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Cosmic collision in prehistory
The Chiemgau Impact: research in a Bavarian meteorite crater strewn field
(translated from German)

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Abstract – "Chiemgau Impact" is an event which took place in the Bronze Age / Iron Age with the creation of a large meteorite strewn field by the impact of a comet / asteroid in southeast Bavaria. The research is interdisciplinary from the outset. It covers, among other things, geology, geophysics, limnology, archaeology, mineralogy, speleology, astronomy, and historical sciences. The research results show that a major disaster must have taken place in the area between Altötting, the Lake Chiemsee, and the Alps. Finds of exotic material, found only in meteorites, extremely stressed and altered rocks, caused by extreme pressures, high temperatures and the action of acid, strange carbon spherules, glass-like carbon, nanodiamonds, magnetic anomalies, soil compaction, sinkholes, and many other abnormalities can be explained by the hypothesis of a post-ice age impact. All the impact criteria required according to scientific standards were demonstrated. The impact associated with a large air blast may have produced considerable regional and probably transregional effects. People not only from the Chiemgau region were witnesses of the fascinating, shocking and disturbing event. Perhaps quite accurate descriptions of the event and the regional effects were even described in the ancient Greek myth of the young racer Phaeton, driving the solar chariot. The paper presents the current (2017) state of knowledge and briefly also the research history.

Key words: Holocene – crater – impact – meteorite – archeology

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Introduction

The crater strewn field of the "Chiemgau Impact" shows a large meteorite impact that occurred in prehistoric times in the southeast Bavarian foothills of the Alps (Ernstson, 2010; Ernstson, 2015; Ernstson et al., 2010). The area extends approximately elliptically over an area of about 60 x 30 km (c. 1800 km^2 from 47.8° to 48.4° N and from 12.3° to 13.0° E) between Altötting, Lake Chiemsee and the Alps.

More than 80 craters with diameters between 3 m and several 100 m (Ernstson et al., 2010: 74, Fig. 3, 75, Fig. 4) were determined, surveyed, mapped and continuously subjected to mineralogical and geophysical investigations of varying intensity by means of site surveys, the study of aerial photographs and old maps as well as the Digital Terrain Model (LIDAR). In addition to the actual craters, more and more accompanying epiphenomena were discovered and researched, e.g. magnetic anomalies, acid effects, exotic minerals and nanodiamonds, heavily deformed rocks and much more. The cosmic body that caused the catastrophe in the Chiemgau region was probably a rather porous object consisting of various components that broke apart in the atmosphere.

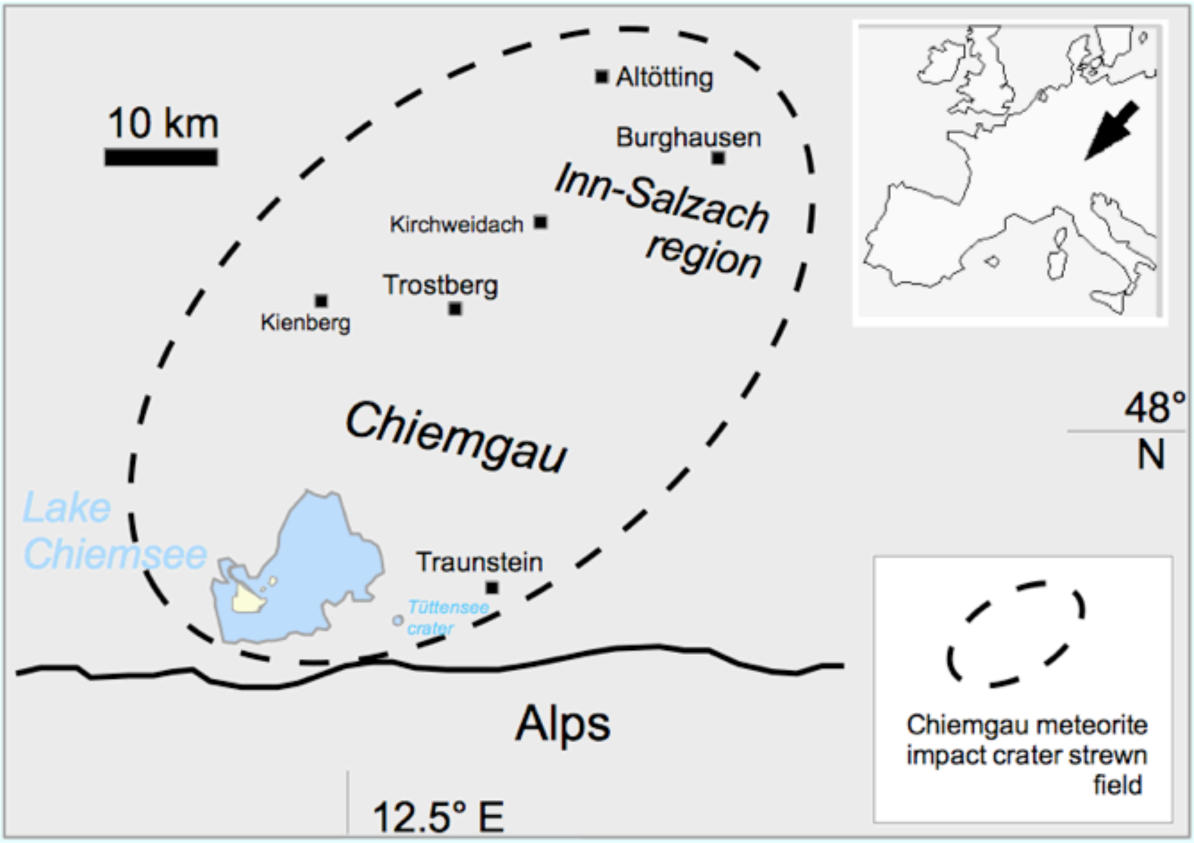

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Fig. 1. Location map for the Chiemgau impact region.

The study of the impact was initiated by a group of local researchers who, from the year 2000 onwards, were searching for archeological relics in the region on official orders and with the appropriate permission, and also came across strange metallic pieces and crater-like structures. They finally asked themselves whether they had found traces of a meteorite impact. This was followed by an eventful odyssey in search of experts who could scientifically evaluate and classify the observations of the local researchers (Fehr et al., 2005: 187). In 2004, the Chiemgau Impact Research Team (CIRT[4]) joined forces, bringing together local researchers and scientists from various disciplines (including geology, geophysics, astronomy and history). Since then, CIRT has cooperated with numerous national and international experts and institutions[5] who have further enriched the spectrum of integrated disciplines and methodological approaches. A wide range of research and analysis methods is used: ground penetrating radar (GPR), geoelectrics, electromagnetics (pulse EM, frequency EM), gravity measurements (gravimetry), seismics, echo soundings, electron microscopy (SEM, TEM) up to helium ion microscopy, X-ray diffraction, Raman spectroscopy, C14 and OSL datings, short time measurement with high speed cameras, LIDAR and many more. The knowledge about the Chiemgau impact explained in the following is based on the results achieved by these scientific methods. They are published in scientific articles and contributions to international congresses[6].

