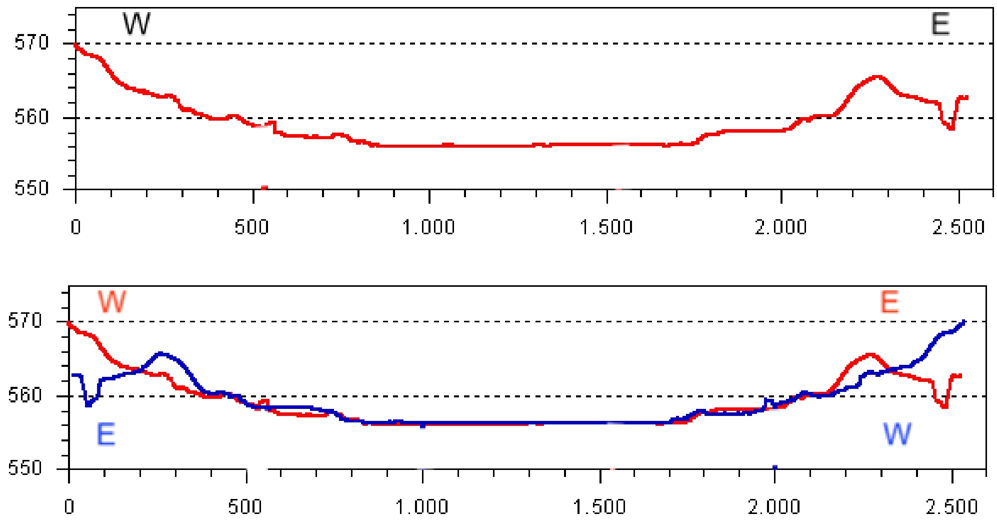
Lake Obing; Google Earth.



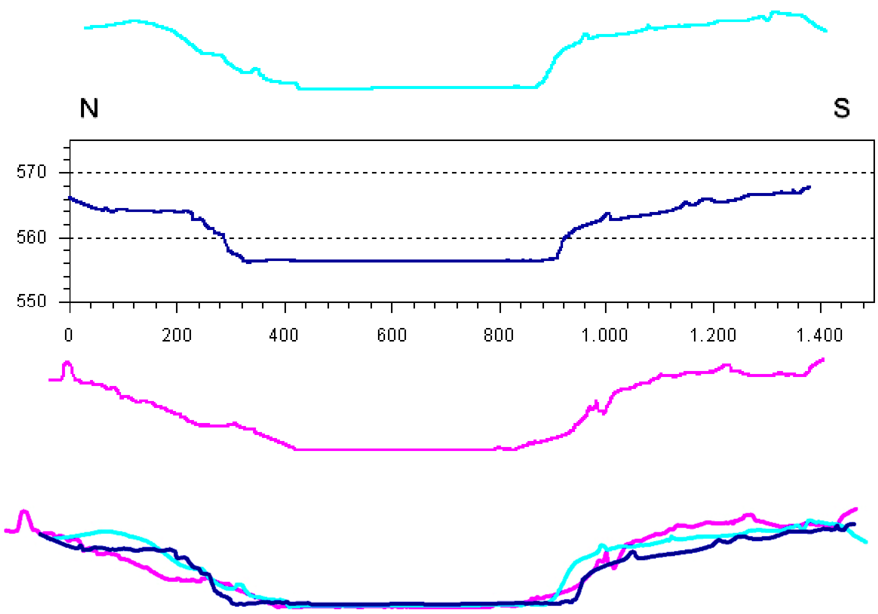
Lake Obing; DGM 1 surface map.



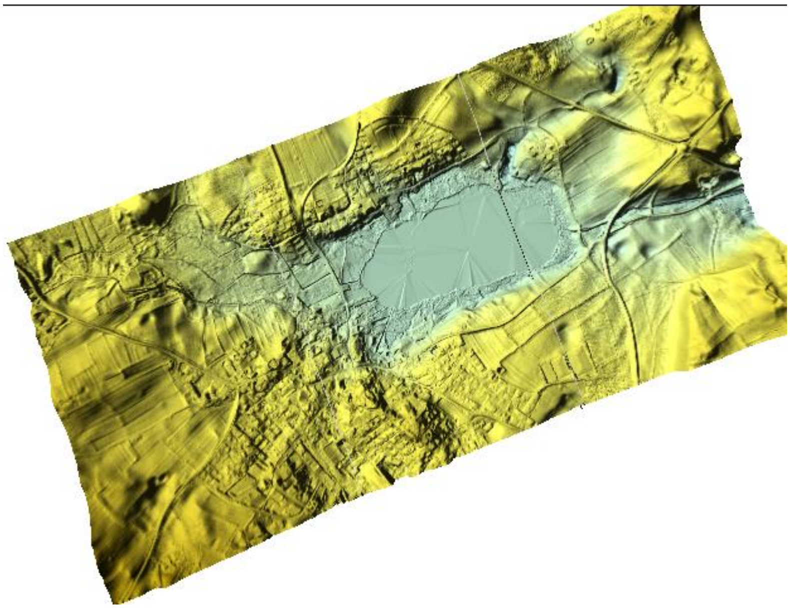
Lake Obing; DGM 1 shadowed relief map and profiles.

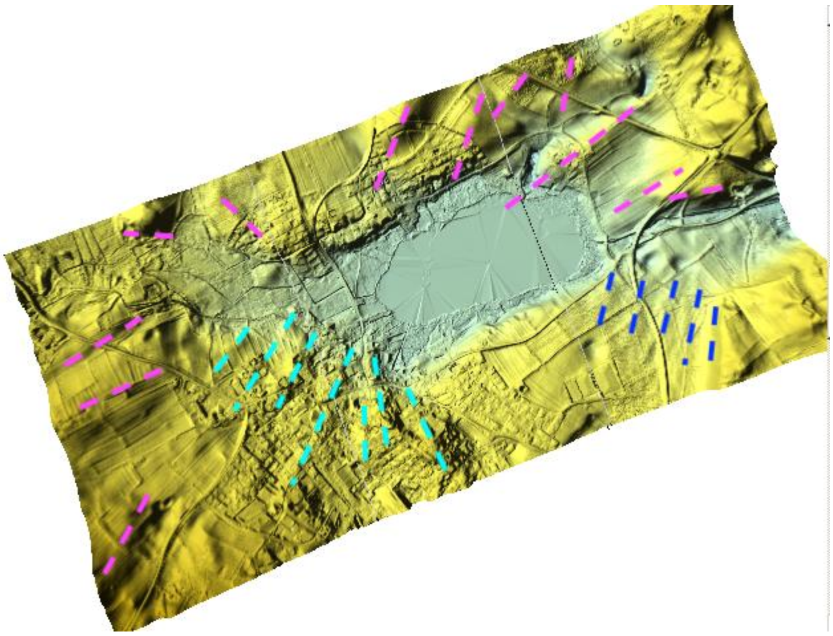


DGM 1 profiles W-E and mirrored profile E-W. The lakeside precision fit over a distance of 2,000 m is remarkably symmetrical.



The DGM 1 N - S profiles fit remarkably morphologically over a lateral distance of roughly 1,000 m.





DGM 1, Lake Obing crater terrain surface map showing fingered and wavy crater rims. Explanation:

Fingered impact craters, Rayleigh-Taylor and Kelvin-Helmholtz instabilities

From Google Chrome AI: The term refers to the fingering instability that can occur when an object impacts a viscous liquid or granular material, which can create finger-like protrusions around the rim of the resulting crater. These features are a result of fluid dynamics and instabilities like the Rayleigh-Taylor instability, and have been observed in laboratory experiments, but are not typically found in large, ancient impact craters on Earth, which typically form with a simple bowl shape, a central peak, or rings, depending on their size.

Laboratory experiments - granular materials: Experiments with granular materials show that "fingers" of material can form during the spreading of the crater.

Natural impact craters: No "fingers." The physics of natural impacts on rocky surfaces do not result in the "fingering" instability seen in experiments with viscous liquids or fine-grained granular materials. Why the difference? The key difference is the nature of the target material. A viscous fluid or fine powder is able to form unstable, finger-like structures, a behavior that does not occur in the solid rock of planets and moons.

Impact conditions (inertia, viscosity, etc.): If the impact inertia is too low, no fingers form; if it is too high, random splashing occurs.

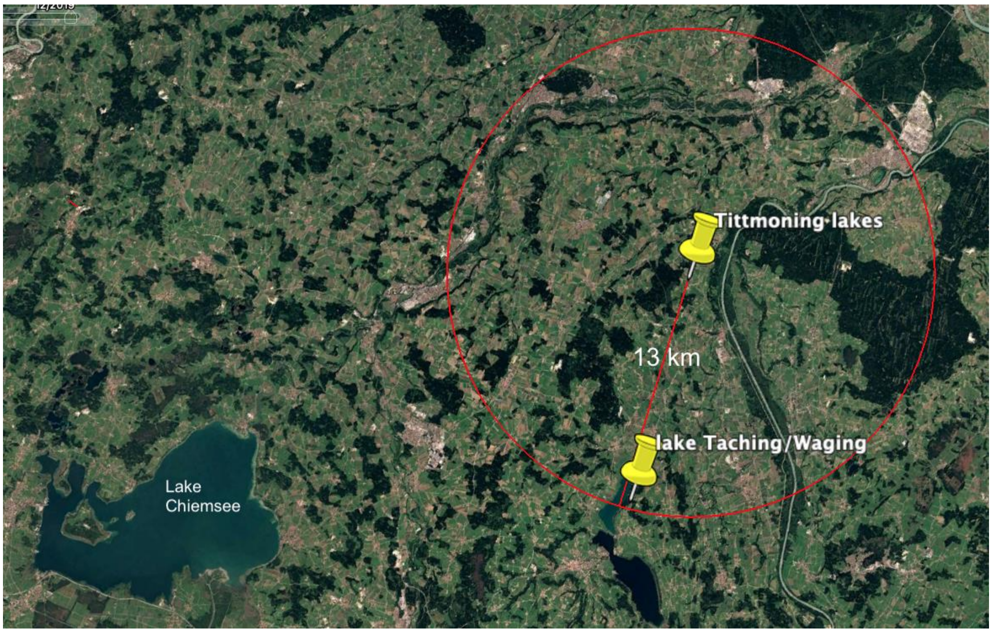
Kelvin-Helmholtz instability (Wikipedia) refers to the growth of small disturbances in the shear layer between two fluids with different flow velocities. The resulting phenomena are referred to as Kelvin-Helmholtz waves, Kelvin-Helmholtz vortices, and Kelvin-Helmholtz clouds, for example.

We add that the KHI may also lead to mushroom-shaped structures, and we will discuss the possibility of the formation of inner rings and "water droplet" uplifts by such instabilities in touchdown impacts in layered unhardened fine-grained targets in the final Discussion section.

4 The two craters near Tittmoning

Google Earth

The Tittmoning lakes, commonly considered Würm ice age dead-ice moraine basins.

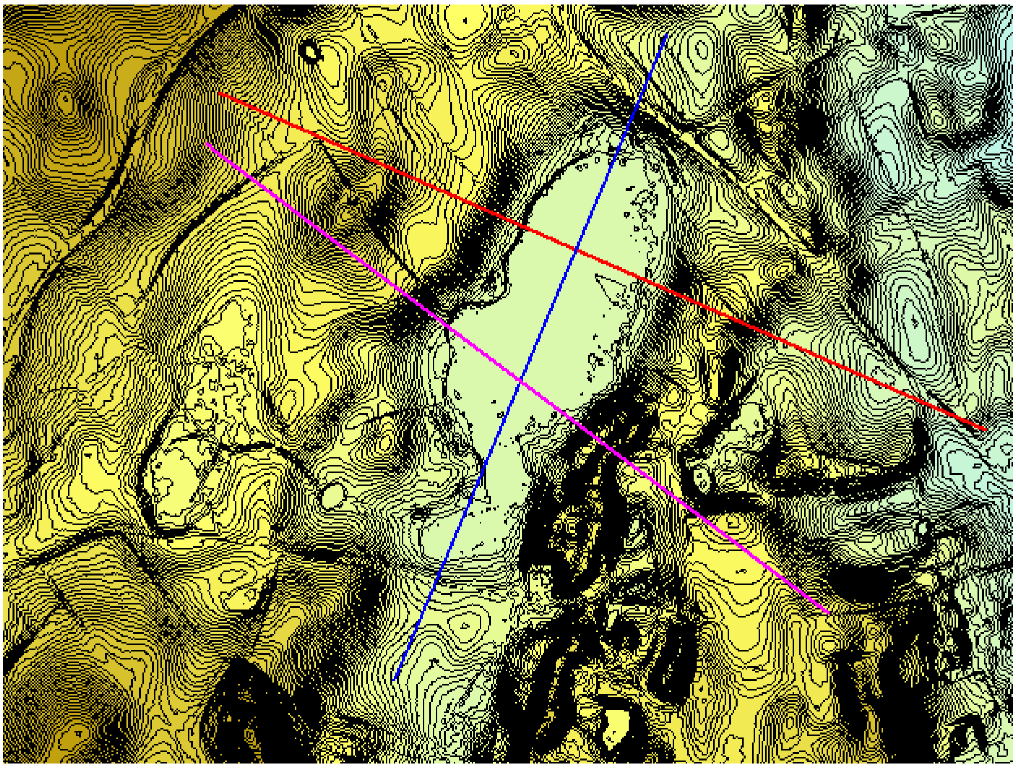


The Tittmoning lakes in the Chiemgau impact crater strewn field. The circle with a diameter of 26 km does not encounter another lake until 13 km away from the Tittmoning Lakes. The entire circle is completely free of lakes, as is the area extending far in other directions. It is difficult to imagine an ice age glacier retreat and moraine zone here.