The crater strewn field: topography and geology

The topographical and geological framework for the Chiemgau impact is the Alpine foothills shaped by the Ice Age. Apart from the northernmost part of the strewn field, where Tertiary gravel, sands and marls are found in the hilly terrain, the impact area is mainly composed of Pleistocene moraine sediments and gravel. The components are representative alpine material in the form of sedimentary rocks, magmatites and metamorphites. Occasionally larger blocks of cemented conglomerates (Nagelfluh) can be observed. Holocene gravel, loess and loess loam can locally contribute to the uppermost layers in the impact area. The diversity of rocks in the target area contributes to a diversity of impact phenomena in the affected rocks. The crater strewn field is divided into two areas of almost equal size by an imaginary line marking the furthest advance of the glacier ice of the last (Würm) glaciation roughly 10,000 years ago (Ernstson, 2010: 72 Fig. 7). There are craters in the southern area of the last glaciation, but also to the same extent in the northern large gravel plains and in the areas of the older glaciation there. With a correspondingly large age of origin, however, the northern craters should no longer show today's fresh preservation, which proves a very young age. This is an important point in the discussion about a repeatedly claimed ice age origin ("dead ice holes"; Darga & Wierer, 2009: 174-185) of the craters.

In view of this ongoing controversy, it seems advisable to briefly present the reader with the criteria on the basis of which research classifies a terrain hollow form as a "dead ice hole" or as a "meteorite crater".

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[4] see http://www.chiemgau-impakt.de/cirt/

[5] Carl Zeiss Microscopy, Oberkochen; Oxford Instruments, Wiesbaden; Diamond Lab. Institute of Geology Komi SC UB RAS, Syktyvkar (Russia); University of the Aegean, Laboratory of Archaeometry (Greece); Institute of Hydrogeology, Engineering Geology and Applied Geophysics, Charles University, Prag (Czech Republic); Werner Mehl (Fa. Kurzzeitmesstechnik Werner Mehl, Diebach); et al.

[6] see References und http://www.chiemgau-impact.com/publications/

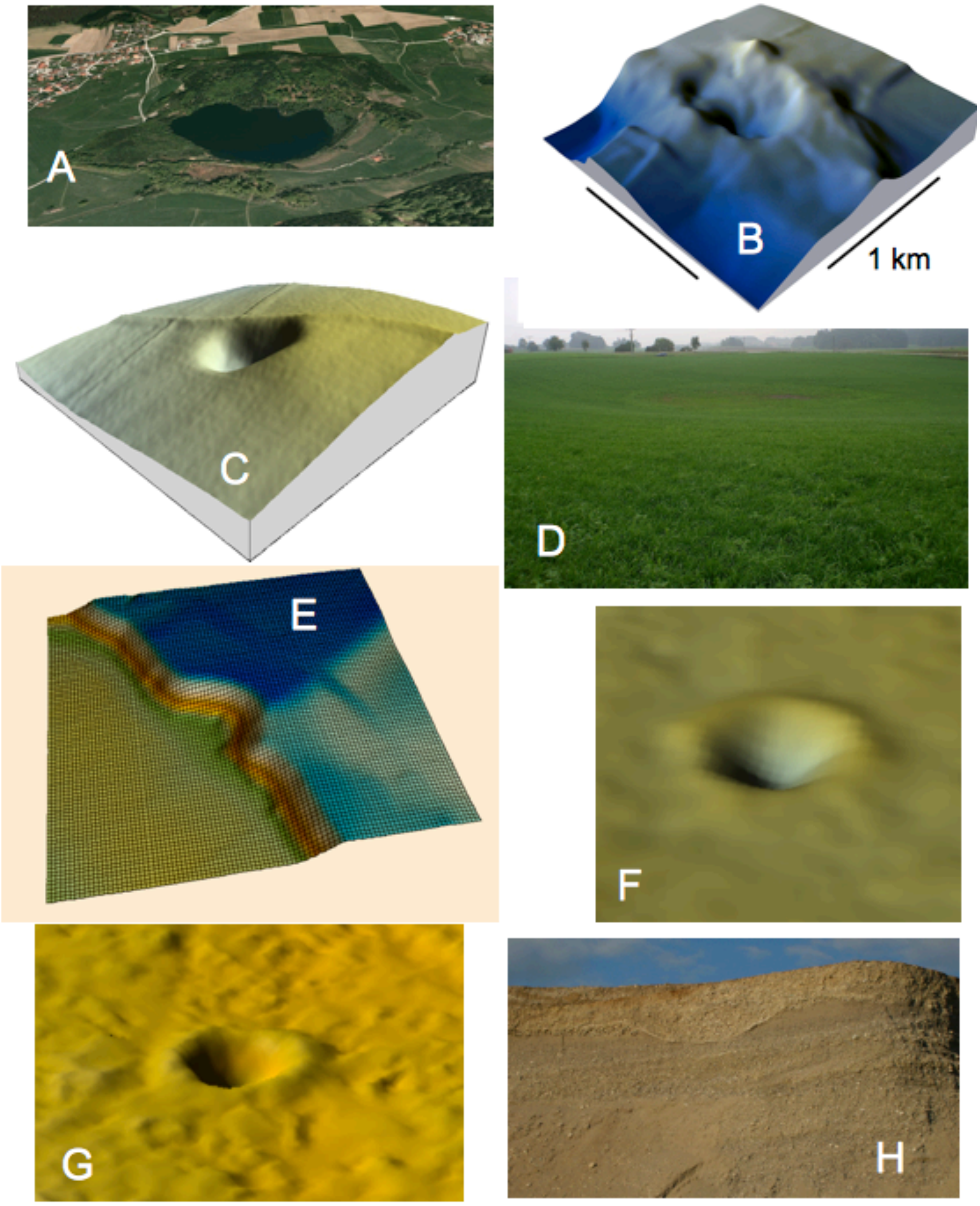


Fig. 2. Craters of varying size in the impact strewn ellipse. Der crater diameter (for the rim crest) is given in meters. A: Lake Tüttensee (600), B: doublet crater in Lake Chiemsee (800 x 400), C: Purkering (75), D: Bergham (150), E: semi crater in the valley slope of the Inn river, (55), F: Einsiedleiche (15), G: Schatzgrube (13), H: gravel pit, Emmerting (4).

Criteria

(a) Dead ice hole

When glaciers come to a standstill or retreat, ice bodies can detach and - covered with glacial debris and shielded from heat and solar radiation - remain underground for long periods of time. When the glacier debris finally melts together, it subsides and troughs are formed - the dead ice holes in which lakes can possibly form. The fact that a terrain hollow form is a dead ice hole is derived from the general geomorphological character of the landscape by ice age relics such as moraines, without being able to be proven directly from within.

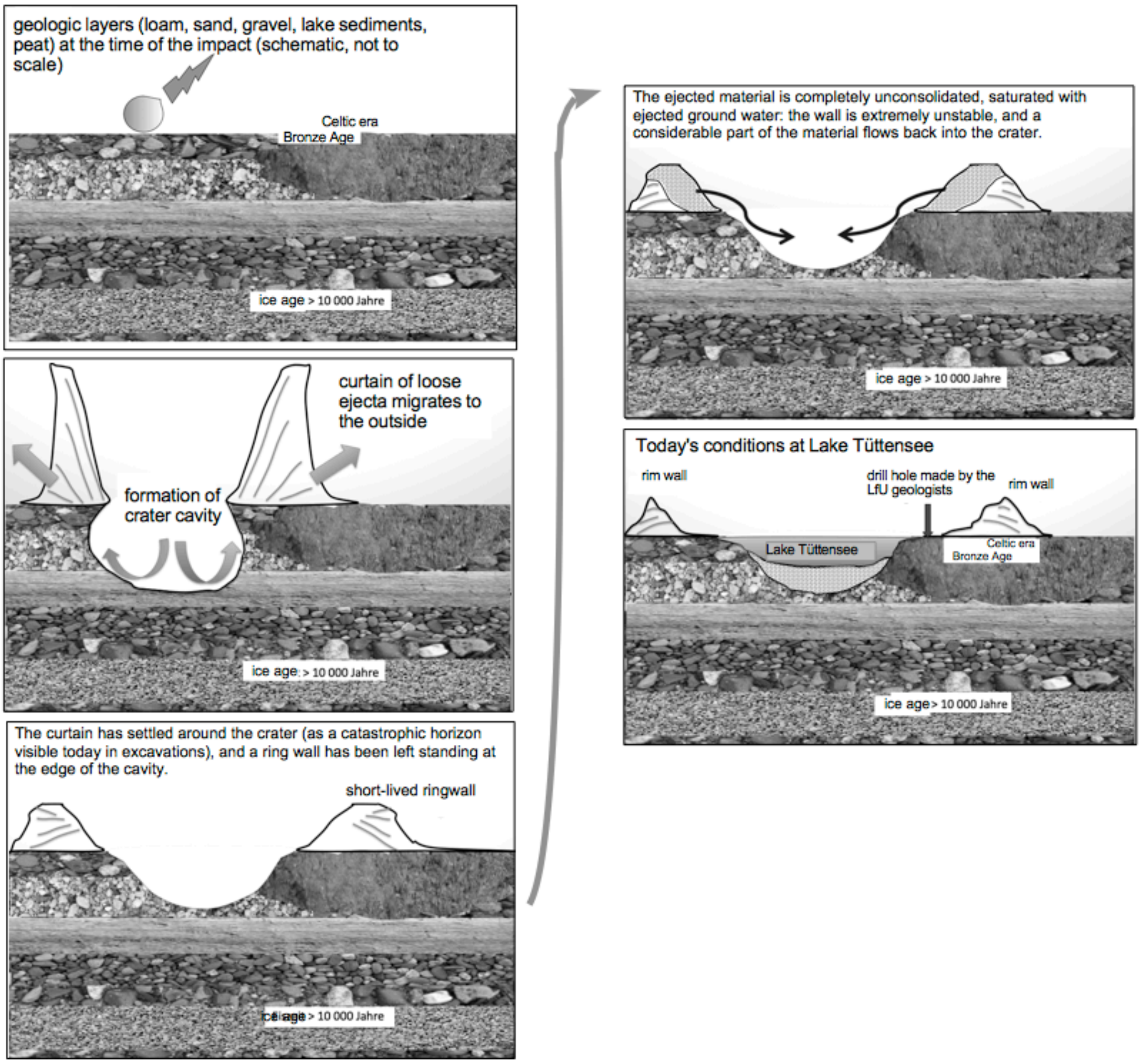
b) Meteorite crater

Meteorite impacts are characterized by the simultaneity of enormous speed (11.2-72 km/s) and enormous pressure (from 5-10 up to 100 Gigapascal [GPa]) with extreme temperatures (up to several 1000 C°) (= shock). The special impact physics and the enormous forces which become effective during an impact leave numerous traces on the rocks which often lead to confusion for geologists who are only concerned with "traditional" geology or which are not recognized at all, but which provide the impact expert with clear evidence for what is happening. In research, morphological, geological, geophysical, mineralogical-petrographic and geochemical criteria have therefore been defined as the basis for the existence of a meteorite crater (e.g. French & Koeberl, 2010). Some of these are considered good indications of an impact, others are mandatory evidence. In the first category belong: morphology, geophysical anomalies, special exotic geological horizons, similarity with magmatic rocks, special deformations, breccias, melt rocks and natural glasses, spherules, accrecionary lapilli. Mandatory impact criteria include shock effects (see below), shatter cones (cone-shaped fractures with typical fracture markings produced by shock waves), projectile remains (fragments of meteorites) and observation (eyewitnesses, historical records). Each of the criteria of this second category is considered a confirmation of an impact.

Knowledge of the criteria makes it possible to assess the significance of the research results on the Chiemgau impact presented below.

Lake Tüttensee and other large craters

The largest crater of the Chiemgau impact is today filled by Lake Tüttensee near Grabenstätt (see Fig. 2A). The surrounding wall has a height of up to 8 m and the diameter from one rim crest to the next is 600 m. The projectile that created the crater probably measured 25-50 meters. The graphics sketches the different stages of formation: The meteorite arriving at cosmic velocity (approx. 11-72 km/s) collides with the earth's surface under enormous pressure, which propagates into the subsoil in the form of shock waves. The shock pressure leads to extreme temperatures that can exceed 10,000 degrees. As a result, the meteorite evaporates as it penetrates into the subsurface, and very small amounts of the meteorite material can survive. But also the rock of the directly affected underground evaporates behind the spreading shock front, and in a following zone it is melted. As the shock front continues to spread, the energy is no longer sufficient to vaporize and melt, but part of the rock is violently deformed and shattered. The minerals in the rocks undergo characteristic changes that are recognized under the microscope as shock effects (shock metamorphism). Behind the shock front, the rock begins to move out of the developing crater on curved paths. Rock melt, smashed (brecciated) rocks and less affected pebbles, sands and gravel are ejected as ejecta from the growing crater behind the shock front. Like a steep curtain, the ejecta masses move radially outwards, forming a ring wall and a subsequent ejecta blanket. The impact into the very loose, water-saturated material is probably more related to an impact into water than into a hard rock. For this reason, the ring wall does not retain a stable shape, but large parts of the volume flow back into the resulting cavity. In addition, most of the pebbles in the remaining ring wall are deformed with little or no visible deformation. The crater fills with groundwater ... and is called the Lake Tüttensee much later.



geologic layers (loam, sand, gravel, lake sediments, peat) at the time of the impact (schematic, not to scale)

The ejected material is completely unconsolidated, saturated with ejected ground water: the wall is extremely unstable, and a considerable part of the material flows back into the crater.

The curtain has settled around the crater (as a catastrophic horizon visible today in excavations), and a ring wall has been left standing at the edge of the cavity.

Fig. 3. The Formation of the Lake Tüttensee depression as a meteorite crater (schematic, not to scale). As far as the LfU drill hole is concerned: It is located outside the actual crater.

The relics of this process and thus the meteoritic origin of the Lake Tüttensee depression were documented with a whole arsenal of mineralogical and geophysical methods. Numerous thin sections of rocks from the Lake Tüttensee rim wall and the more than 70 excavations in the immediate vicinity show a broad spectrum of shock effects (Ernstson, 2010: 44-51). Shock effects in minerals are caused by the propagation of shock waves in rocks. A shock wave is a deformation that propagates in a medium at a velocity higher than the speed of sound (seismic velocity). Shock waves in minerals leave different traces depending on their intensity. Among the most important are so-called planar deformation features (PDFs), which require a pressure of at least 5-10 GPa. These special structures are extremely narrow, parallel and optically isotropic lamellae aligned according to crystallographic planes in the quartz. According to the current state of knowledge (e.g. Stöffler & Langenhorst, 1994), multiple sets of these narrow isotropic lamellae form only at extreme shock pressures, and their natural occurrence in rocks is - as mentioned above - generally regarded as evidence of an impact. PDFs and even stronger shock effects (diaplectic glass, > 10 GPa) were detected in thin sections of numerous samples from Lake Tüttensee, as well as in rock samples from a number of smaller craters (Ernstson, 2010: 47, Fig. 29; 48, Fig.

30; 82, Fig. 19; 83, Fig. 20, 21; Rappenglück, B. et al., 2010: 432, Fig. 3, Ernstson, 2015: 56, Fig. 25).