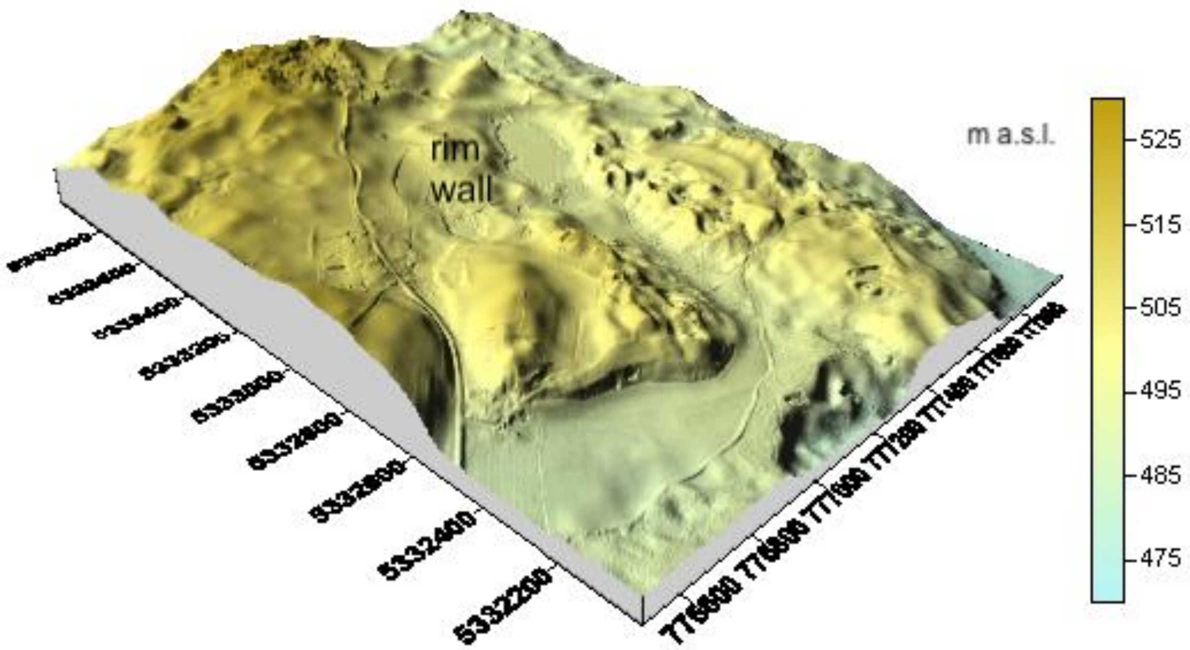
4.1 Crater chain Asten/Tittmoning

Wikipedia: The body of water known locally as Astner Weiher is a glacial lake that formed at the terminal moraine of the Salzach Glacier during the peak of the last ice age (Würm glaciation)

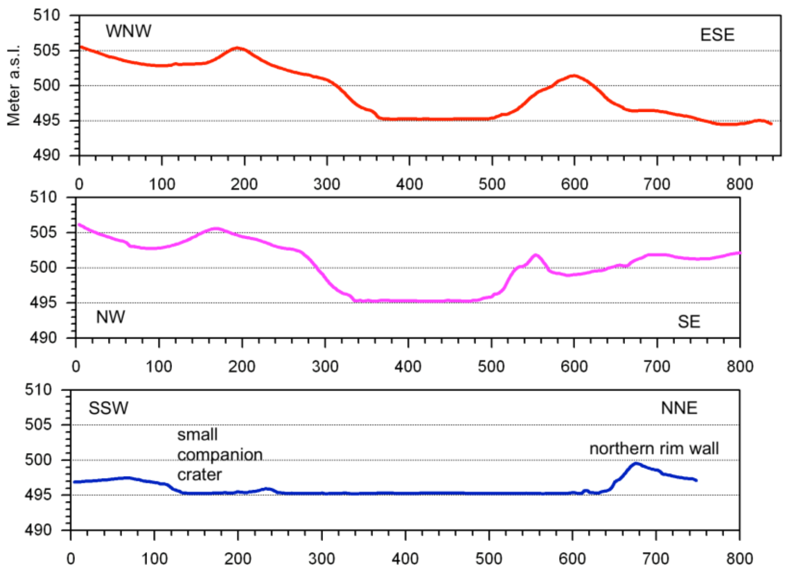
Lake Asten crater chain; Google Earth.



Lake Asten DGM 1 contour map, contour line interval 0.2 m. DGM 1 profiles see below.



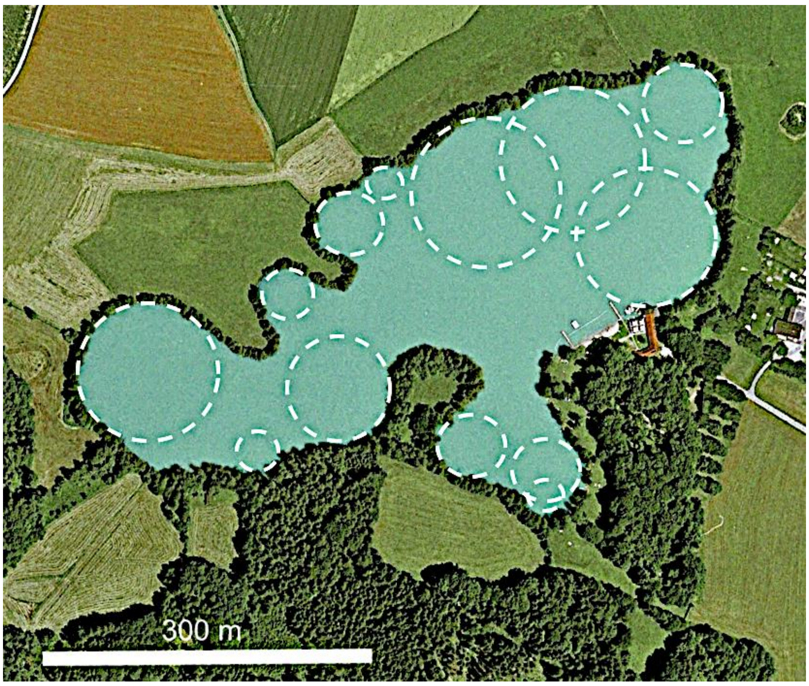
DGM 1 terrain surface of the Lake Asten crater.



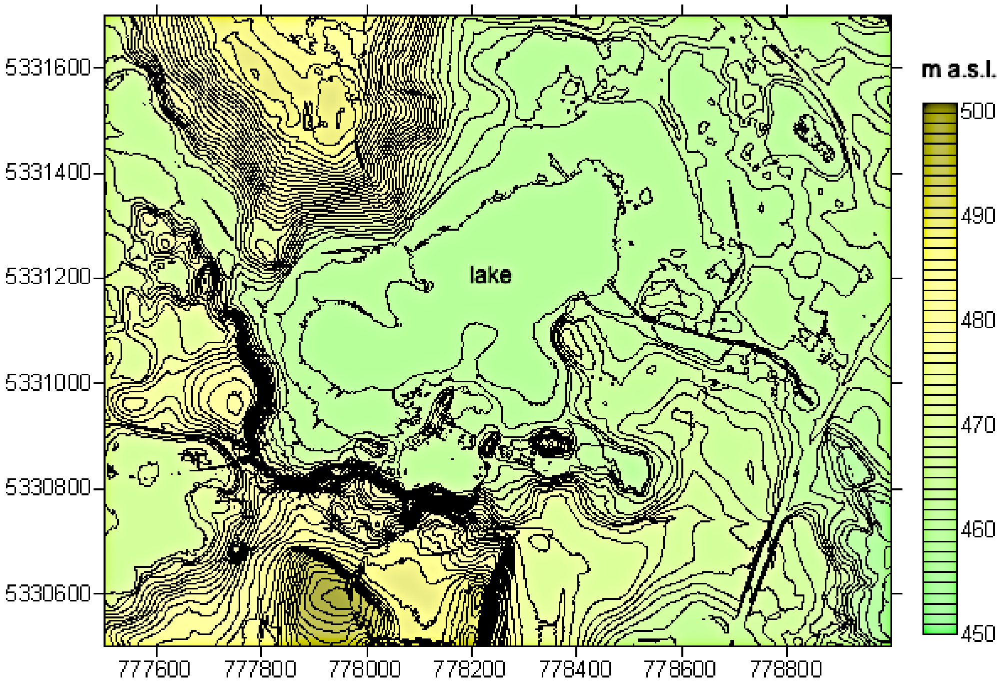
DGM 1 terrain profiles. The all round rim wall contradicts the ice age formation.

4.2 Furth/Tittmoning multiple impact, Leitgering crater

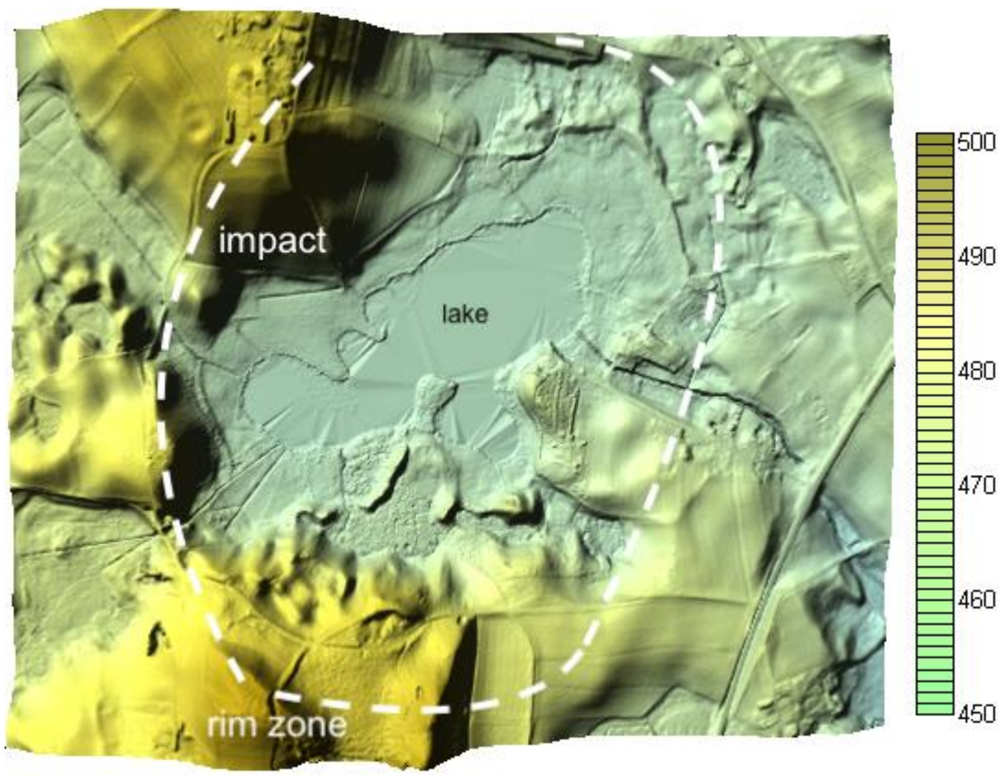
AI Google Chrome: Lake Leitgeringer is a remnant dead ice lake formed during the Ice Age. During the Ice Age, glaciers shaped the landscape, and the lake was created as the remaining part of a glacial valley between the moraines of the Radegunder and Lanzinger phases.