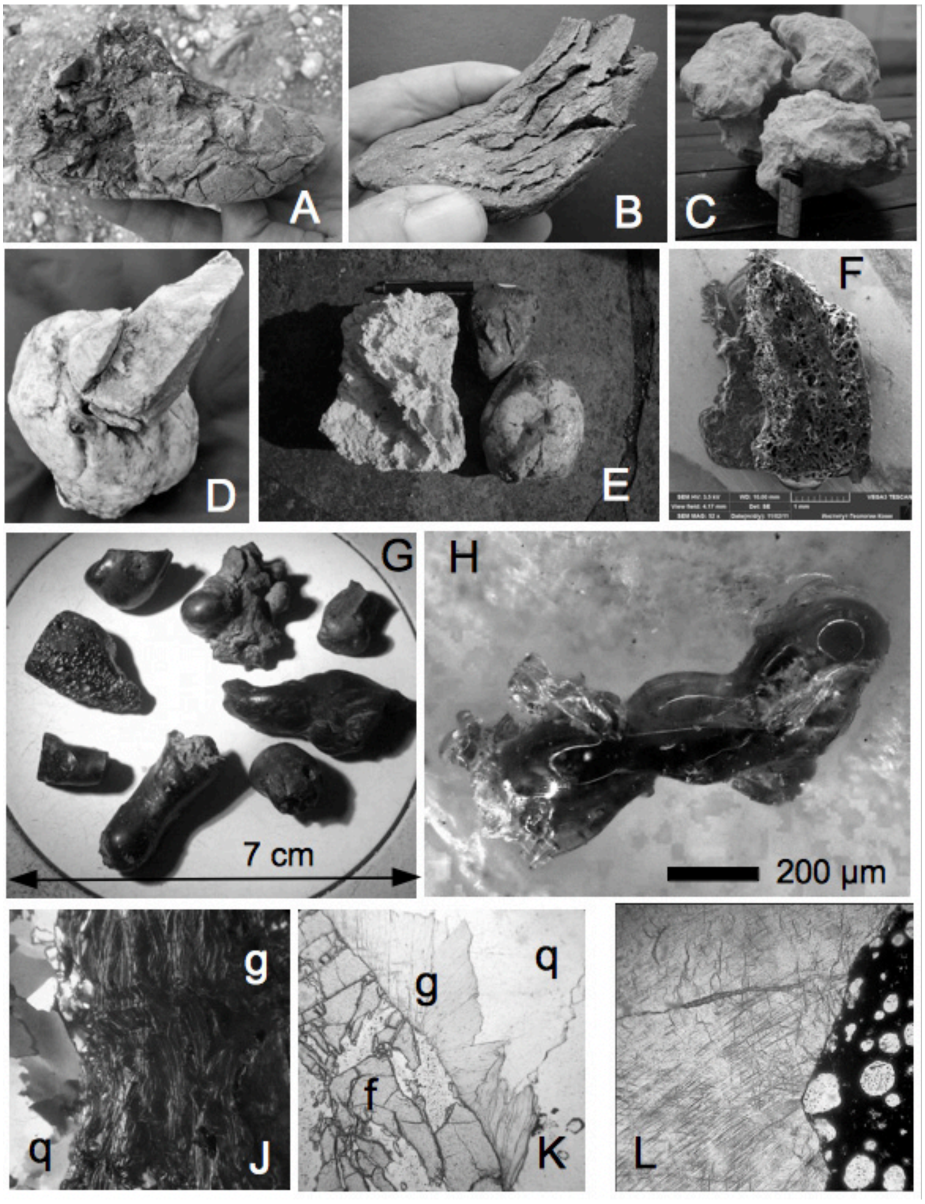


Fig. 4: Extreme pressures, temperatures and corrosion effects in the crater strewn field. A: Typical fracture deformation and corrosion of an Alpine cobble - exposed during a gravel pit expansion. B: Broken boulder fragment of a sandstone; from crater 004 (near Emmerting). C: Extremely corroded limestone block from the edge of Lake Chiemsee. Effect of carbonate melt and/or acid dissolution. D: Intensively baked rocks - fractured cobble and quartzite fragment with glass coating (from crater 004). E: Two extremely short-lived and highly heated pebbles with sub-millimeter thin glass skin all around; relic fragment from decarbonization/carbonate melt of an Alpine limestone cobble (from crater 004). F: Chiemite from the Chiemgau crater strewn field under the scanning electron microscope. The content of special carbon allotropes (carbyne) requires temperatures between 2500 and 4000°C to form. G: Aerodynamically shaped black glasses that can be abundantly picked up in the crater strewn field. H: Example of a microtektite from soil samples in the first Alpine foothills south of Lake Chiemsee. J, K: Strong shock effects in minerals - optically isotropic, normally birefringent minerals mica (g) and feldspar (f) are converted to diaplectic glass. q = ordinary quartz. J = crossed polarizers, K = linearly polarized light. Thin section of a quartzite from the

Schatzgrube crater; image width 1mm. L: Planar deformation features (PDF) as a strong diagnostic shock effect in a quartz in contact with a vesicular glass. Thin section of a melt rock from crater 004. Image width 480 µm.

Many conspicuously deformed pebbles could be recovered from the rim wall of Lake Tüttensee. These include heavily broken but nevertheless cohesive blocks, wide open sharp-edged cracks in likewise coherent boulders, rotated fractures, and brecciations with signs of grit brecciation and mortar texture (Ernstson, 2010: 27-28 with illustrations). They show a high-pressure/short-time deformation due to the impact shock. If the shock pressure waves hit free surfaces, they are reflected there as almost equally strong tensile waves, which can cause significantly more damage than pressure waves (Ernstson, 2015: 34-38). This is due to the fact that the tensile strength of rocks is much lower than the compressive strength. A reflection of compressive energy as tensile energy occurs at all interfaces in the rock where the so-called impedance (the product of density and sound velocity of the rock) decreases. In the Chiemgau, where hard, dense rocks (alpine cobbles and boulders) are often in contact with loose, soft rocks (sands and loams), this situation is widespread. The blocks and pebbles must have experienced the high-pressure/short-term deformation on site, because transport from the Alps through glacial ice or a river would not have survived these phenomena.

From Lake Tüttensee, in a radius of up to 1000 m, a characteristic sequence of layers was repeatedly encountered in numerous excavations (Ernstson, 2010: 33-39): at the bottom autochthonous moraine material or lake clay, above it fossil soil and a "catastrophic layer", as well as a cover by a colluvium or directly by the plough horizon. The so-called "disaster layer", a diamictite, which is to be understood as ejecta material from the Lake Tüttensee crater, is characterized by a completely unsorted mixture of stones of different sizes in a clay matrix. Some of the stones are melted, strongly plastically deformed and often heavily corroded or sharp-edged. In thin sections they repeatedly show the impact-specific shock metamorphism (PDFs). In addition to the stones, wood splinters and pieces of charcoal are frequent in the layer; occasionally broken animal bones and teeth also occur. Exceptional finds in the disaster layer are the blank of a Neolithic/Bronze Age stone axe and Bronze Age or Iron Age pottery shards. They play an important role in the dating (see below) of the Chiemgau impact and underline that the diamictite has nothing to do with the Ice Age, which was already many millennia past when the fragments got into the ground.

The clear evidence that the stones provide for a genesis of the Lake Tüttensee depression as an impact crater is further substantiated by the results of the following studies of various geophysical investigations. Gravimetry (= gravity measurement) is based on differences in the density of the rocks, which can be measured locally, regionally and continentally can influence the general earth gravity. Using highly sensitive instruments (gravimeters), changes in gravity are measured and displayed in maps. They provide information on the type, shape and depth of geological structures hidden underground. This also applies to impact structures/meteorite craters. The Lake Tüttensee crater shows a so-called negative gravity anomaly (Ernstson et al., 2010: 90-91). It indicates that rocks in the subsurface have a lower density or that mass in the subsurface is missing. For the Tüttensee crater this is immediately understandable because of the lake water with the low density. A ring of relatively positive anomalies means a ring-shaped rock compaction around the crater. This is not the visible wall, the effect of which has been calculated before, but the enormous pressures in the outwardly moving shock front compressed the loose material (see Fig. 5 above).

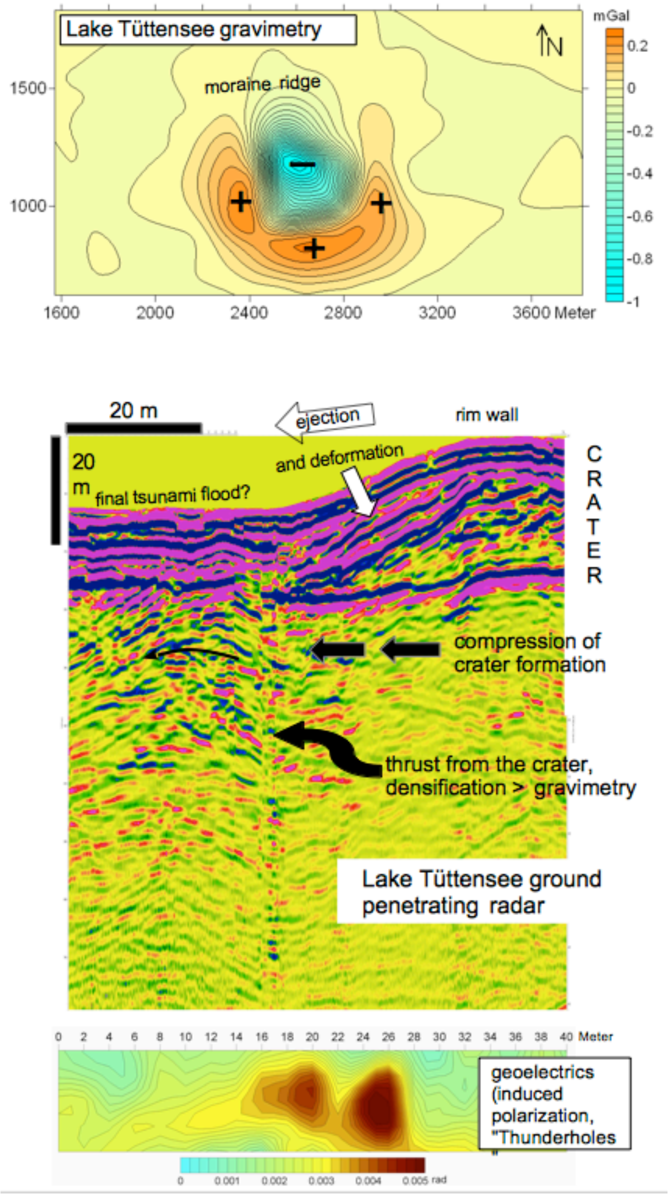


Fig. 5: Geophysical measurements in the crater strewn field. Above: Gravimetric measurements on the frozen Lake Tüttensee crater and its surroundings. The central negative gravity anomaly (-) is mainly generated by the water-filled cavity. The relatively positive anomalies in the frame of the lake (+) are explained by a shock compression of the loose sediments during crater formation. Middle: Ground penetrating radar (GPR) measurements (25 MHz antenna; data: P. Kalenda, R. Tengler, J. Poßekel.) on a profile over the Tüttensee crater ring wall with significant structural features. Radial GPR profiles around the crater with comparable indications "pressure from inside to outside" definitely exclude a dead ice genesis. Below: Geoelectric measurements of the parameter induced polarization over a freshly formed sinkhole ("Thunderhole"). The measurements show the extremely deformed underground caused by the impact "earthquake".

Another geophysical method, ground penetrating radar (GPR), uses electromagnetic waves that are sent underground via antennas as impulses. In different types of rock, these waves propagate at characteristic velocities and are reflected by discontinuities in the subsurface. The travel time of the waves and the resulting reflection patterns provide information about the type and structure of the subsurface. Radar signals of different frequencies can penetrate the subsurface to different depth and further differentiate the resulting image. GPR measurements (in different frequency ranges: 25 MHz antenna bistatic; 200 MHz antenna monostatic; 300 MHz antenna monostatic) on Lake Tüttensee, around the lake and in numerous profiles across the wall show a clear result (see Fig. 5 middle): The wall has internally dipping layers rising and descending outwards from the crater. This finding proves how the successive ejection of material, including slipping back, produced a "roof tile" layering during the formation of the crater.

The mineralogical results as well as those of gravimetry and GPR are basically not compatible with the formation of the Lake Tüttensee as a dead ice hole - as claimed by the Bavarian State Office for the Environment (Doppler et al., 2011) and Darga & Wierer (2009). They speak clearly for a genesis as meteorite craters.

The Tüttensee crater is not the only large crater in the crater strewn field. SONAR echo sounder measurements, carried out by the CIRT research group together with the Chieming water rescue service, show a striking structure at the bottom of Lake Chiemsee that is quite atypical for the bottom of an ice age lake (see Fig. 2 B; Ernstson, 2010: 20-21). The structure, measuring about 800 m x 400 m, is a doublet crater with a rim wall. Since the crater strewn field extends beyond the Lake Chiemsee, it is plausible that fragments of the big meteorite have also fallen into the Lake Chiemsee and created craters at the bottom. The height of the resulting tsunami waves can have been more than 25 meters. Clear indications of such a tsunami are given by diamictites with pronounced block layers and cross bedding, which can be found in various gravel pits on the eastern side of Lake Chiemsee (Ernstson, 2016).

Mineralogy, petrography, geochemistry - a look into the rocks

a) Meteoritic material

Unusual metallic particles were at the beginning of research into the Chiemgau Impact (Schryvers & Raeymaekers, 2004; Schüssler et al., 2005; Rappenglück, M. et al., 2005, Hoffmann et al., 2006) and over the years and in the course of comprehensive analyses have increasingly turned out to be more than one of the keys to events. The special iron silicides xifengite and gupeiite were rapidly detected (Schryvers & Raeymaekers, 2004), but prematurely classified as industrial and pseudo-meteorites (Fehr et al., 2004)[7] In nature, the iron silicide minerals Fe3Si (gupeiite) and Fe5Si3 (xifengite) are extremely rare, and only a few individual finds have become known. The reason: iron silicides can only form in an extremely reducing, oxygen-poor environment, which as a natural environment hardly occurs on earth. But in the Chiemgau crater field, iron silicides can be found over hundreds of square kilometers, often in aerodynamically shaped forms such as spheres, buttons and drops, but also as splinters and pieces, up to a chunk weighing 8 kg. The sites are worth mentioning with regard to the discussion about an industrial origin: in deep soil layers, under ancient tree roots, under a medieval coin treasure, under medieval castle walls, in bogs and up to the first Alpine mountains.

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[7] At this point an abstract and poster should be mentioned briefly (Huber et al., 2017), which denies all results listed in the following and describes the finds as "pseudometeorites". The readers are asked to compare the scientific approach presented there (description of analysis and argumentation structure) with the literature mentioned here.