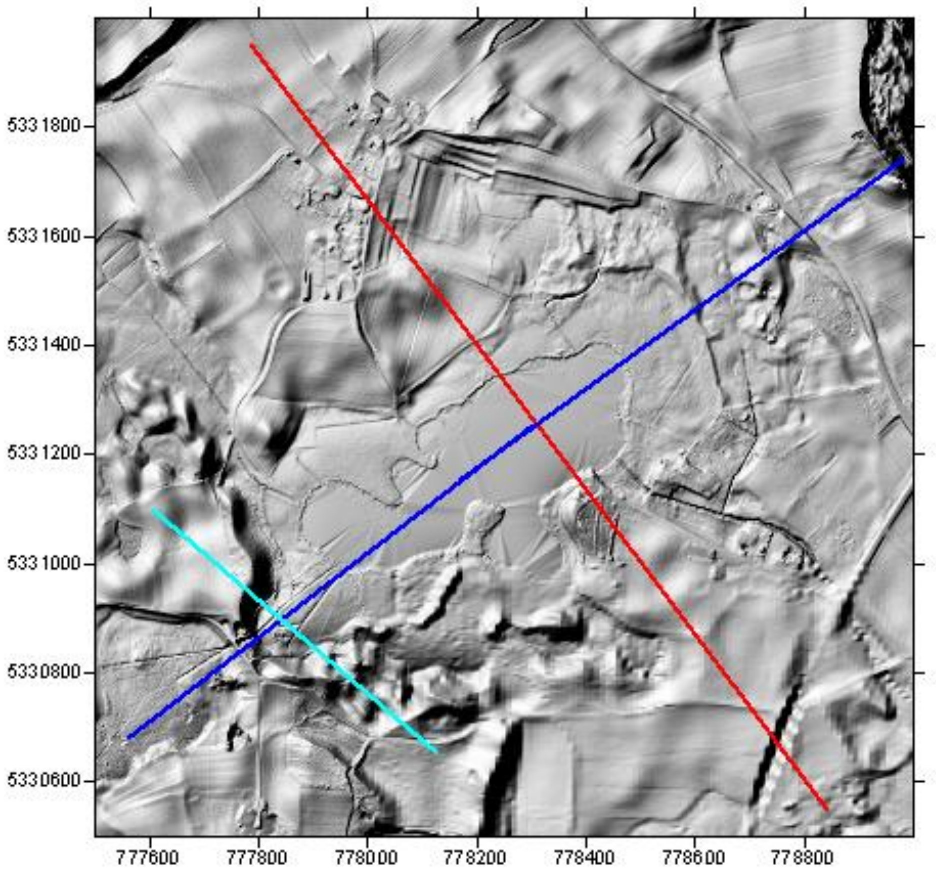
Google Earth, Lake Leitgering. The rim of the lake is conspicuously formed by strongly irregular overlapping almost perfect circular structures. It is difficult to imagine this being formed from a block of dead ice. A dense swarm of impacting cosmic projectiles seems more likely.



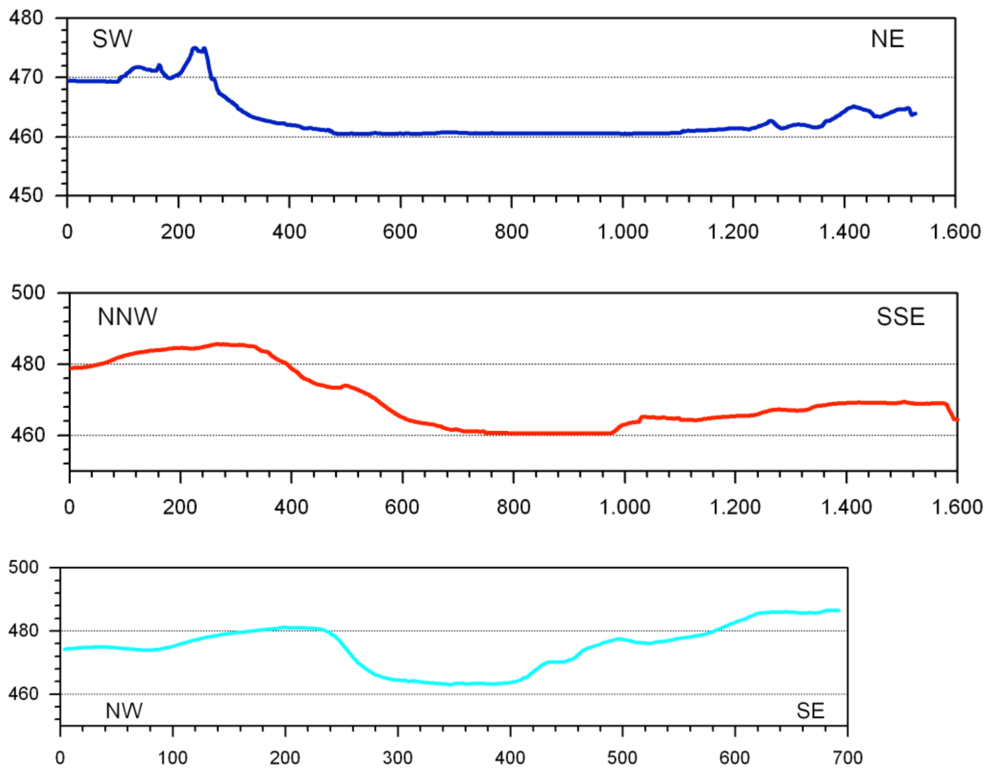
DGM 1 Lake Leitgering crater, contour map, contour line interval 1 m.



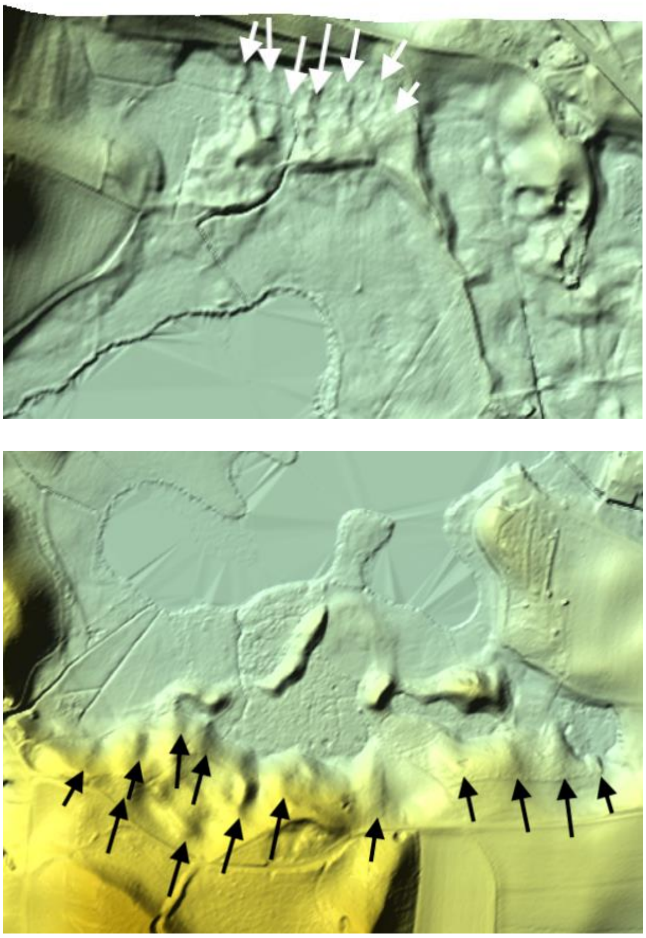
DGM 1 Lake Leitgering crater, terrain surface map establishing the impact rim zone.



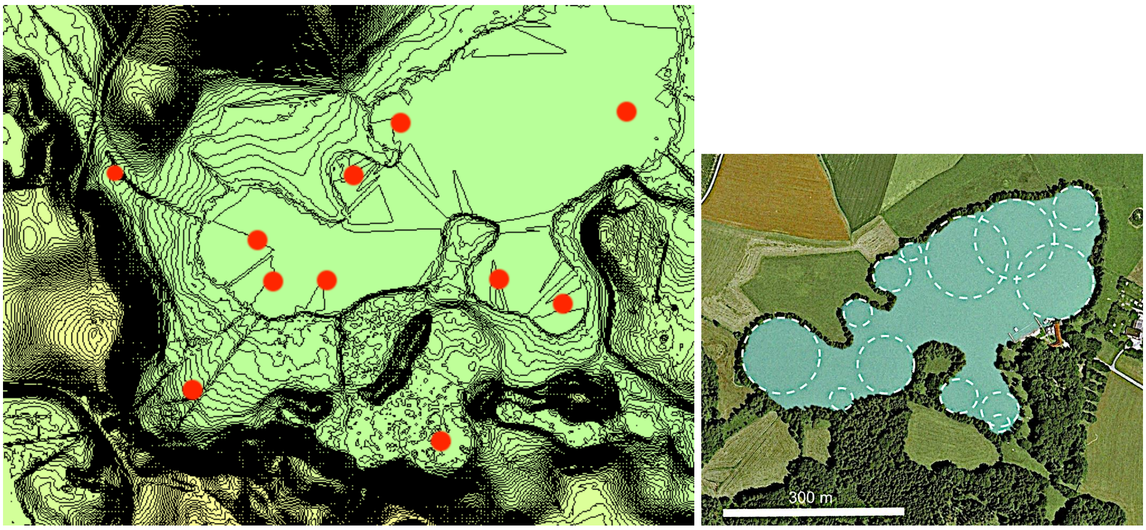
DGM 1 Lake Leitgering shadowed relief map and DGM 1 profile extraction (below).



DGM 1 profiles; a longitudinal and cross profiles.

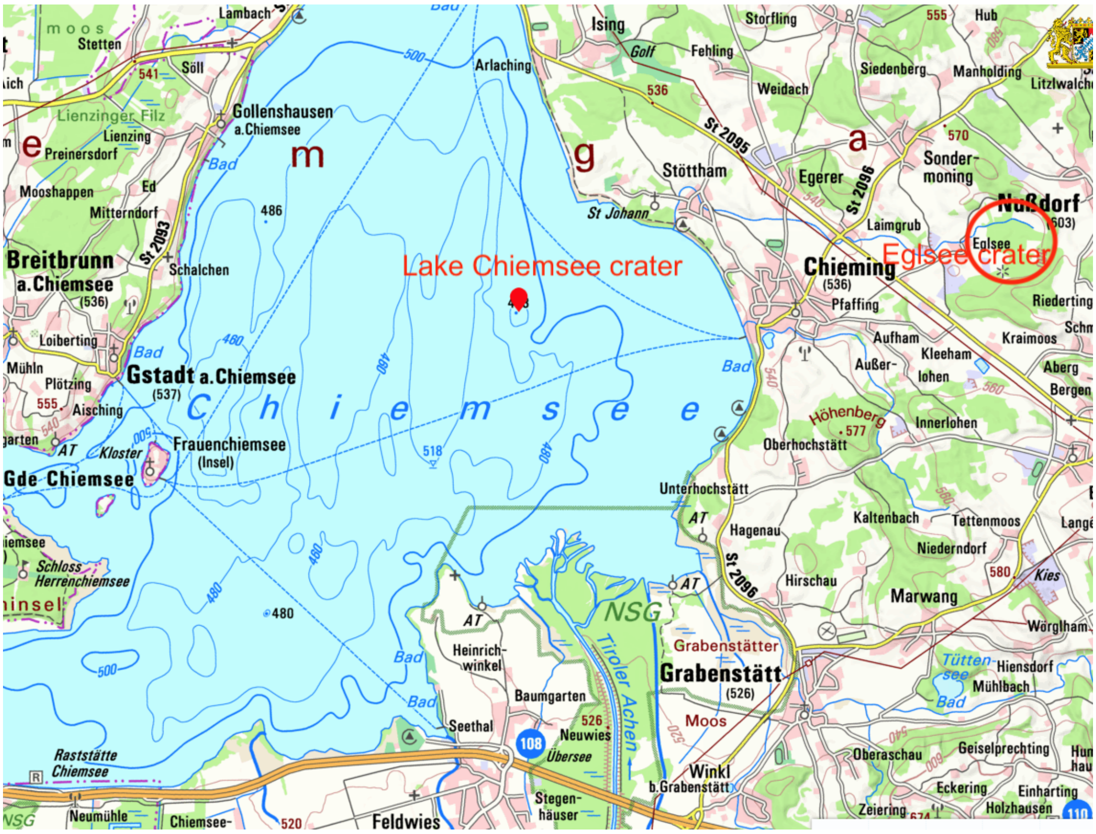


DGM 1 surface maps; Lake Leitgering fingered crater rims; looking for detailed comments on the Obing crater.

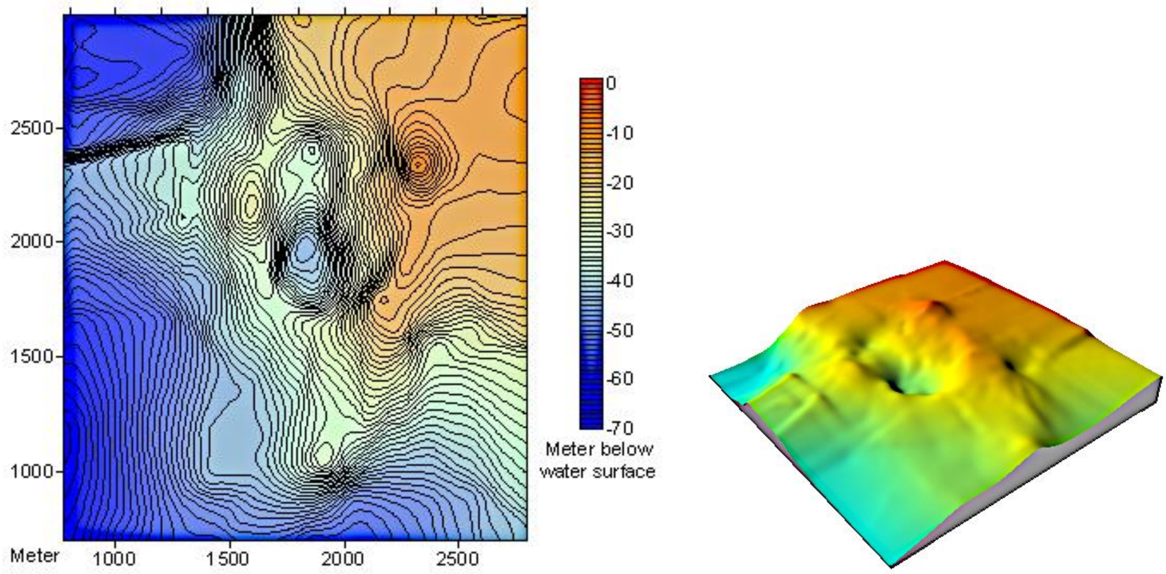


DGM 1 contour map. Suggested impact spots as midpoints of overlapping circular touchdown structures.

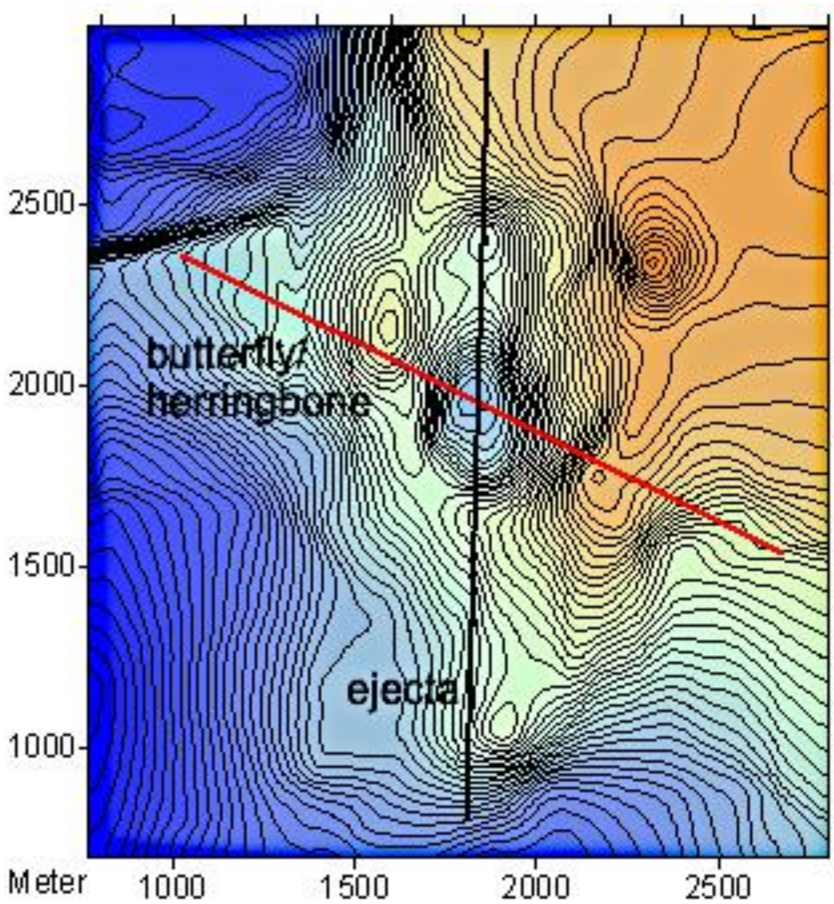
5 Lake Chiemsee multiple impact crater



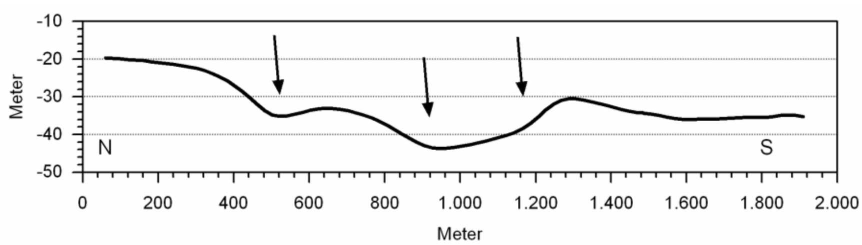
Location map for the Lake Chiemsee multiple impact (and the Eglsee crater discussed below). Map source: BayernAtlas.



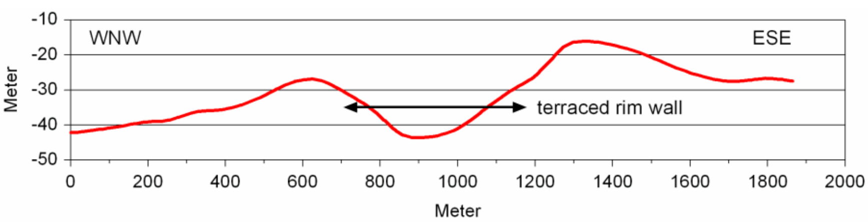
Contour map and 3D bottom map from echo sounder measurements.



Contour map of the lake bottom, profiles and ejecta interpretation. Butterfly ejecta is a well-known feature of Moon and Mars craters and also observed for several Chiemgau craters on land.

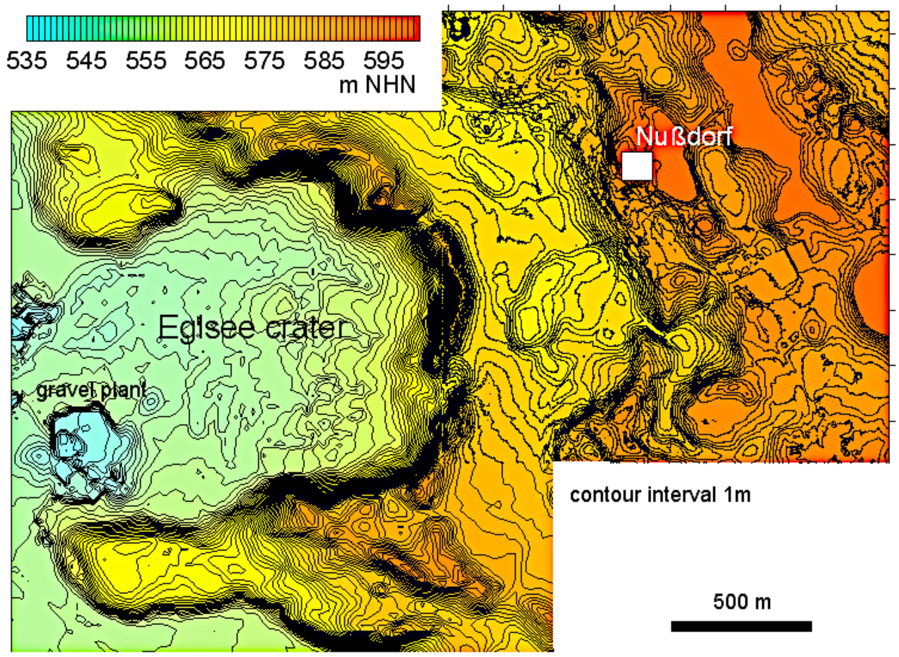


Three craters stringing on the bottom of Lake Chiemsee; DGM 1.

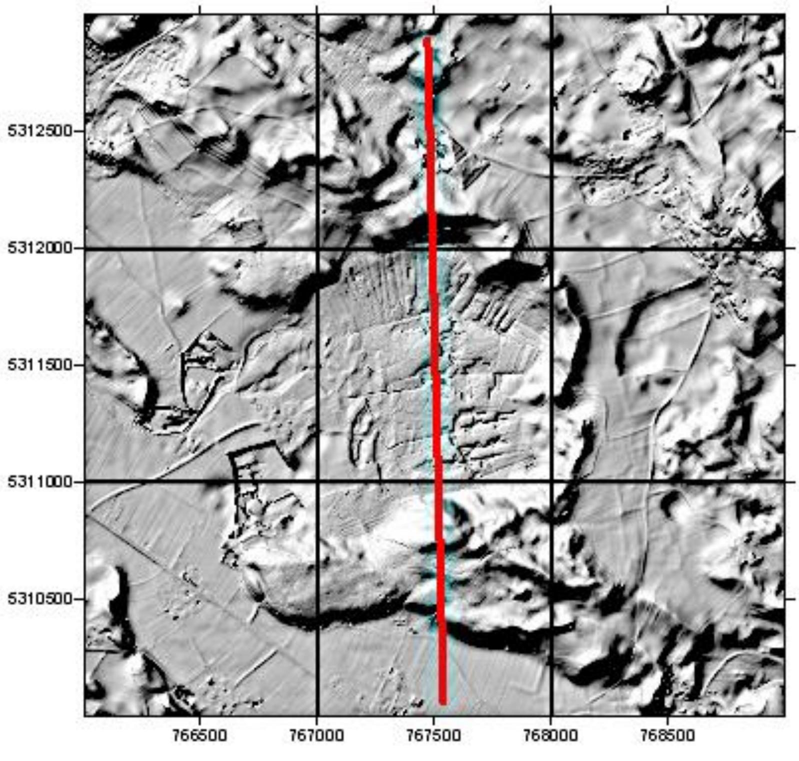


DGM 1 profile across the main crater.

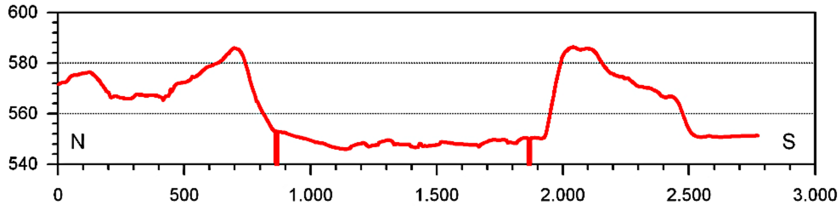
6 Eglsee crater



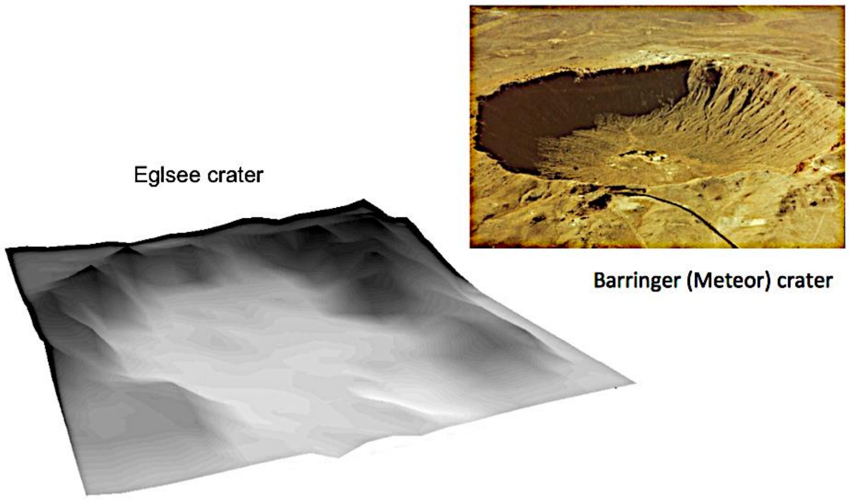
Topographic map of the Eglsee crater from DGM 1 data, contour interval 1 m. The hills east of the town of Nußdorf belong to a chain of terminal moraines. The difference to the Eglsee ring wall is striking. The opening of the wall to the west is discussed below.