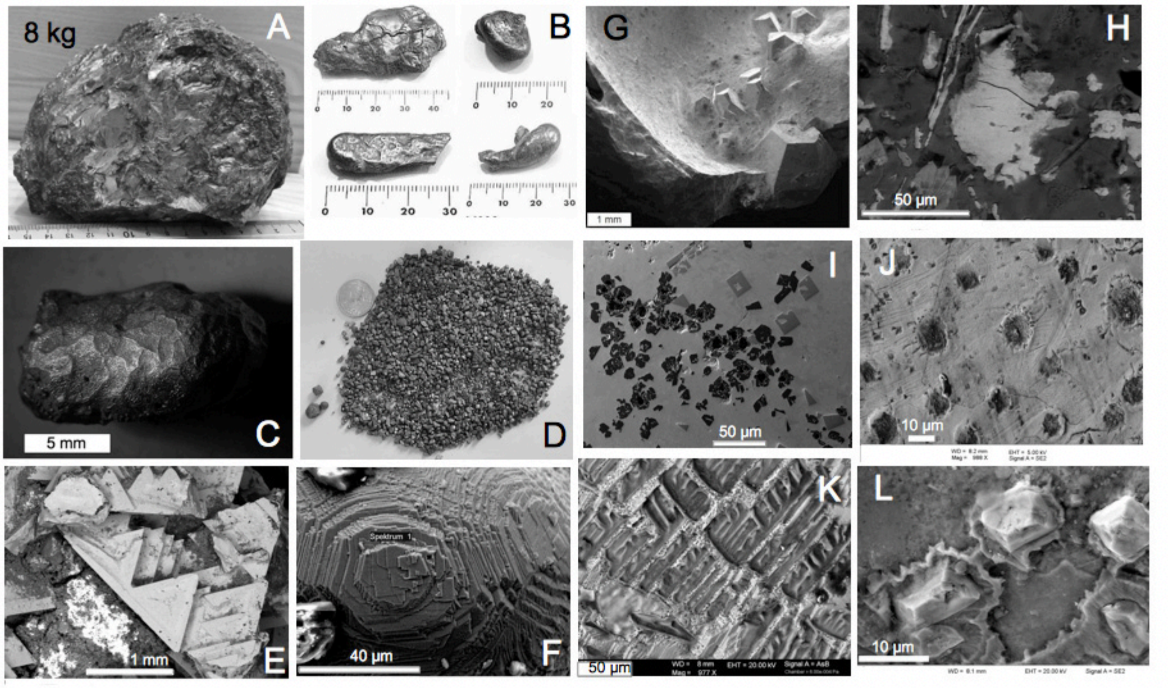

Fig. 6: Iron silicides from the Chiemgau crater strewn field. A: 8 kg heavy iron silicide boulder; found about 30 years ago near Grabenstätt at Lake Chiemsee. B: Iron silicide samples from the strewn field with aerodynamically shaped forms and surfaces. C: Iron silicide particles from the strewn field with regmaglyptic surface sculpture. D: Fine-grained fraction of iron silicides from the strewn field. E, F: Iron silicides under the scanning electron microscope (SEM). G: Cubic moissanite (SiC) crystals in iron silicide matrix. H: Iron silicide with uranium and cerium (light), SEM. I: Crystals of moissanite (black) and titanium carbide (TiC, grey) in iron silicide matrix. J: Microcrater on iron silicide (impact of cosmic dust particles?), REM. K: Exsolution lamellae of iron silicide and zircon in iron silicide sample, SEM. L: Zircon crystals immersed in plastic iron silicide matrix.

Gupeiite has only been synthesized since the 1950s, xifengite even since 1997. However, the minerals gupeiite and xifengite could previously be produced in very small quantities and only for a few years in a very specific kiln process in a south-eastern Bavarian factory, without this being recognized at that time. These artificially produced iron silicides are logically incompatible with the above-mentioned find circumstances in the Chiemgau crater field. Much more important, however, is the fact that in the meantime it has been shown with considerably better investigation methods that a confusion with the very special terrain finds in the crater strewn field is only possible with very superficial analysis. Already the so far worldwide rare finds of xifengite and gupeiite are in 13 out of 19 cases of cosmic origin. However, the new analyses (Bauer et al., 2013) even proved hapkeite (Fe_2Si) in iron silicides from the Chiemgau crater field, which was first discovered in 2004 in the moon meteorite Dhofar 280, and since then only in other meteorite or supernova material. The mentioned iron silicides (xifengite, gupeiite and hapkeite) all require a very oxygen-poor environment, as it is given in space, as well as high temperature (1500°C - 2800° C) and high pressure (some GPa).

The special iron silicides xifengite, gupeiite and hapkeite for their part form a matrix in the Chiemgau finds for partly exotic mineral inclusions: carbides and CAI (calcium-aluminum-rich inclusions). For example, cubic moissanite ([β]3C-SiC) crystals of extreme purity have been detected (Hiltl et al., 2011). While simple terrestrial silicon carbide, which is used e.g. as an abrasive, has a hexagonal crystal lattice, moissanite with a cubic crystal structure is mostly of extraterrestrial origin and is found e.g. in presolar grains. It is formed at temperatures between 1400° and 1600° C. Krotite (CaAl2O4) was confirmed as CAI (M. A. Rappenglück et al., 2013; M. A. Rappenglück et al., 2014), which is formed at high temperature (>1500°C) and low pressure and was detected in meteorites (NWA 470 CH, chondrite; NWA 1934, carbonaceous chondrite). Dicalcium dialuminate (Ca2Al2O5), which is stable at high temperature (1500° C) and high pressure (between 4 and 9 GPa), is also proven. It has only been known since the year 2000; so far no natural occurrence has been established. The direct coexistence of the high-temperature/low-pressure mineral krotite with the high-temperature high-pressure phase of the dicalcium dialuminate in the Chiemgau iron silicides proves a very complex history of origin and suggests a mixture in space (M. A. Rappenglück et al., 2014). They must be regarded as a special type of meteorite, which is closely related to the Chiemgau impact.

(b) Melt rocks

Glass and melt rocks are a common feature in the crater strewn field and are discussed in their diverse formation and with regard to possible confusion with artificial products. Because of their fundamental importance for the understanding of the processes that took place during impact, they have been examined in great detail mineralogically and petrographically. A clear emphasis was placed on the many unusual melt rocks from the 004 crater near Emmerting, right in the northeast of the strewn field. This crater, with a ring wall diameter of 11 m one of the small ones in the strewn field, has a halo of approx. 20 m diameter, in the area of which the underground rock must have been heated to 1500° C (Hoffmann et al., 2005). Numerous stones of different lithologies show an outer vitrification which is partly only micrometer-thin and speaks for a very high and very short heating (Ernstson et al., 2010: 92; Prochazka & Trojek, 2017). In thin sections, PFs (planar fractures) in quartz, multiple sets of PDFs (planar deformation features) in quartz and feldspar and diaplectic SiO_2 can be observed, which are all signs of shock metamorphism at high pressures. Fused glass also penetrates internal fissures in the rock or is additionally melted onto the rock surface as an allochthonous lump. The laboratory analyses exclude normal tectonic processes and human activities as the cause of all these melting phenomena, but refer with the proven shock effects clearly to a connection with the meteorite impact.

Glass is also found in the form of small glass spherules (Neumair & Ernstson, 2013), tektites and microtektites (Ernstson et al., 2014; Ernstson, 2015: 12-15). According to prevailing opinion, tektites are formed in a very early phase of a meteorite impact by melting surface rock, which is ejected as melt. As they fall back and cool, they take on their characteristic aerodynamic shapes. Tektites belong to the impact ejecta and were found in soil samples in the Chiemgau up to the foothills of the Alps. Their chemical composition refers to alpine silica limestone as the source rock.

In addition to stones with glass crusts, the Chiemgau crater field shows ample evidence of converted carbonate melts (Ernstson, 2010: 57). Under suitable pressure, temperature and environmental conditions, limestone can transform into a carbonate melt, which becomes thin like petrol and very rapidly crystallizes again into carbonate minerals when cooled down, i.e. above all into calcite or aragonite. Typical is the occurrence of highly porous masses, which sometimes have a cotton-like character. In the highly porous carbonate masses there are some relics of non-melted calcite crystals with micro-twinning, which is considered a sign of shock.