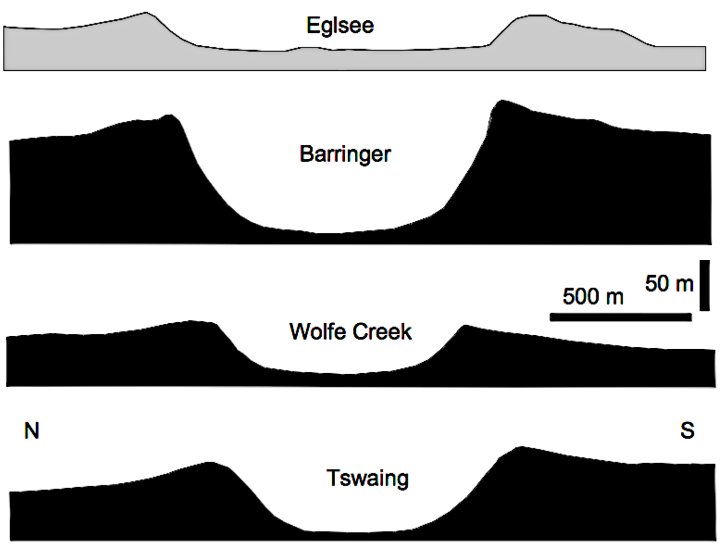
DGM 1 shadowed relief map of the Eglsee crater and a diametral DGM 1 profile (below).



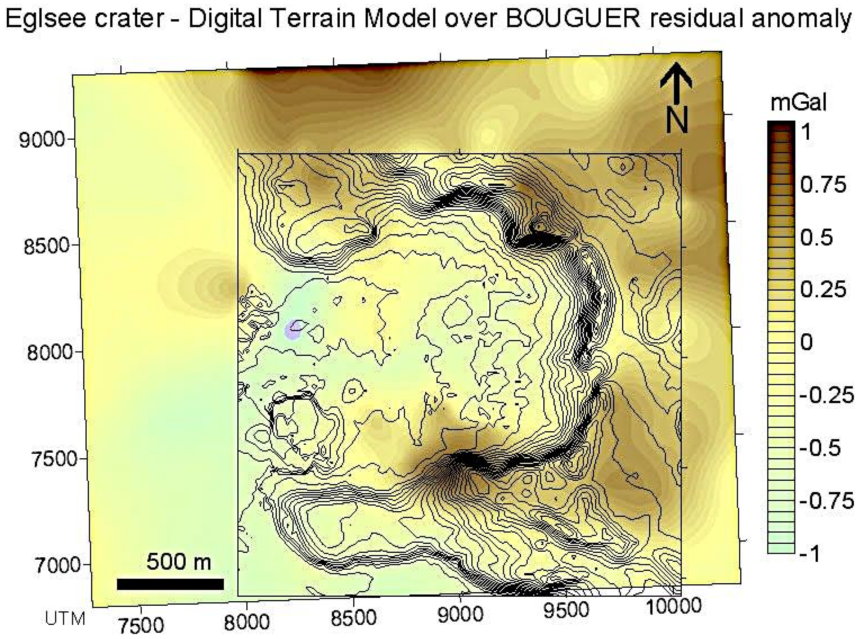
The Eglsee crater diametral profile from the above map.



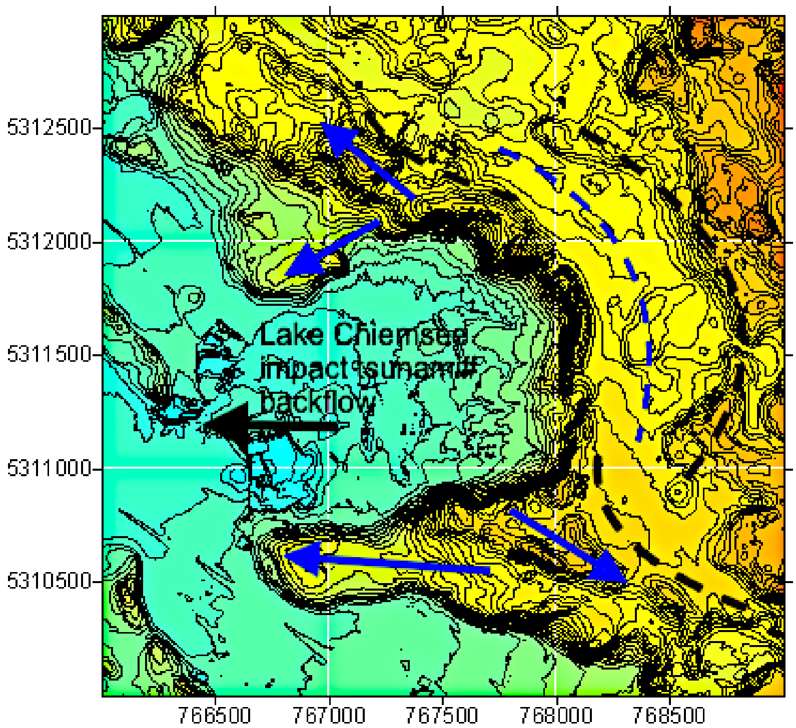
The similarly sized Eglsee and Barringer craters. DGM 1 map; Barringer crater photo: NASA.



Cross sections of young small bowl-shaped impact craters (from Goggle Earth, same scales) in comparison with the similarly sized Eglsee crater. The same shape of the rim walls is remarkable. The shallower depth of the Eglsee crater can be explained by the lower energy of the airburst touchdown impact or by partial filling with tsunami masses from the Lake Chiemsee impact (see below), or both.

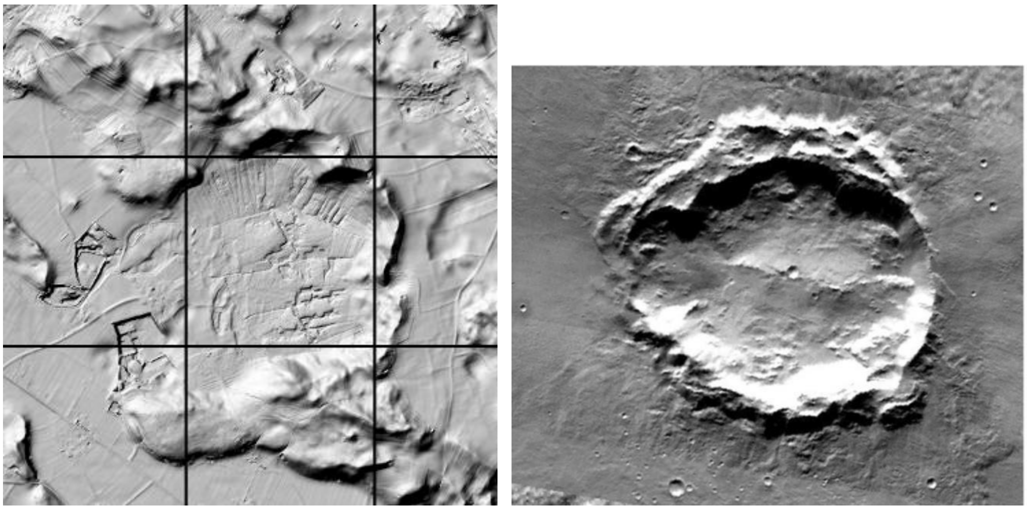


Superposition of gravity Bouguer residual map and DGM 1 contour map.



Blue dashed line: peripheral depression zone; black dashed line: outer ring.

Interpretation of the wall opening to the west. A: The opening of the wall to the west is explained as a secondary effect after the impact, when gigantic tsunami waves, possibly a few decameters high, overrun the just formed crater on their way from Lake Chiemsee only 2.5 km apart and, in particular, when the likewise strong tsunami return flow opened the loosely packed ring wall completely. - B: Highly oblique impact forming butterfly shape of the rim and ejecta zone (blue arrows). Also see images below.



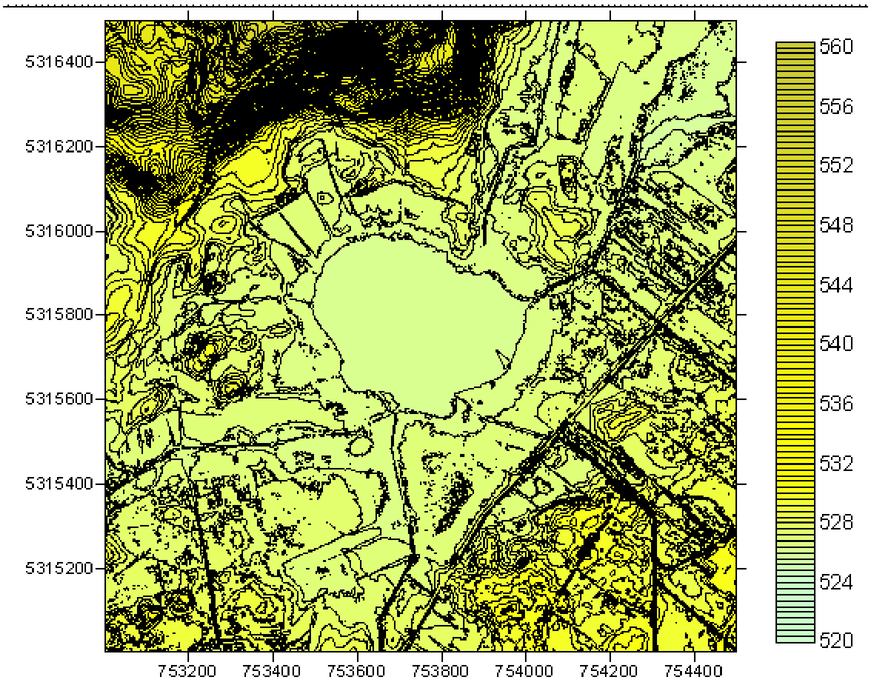
Eglsee crater and unnamed butterfly crater on Mars, 30 km diameter. THEMIS image. Oblique impacts in both cases?

Countless sharp-edged broken and heavily corroded boulders from the ring wall of the Eglsee structure. Identical impact deformations are found on the ring wall of the Tüttensee crater.

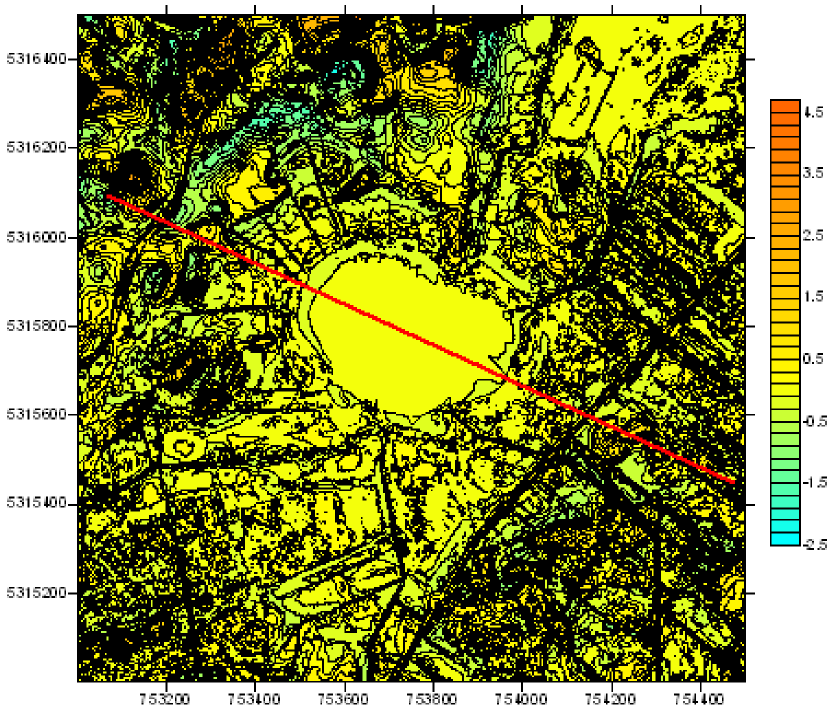
7 Lake Eschenau and Lake Laubensee craters

Lake Eschenau and Lake Lauben, located north-northwest of Lake Chiemsee, belong to the Eggstätt Lake District, which is commonly regarded as a collection basin of Würm-era dead ice basins, but which we now interpret as having been created by the large Chiemgau airburst impact. Google Earth.