(c) Coalification varieties and a new impact rock

In the context of the Chiemgau impact, carbon is widespread in many forms (Ernstson, 2015: 15-21). Carbon spherules were deposited as fallout in at least all of Western Europe (Rösler et al., 2005); nanodiamonds, the formation of which requires a pressure of at least 5-6 GPa depending on the manufacturing process, were already found very early in carbon spherules, which in turn were embedded in the fusion crust of a rock from the 004 crater (Rösler et al., 2005; Yang et al., 2008). In addition, a remarkable consequence of increasing coalification can be observed in the area of the crater strewn field, which has been intensively analyzed in recent years (Ernstson et al., 2013; Isaenko et al., 2012; Shumilova et al., 2012). Coalification refers to the transformation of plant remains via peat, lignite, black coal, anthracite to graphite. Pressure and temperature are decisive factors. In geological periods, coalification leads to coal deposits on earth; technically, however, it can be imitated within hours by heating biomass in pressure vessels. The coalification variants in the crater strewn field range from charcoal particles via various intermediate forms to dense, very hard, black, glassy pieces ("glassy carbon") and a glass-like carbon ("chiemite"), which, in contrast to glassy carbon, is pumice-like porous inside and has flat inclusions. Raman spectra of a sample of glassy carbon show largely disordered elemental carbon in amorphous state. Very similar Raman spectra of an abnormal carbon are known, for example, from the Allende carbonaceous chondrite and from carbon from the Sudbury impact structure. Chiemite has undergone extensive analyses (Raman spectroscopy, X-ray diffraction [XRD], scanning electron microscopy [SEM] and atomic force microscopy [AFM], transmission electron microscopy [TEM] and differential thermal analysis [DTA]). Chiemite is over 90% pure carbon; the remainder is silicon, aluminum and iron, subordinately sulfur and traces of few other elements. Carbon is a mixture of amorphous carbon and chain bond carbon from the group of carbon carbines. The production of these carbines requires pressures of 4-6 GPs and temperatures of 2.200-3.700°C. At the same time, the porosity of the chiemite indicates that it was formed from a degassing carbon melt at about 3,500-3,700° C. With these properties, chiemite has so far been on Earth not known as a natural material; due to its first discovery in the Chiemgau crater strewn field, it received its name. The conditions of origin - very high pressure and very high temperature - characterize the Chiemit as a new impact rock.

But how did the different carbon varieties and especially the chiemite originate in the Chiemgau crater strewn field? The following explanatory model has been developed (Ernstson et al., 2013): The impact causes a shock front, combined with violent explosions (airbursts), highest pressures and extreme temperatures, and hits the vegetation, which in a process of short-time carbonization shapes the different carbonization varieties. The extreme forms, namely the nanodiamonds and the dense, hard, glassy carbon, require above all high shock pressures, while the chiemite requires above all extreme temperatures for the formation of a degassing carbon melt.

d) Macroscopically deformed stones

There was already talk of boulders with enormous mechanical deformations at Lake Tüttensee. They are by no means limited to these, but can be found in many of the craters on the ground, in the crater walls and in the material that builds up the ring walls.In the Chiemgau crater field there are also extremely corroded, sometimes even skeletal Alpine rocks of various types (Ernstson, 2010: 51-57). The cobbles and boulders thus overprinted always consist of two or more different types of rock: e.g. quartzite or slates with calcite veins, limestones with quartz veins, sandstones with calcareous cementation, chert nodules and silicified fossils in limestone and others. This indicates a corrosion process that attacks one type of rock much more than the other. Direct chemical dissolution processes or high temperatures are possible. Lime, for example, decomposes at temperatures above about 1,000° C or can even pass into a carbonate melt. However, oxygen and nitrogen can also react to nitrogen oxides in the atmosphere during an enormous impact explosion (airburst), which combine with water (steam) to form nitrous acid and nitric acid. At the Chiemgau impact it could have been the nitric acid alone that rained off an unknown time and corroded the rocks on the ground, whereby understandably lime decomposition could work together under high temperature and acid solution. This process must have taken place in situ; during transport these sharp-edged decomposed, brittle, often easily friable pebbles would have been quickly rounded again or even completely decayed.

Secondary phenomena

The Chiemgau impact was accompanied by a great variety of secondary phenomena, e.g. the tsunami triggered by the impacts into Lake Chiemsee (Ernstson, 2016) or the so-called "thunderholes" (Ernstson et al., 2011; Ernstson & Poßekel, 2017), which will be discussed in more detail. The region north of Lake Chiemsee, from Obing, Kienberg and Traunreut to Kirchweidach (see Fig. 1), was and still is affected by sudden sinkholes (the "thunderholes"). The soil, with a diameter of up to several meters and a depth also of up to several meters, collapses steeply. The cause of the thunderhole formation was always a mystery and for geologists often associated with a vague reference to the ice age. Possible explanatory approaches such as karstification, volcanism, gas leaks, mining and mud volcanism are ruled out due to the local geology. Extensive geological and geophysical investigations (ground penetrating radar, geoelectrics, see Fig. 5 below) of several thunderholes, including excavation, provided information. In all cases, a material transport from bottom to top, sometimes very rich in energy, could be demonstrated, which in explosive pressure discharges lifted boulders weighing up to 200 kg by up to 1 m. An explanation brings all observations coherently in connection with earthquake-like shock and resulting rock liquefaction (soil liquefaction), which was explosively discharged upwards by weak points of the covering rock layers. Earthquakes of the required magnitude are not known in the region, but the shock waves of the Chiemgau impact were a plausible trigger for this process. The material often got stuck in the resulting transport channels, but over the millennia it is gradually washed out - another thunderhole collapses.

What do you think came down there and how?

The shape and position of the strewn field, its size and the distribution of the craters allow certain rough conclusions to be drawn about the size, composition, density and speed of the celestial body that entered the Earth's atmosphere, and its trajectory. The craters identified so far show a certain "sorting" in the elliptical strewn field: the small craters are mainly located in the northern area, the large ones in the southern area. This distribution can be explained by the kinetic energy of the fragments of a single body or of the objects of a swarm, depending on their mass at originally the same entrance velocity. The greater momentum of the more massive fragments leads to a longer path in the atmosphere before the air friction slows down the object. Lower-mass fragments follow a shorter path in the atmosphere before being decelerated and run on a steeper path. Depending on their composition (density, strength, shape, material), the fragmentation of the parts can occur several times explosively: The result is a cascade of falling fragments, whose different drop curves along and laterally to the trajectory give the observed size distribution of the craters on the ground. Pressure waves, which are triggered by the objects flying at high speed in the swarm by the compression of the air, contribute to lateral downthrust.