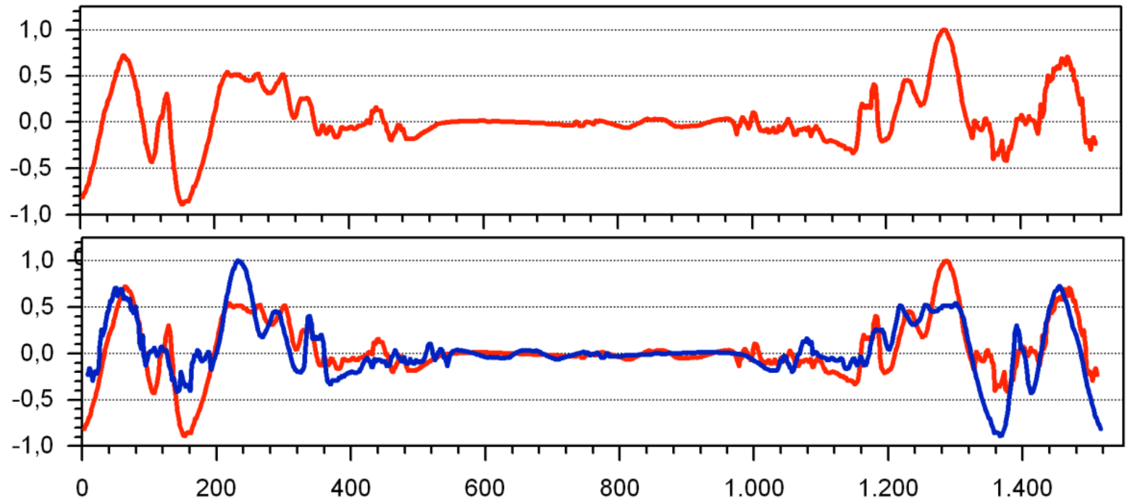
7.1 Lake Eschenau crater



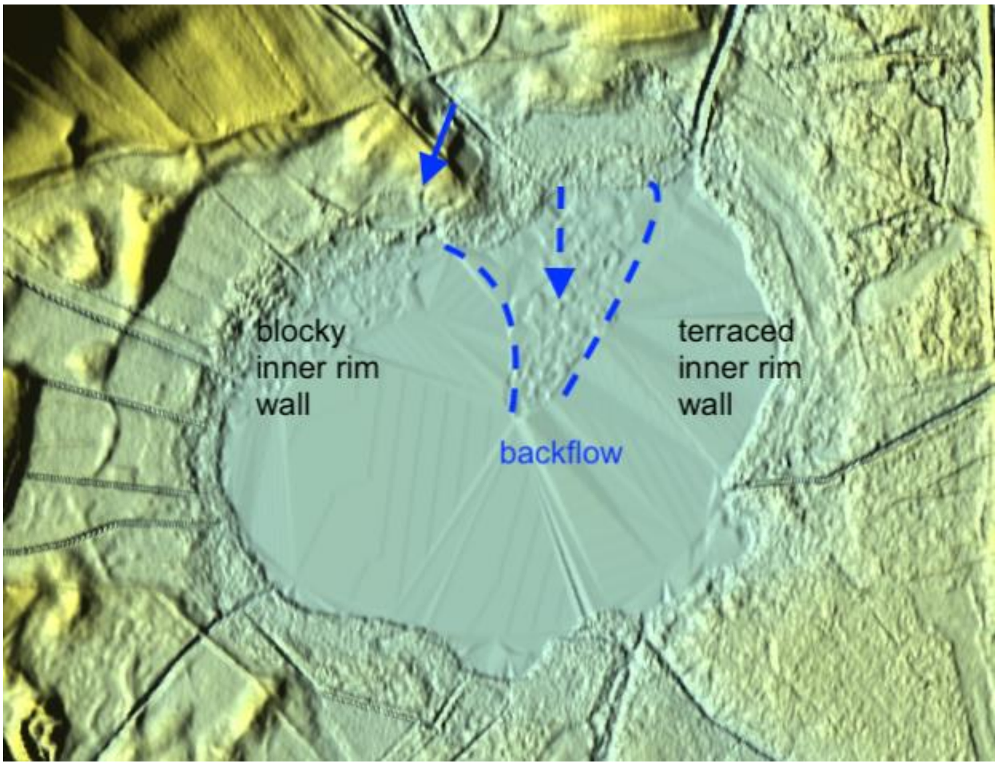
Lake Eschenau crater as DGM 1 contour map; contour line interval 0.4 m



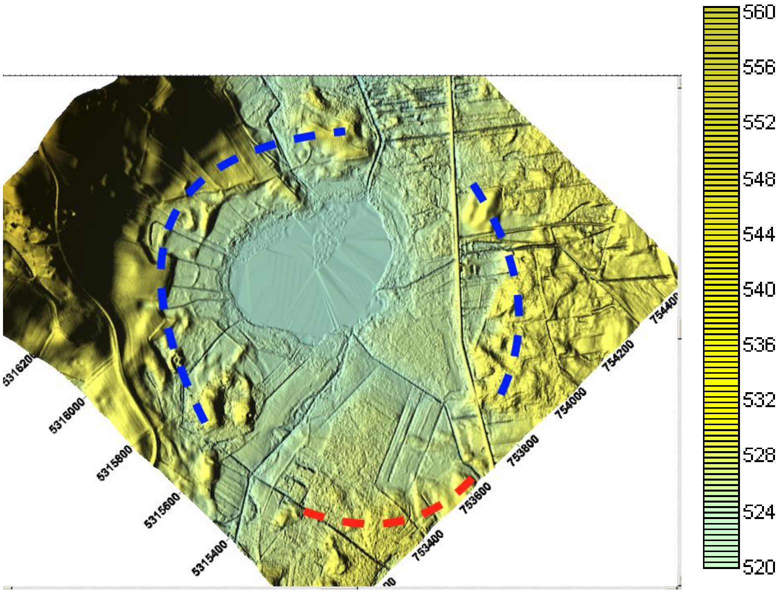
DGM 1 contour map, low-pass filter trend field removed. Contour line interval 0.2 m. DGM 1 profile below-



DGM 1 profile NW - SE and superimposed mirrored profile SE - NW (blue). The symmetrical accuracy of the 500 m wide edge zones is very remarkable and emphasizes the tremendous importance of the extremely high-resolution DGM 1 for researching young impact structures. In this case, too, the formation of a dead ice basin can be definitively ruled out.

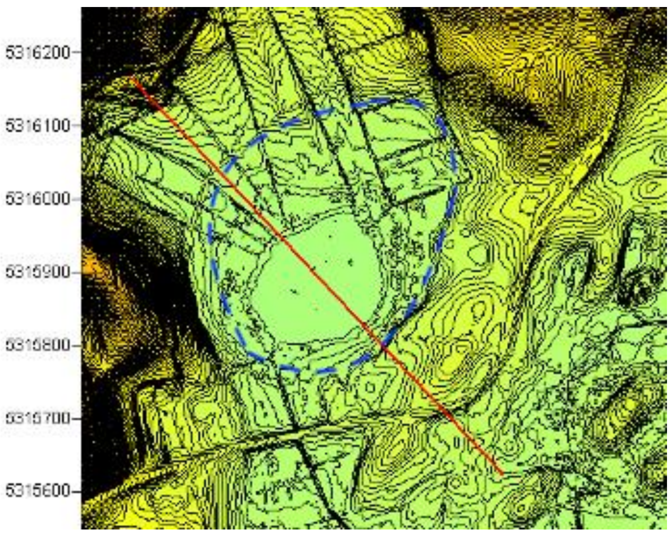


DGM 1 terrain surface map; inner crater lake depression and backflow from collapsed inner rim wall.

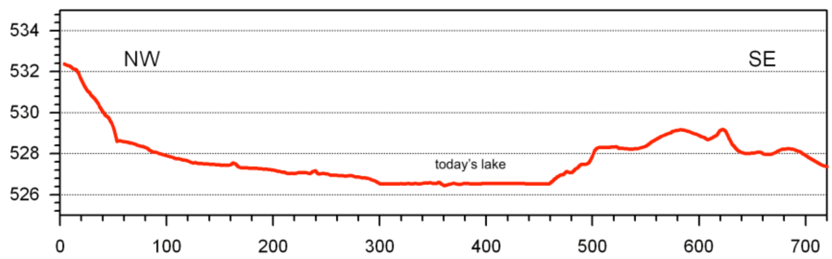


DGM 1 surface map; Lake Eschenau, outer rim zone. Rayleigh-Thomsen and Kelvin-Helmholtz instabilities (copy Obing crater, above): *Impact conditions (inertia, viscosity, etc.): If the impact inertia is too low, no fingers form; if it is too high, random splashing occurs.* - Blue: inertia, viscosity (we add density) too high, and random splashing of the rim wall occurs. Red: fingered rim wall: *These fingers may retract, but the process can get "jammed," leaving finger-like protrusions on the surface of an asymmetric crater.* Lake Eschenau clearly exhibits precisely these target instabilities, which can be easily explained by the contact between layers of vastly different viscosities. The lake is only 2-3 m deep, which should also be the depth of the surrounding groundwater table in the gravel moraine.

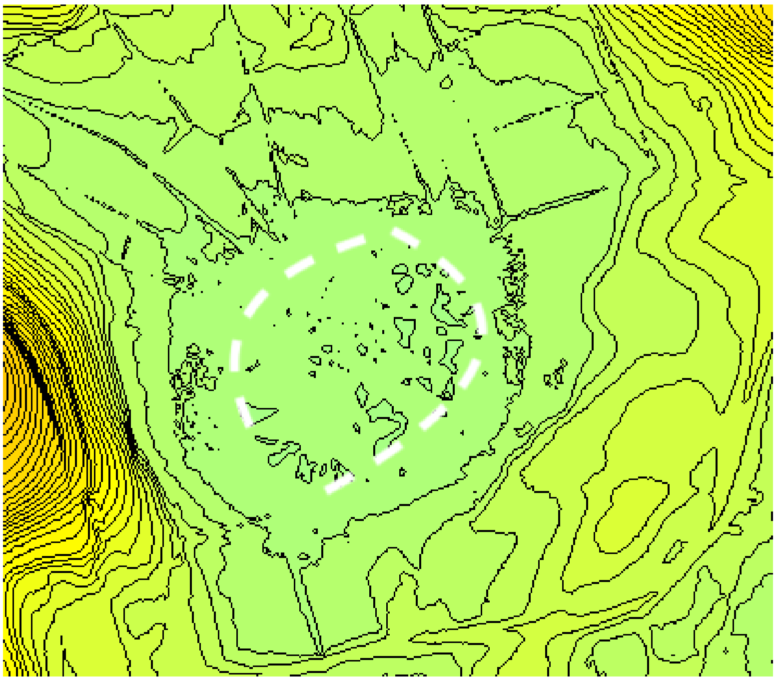
7.2 Lake Laubensee crater



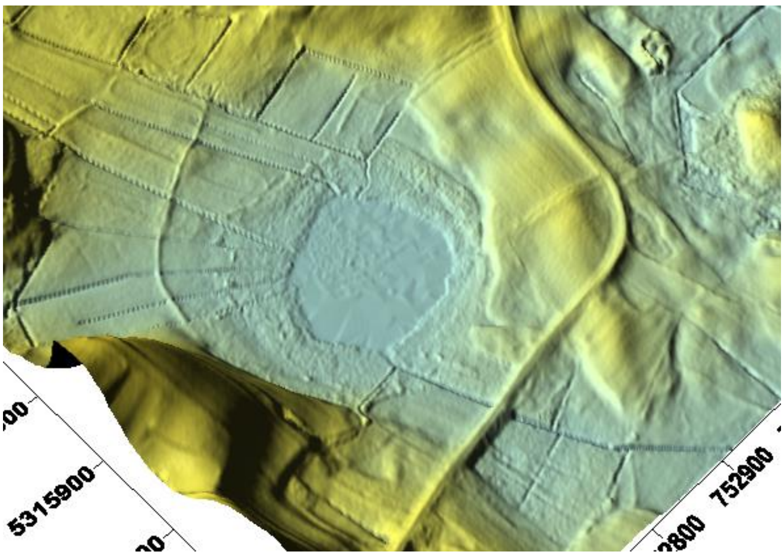
Asymmetric elliptical inner crater structure and profile. DGM 1, contour line interval 0.2 m.



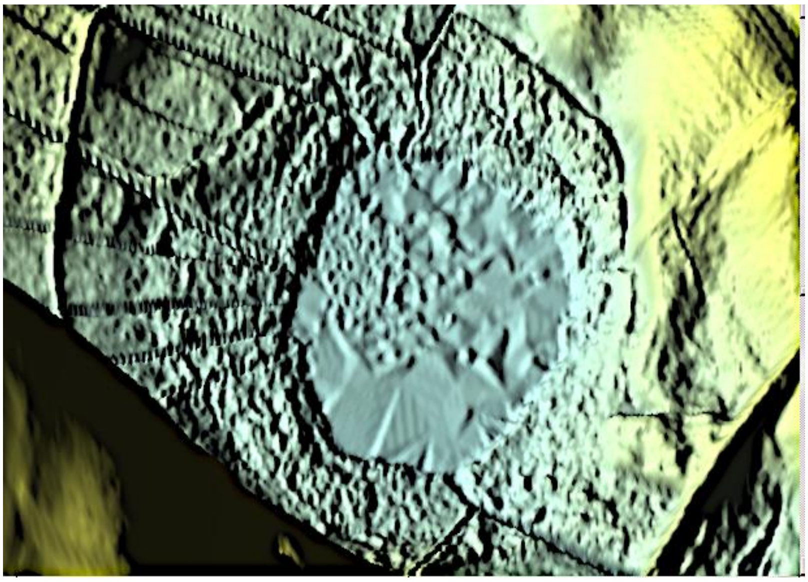
DGM 1 profile.



Probably inner ring just below the water surface overgrown with aquatic plants. The maximum lake water depth is only 2 m.



DGM 1 surface map of Lake Laubensee crater.

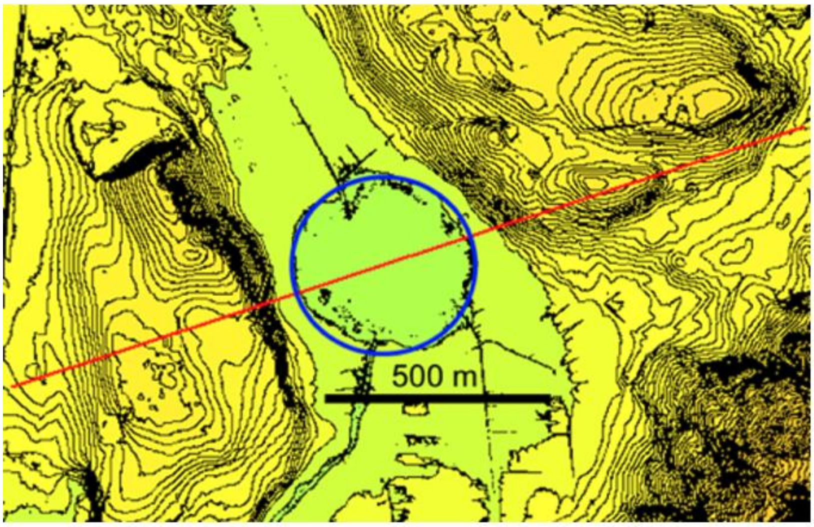


DGM 1 surface, detail. Modification stage: staircase shaped backflow of ejecta blanket around the central lake crater depression. The backflow masses may be deposited just below the water surface enabling overgrown with aquatic plants (see image above with inner ring). The current ice age dead-ice hole interpretation can definitely be excluded.

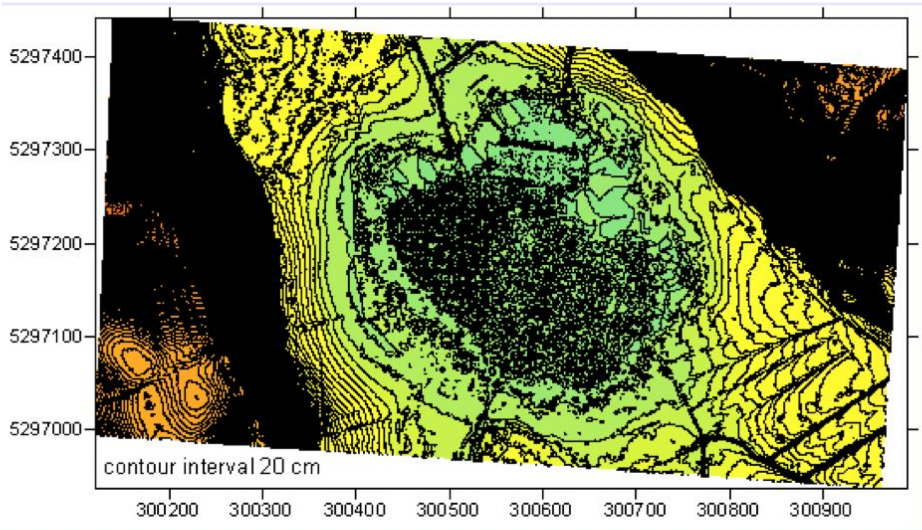
8 Lake Bärnsee

Geologically, the depression os currently interpreted as the former tongue basin lake of the Prien Glacier. Over many thousands of years, silting caused the tongue basin lake to shrink to a bog. With the DGM 1, we can show that this interpretation can no longer be upheld; see the iPoster for more information.

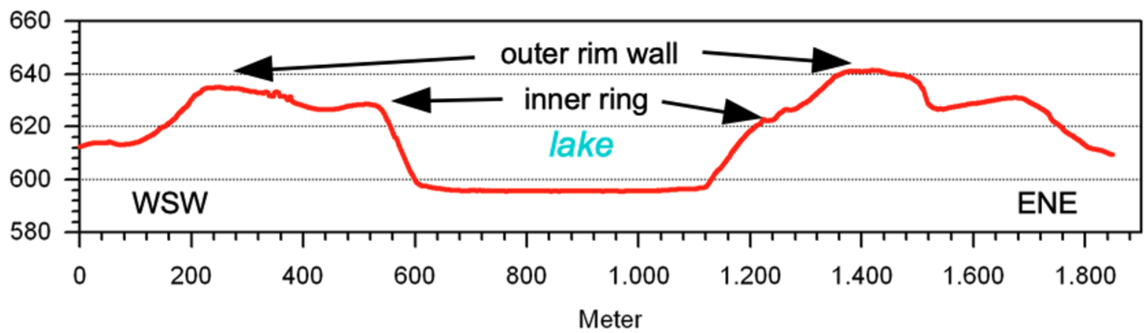
Lake Bärnsee in a Google Earth aerial view (2024). The rounded, almost circular vegetation and soil color are striking.



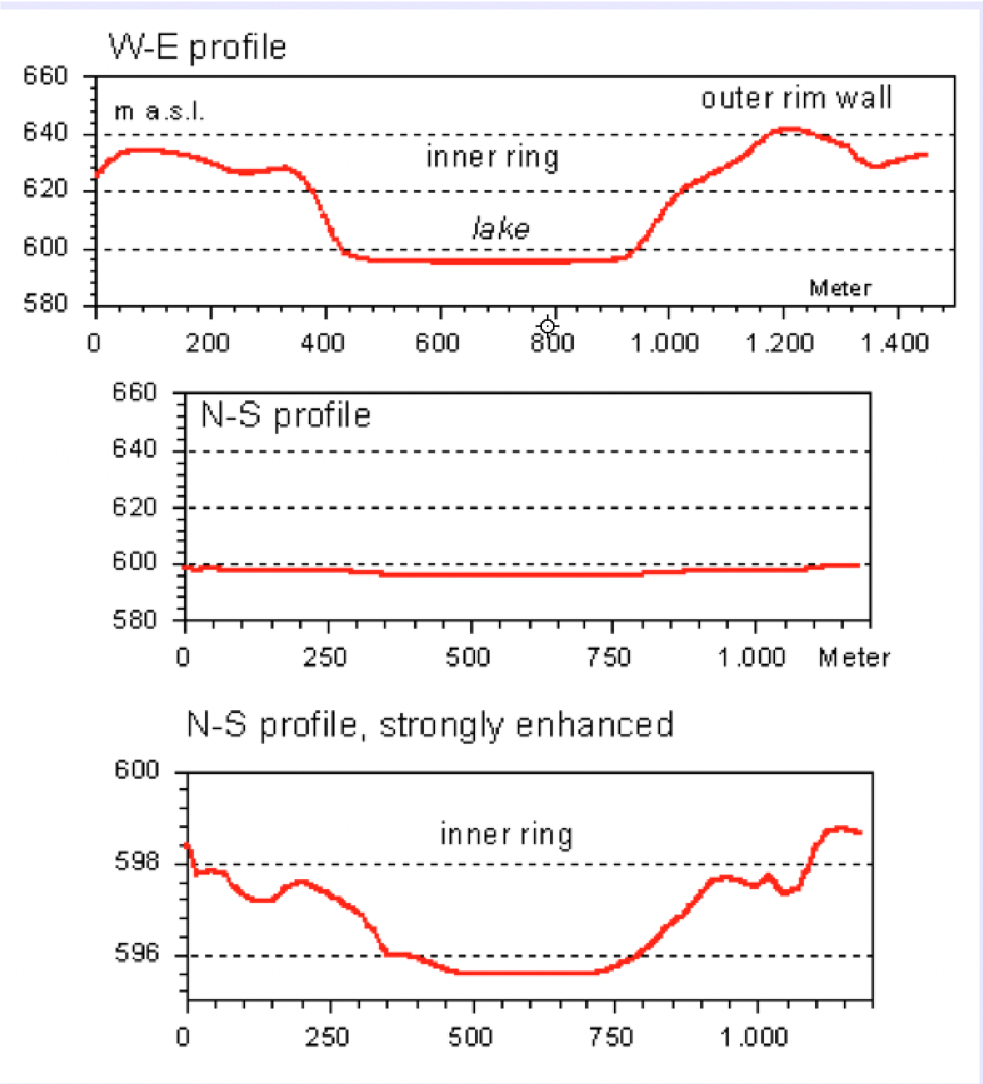
Contour map (contour interval 2 m) of the German Digital Terrain Model DGM 1; the lake shore forms a nearly perfect circle (blue line).



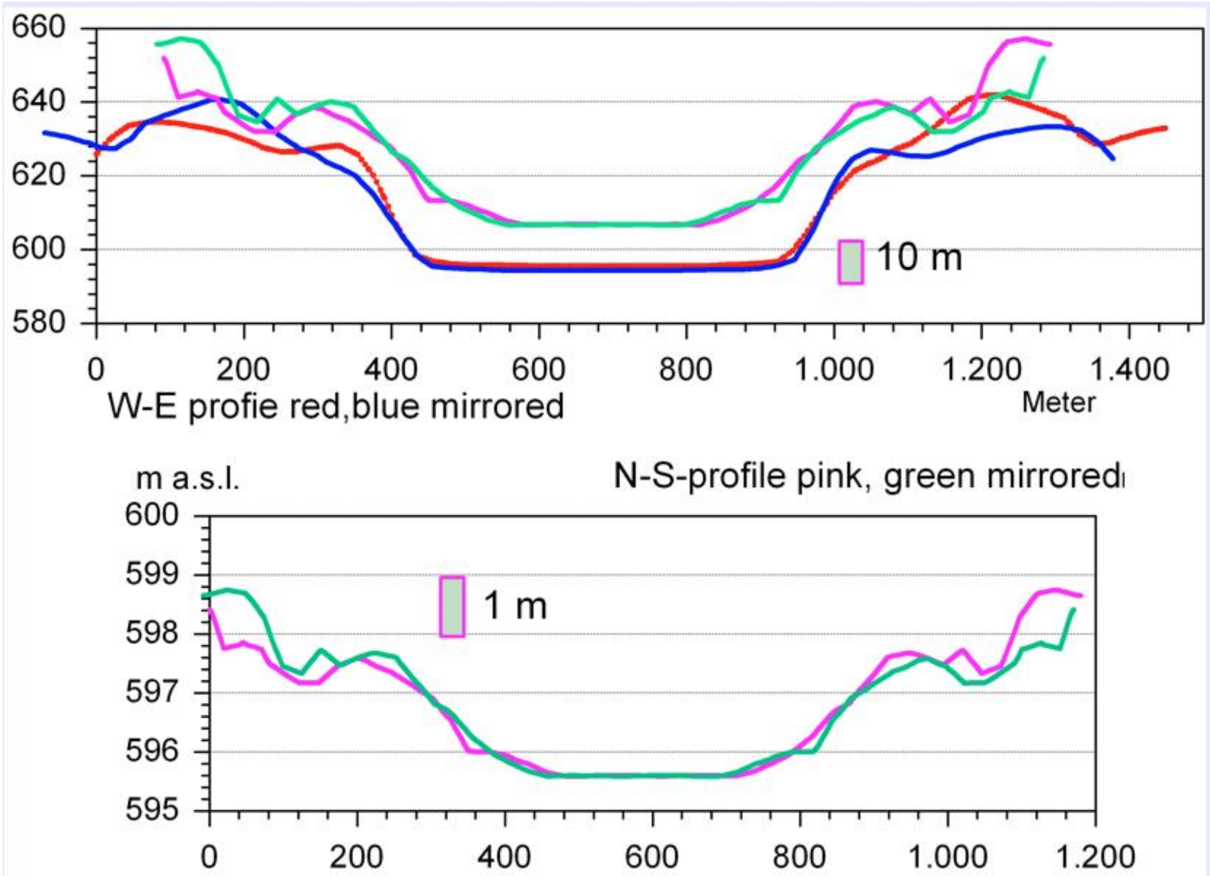
Lake Bärnsee in the digital terrain model DGM 1, topographic map, contour line interval 20 cm. The LiDAR image taken in summer shows a dense carpet of aquatic plants on the lake surface.



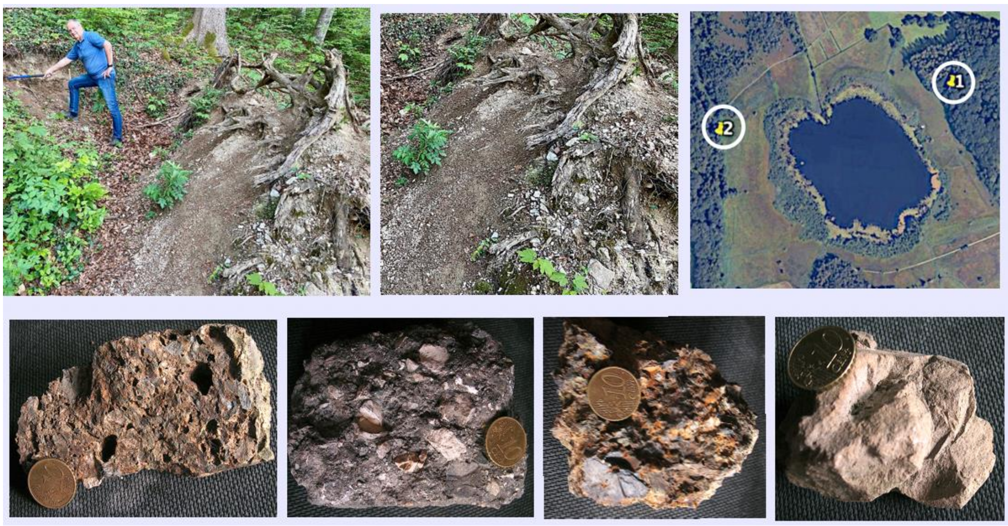
A DGM 1 diametral profile (red line in the map above) across Lake Bärnsee, 0.1 m height resolution. Significant is a double ring structure with a wall-to-wall diameter of the main ring of approximately 1100 m.



Crossing W-E and N-S DGM 1 profiles revealing the valley morphology. The double-ring structure is even evident along the exaggerated N-S valley profile.



Mirroring and superimposing the W-E and N-S profiles shows almost perfect symmetry of the Bärnsee profiles, and a comparison in the upper image also reveals impressive circular symmetry despite the original differences in level. We explain the striking valley through the crater with flash floods from the adjacent Alpine foothills that began immediately after the impact.

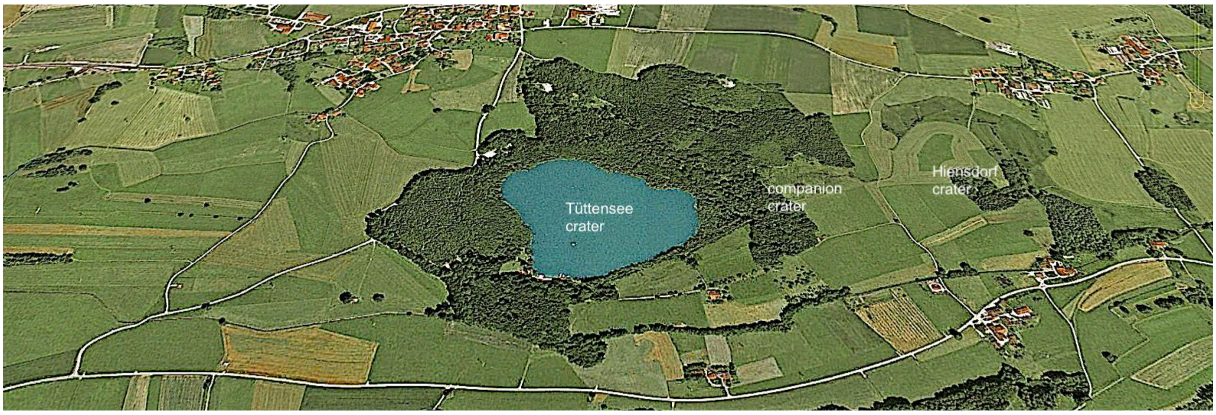


Sampling ejecta rocks from the Lake Bärnsee rim wall. The rubble of sharp-edged rock fragments argues against a terminal moraine. Below: Selection of original samples of polymictic breccias and strongly deformed rocks from the outcrops.

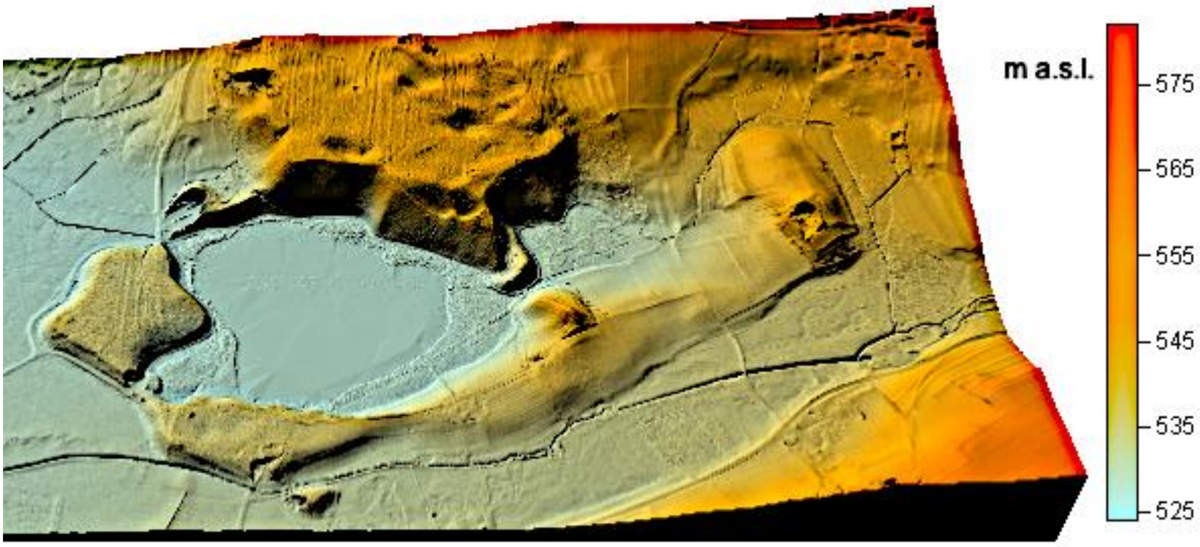
9 The Lake Tüttensee crater ensemble

Recently, the use of the extremely high-resolution digital terrain model DGM 1 has led to the discovery that the Tüttensee crater is only part of an entire crater ensemble consisting of additional two larger and several smaller structures (Poßekel & Ernstson 2025). For the sake of simplicity, we refer you to this iPoster contribution to the LPSC, which can be clicked on below. The following images give a small impression of this remarkable cratering event as part of the Chiemgau impact discussed here.

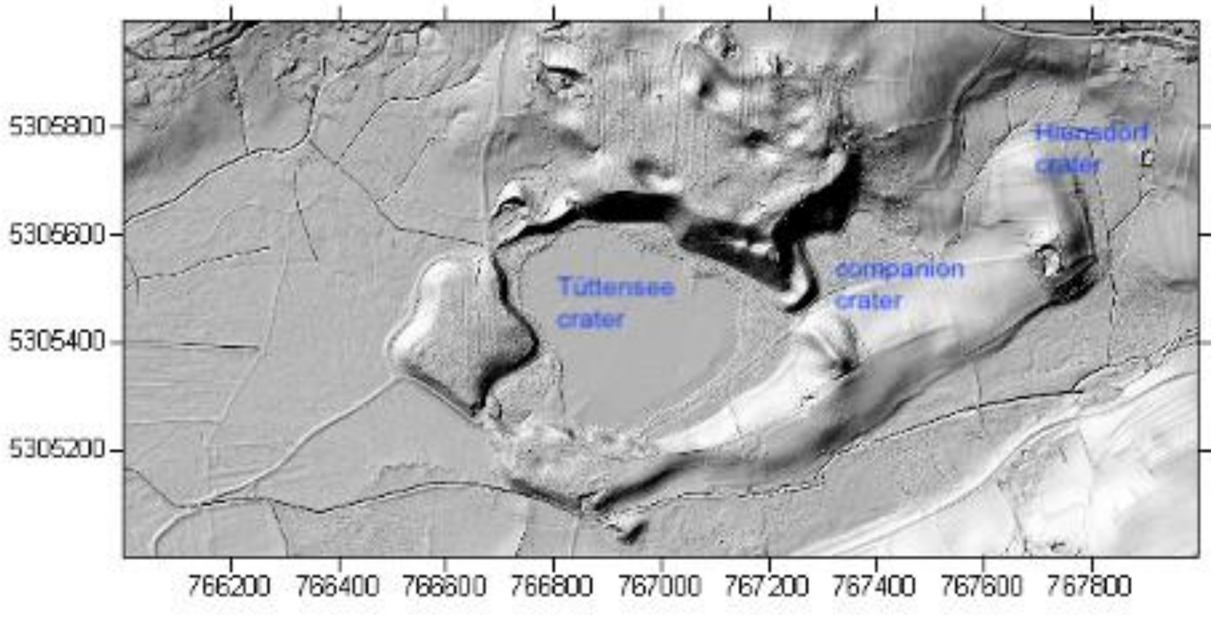
file:///Users/kordernstson/Dropbox/TuttenseeIpiiPosterSessions-anaMuzeInteractivesystem.pdf



Google Earth oblique view of Lake Tüttensee.



A DGM 1 terrain surface map of the Lake Tüttensee crater ensemble.



The DGM 1 shadowed relief map of the three Lake Tüttensee ensemble main craters. The remarkable central uplift of the Hiensdorf crater is explained due to the different geology with the significantly higher exposed moraine subsoil. To the north of the lake, on top of the terminal moraine, you can see a cluster of smaller accompanying craters.

10 Discussion and conclusions (essentially copied from part 2 of the previous article)

Several years ago, research into the Chiemgau impact was given a huge boost by the application and analysis of the extremely high-resolution digital terrain model, which can now be acquired online free of charge in the form of the original data sets for the entire crater strewn field and the closer and wider area around the Chiemgau crater strewn ellipse. With this data and the enormous possibilities of modern graphics programs, impact research has led to a paradigm shift, which is justified in particular by the new findings on the Chiemgau impact and the widespread newly recognized impact fields in Central Europe between the Czech Republic and the Lorraine-French border (Poßekel et al. 2022). While the Canadian database mentions around 200 names worldwide as established, apparently proven impact structures (which has been repeatedly criticized, e.g., Claudin and Ernstson 2023), a paradigm shift becomes clear with the simplest geological considerations together with the results of the digital terrain models that are now increasingly available in many countries. The key lies in the extreme resolution of the terrain surface, horizontally and vertically, down to the decimeter and centimeter range, whereby the DTM removes buildings and vegetation with sophisticated data processing, so that even in the densest forests the bare ground is recorded and made available to the user in corresponding data sets (x, y, z). For impact research, it initially has the following consequences:

-- Crater or general impact traces are recognized even in the densest vegetation, such as in dense forests, probably also in jungle regions, or inaccessible swamp areas.

-- Extremely shallow crater structures with surrounding very shallow ring walls are seen.

-- Craters with completely new shapes such as central-peak craters, and terraced and wavy crater rims are described, as they are now published from the Moon and Mars (Rappenglück et al. 2021, Poßekel et al. 2022, Ernstson et al. 2024, Ernstson and Poßekel 2024).

-- Impact structures are recognized, which are observed during severe earthquakes and must therefore be attributed to the quakes triggered by impacts (Ernstson and Poßekel 2024).

-- Craters are described that are geologically very young and, due to their extreme flatness, are subject to geological erosion and sedimentation and quickly disappear again. This effect must of course be thought back into the geological past.

-- The newly conceived considerations and hypotheses on airburst impacts in connection with comets and asteroids and a focus on low-altitude so-called touchdown airburst impacts (West et al.2024) cannot be better supported than by the new observations with the digital terrain model.

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