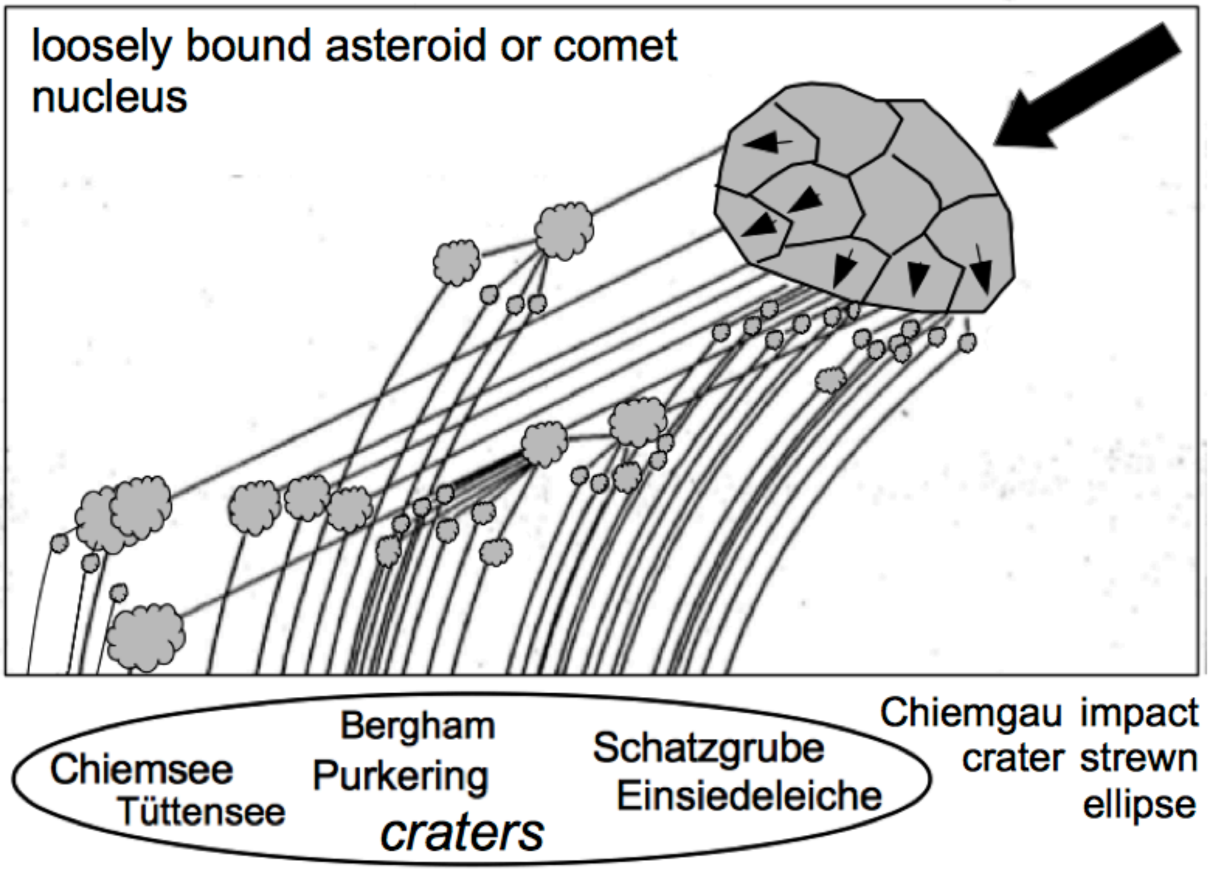

Fig. 7: Projectile and crater grading. Breaking of the asteroid/comet nucleus during the approach, grading of the fragments according to size. Accordingly there is a very rough arrangement of the craters in the scattering ellipse depending on their size. Strongly schematized.

In the case of the Chiemgau impact, the object must have flown from the northeast to the southwest (azimuth 43°) and penetrated the Earth's atmosphere at a very shallow angle of about 7°, according to the known distribution of craters. At about 70 km it broke apart and continued fragmentation began. This scenario applies to a meteoroid that was still intact when it reached the denser layers of the atmosphere. The Chiemgau impactor could have been torn apart into fragments of different sizes by tidal forces at an altitude of about 22,200 km (Roche's limit at 1.3 g/cm^3 density). Especially "porous" objects, whose more frequent existence has been confirmed by space probes and terrestrial radar observations, with only slightly joined components (adhesive bond), are susceptible to such fragmentation near planets. The parts would then have fallen into the atmosphere and - as described - would have been further fragmented in cascades: a "multiple impact". This would be supported by the unusual width of the distribution ellipse of about 27 km. While several fragments crashed extremely short after each other, the earth rotated a little further under its trajectories, which caused an offset from east to west and thus an expansion of the crater scatter field.

From the flight direction of the object and the entrance angle it can be concluded that it ran prograde around the sun and must have been relatively slow (around 12 km/s). Such objects rather originate from the inner solar system, i.e. for example from the planetoid belt between Mars and Jupiter. It could be either a fragment of a planetoid of very low density ($< 1.3\ g/cm^3$) or an inactive comet nucleus (short-period comet) of similar low density. The celestial body may also have originated from the Kuiper Belt or the Oort comet cloud and then been directed into the inner solar system by the planet Jupiter, which is known to influence the orbits of comets.

Some of the exotic substances found in the Chiemgau crater field allow cautious and preliminary conclusions to be drawn about the type of the Chiemgau impactor. Eight of these substances are also known from meteorite impacts: nanodiamonds, (β)3C-SiC (moissanite), Fe_2Si (hapkeite), Fe_3Si (gupeiite), suessite $(Fe,Ni)_3Si$, Fe_5Si_3 (xifengite), khamrabaevite ((Ti,V,Fe) C) and krotite (CaAl2O4). In the Chiemgau they occur in material samples as mixtures of material formed at low and high pressures and low and high temperatures (i.e. under conflicting conditions). Some of them date back to the time of origin of our solar system, others to later periods. The mixture could already have been formed in space by multiple collisions. Ureilites, a class of very rare stony meteorites, show indications of such collisions, and it is interesting to note that it is precisely ureilites in which some of the exotic substances found in Chiemgau samples were detected for the first time, and in some cases only in nature. The Chiemgau impactor could also have been a ureilite.

Dating: When "the sky collapsed"?

A well drilled by the Bavarian State Office for the Environment (LfU) at the edge of Lake Tüttensee, whose cores were dated using the radiocarbon method, caused a lot of irritation. The LfU stated that the borehole had been drilled at the "boiler end" (LfU press release). Under half a meter of decomposed peat, a first age of 4,800 BP (= today) years was determined at a depth of 0.60 m, at a depth of 2.50 m 10,000 years, and below even 12,500 years (Doppler et al., 2011: 274-275). The conclusion was that this proved that Lake Tüttensee was a dead ice hole and that there had never been a cosmic catastrophe (press release LfU). But this conclusion is based on false assumptions (B. Rappenglück et al., 2011: 279): The drilling samples were not taken at the bottom of the Lake Tüttensee boiler end, but at the edge of the shore. There, however, a borehole that wanted to determine the age of the formation of the hollow form was out of place, because it did not hit the actual crater excavated during the impact, which today lies beneath the water surface of Lake Tüttensee, but the undisturbed post-glacial layers (see Fig. 3 below). Thus the drilling with its dating as "manslaughter argument" against the impact is obsolete. On the contrary, the top half meter of apparently undatable, decomposed peat found in the borehole is remarkable: Is this the horizon left over from the impact? Does the drilling quite unintentionally give us a hint at a post-glacial event at Lake Tüttensee which is younger than 4,800 years ago today?

Further up, there was already talk of the finds that CIRT made in the middle of the disaster layer near Lake Tüttensee: On the one hand this is the blank of a stone axe, which can be classified in time between the Middle Neolithic and the Bronze Age. Pottery fragments, also found in the same area in the disaster layer, date back to the Bronze Age or Iron Age and can probably be assigned to the Late Bronze Age (= Urnfield Age). Found in the middle of the impact catastrophe layer, they were embedded during the impact and prove that the impact could not have taken place before the Bronze Age. Roman finds on the Lake Tüttensee rim wall show that the Chiemgau impact was already history, and that the discovery of a Middle/Late Latène period shard in the layer above the ejecta masses - consistent with the settlement evidence in the region attributable to this period - indicates that the impact must have occurred before about 300 BC.

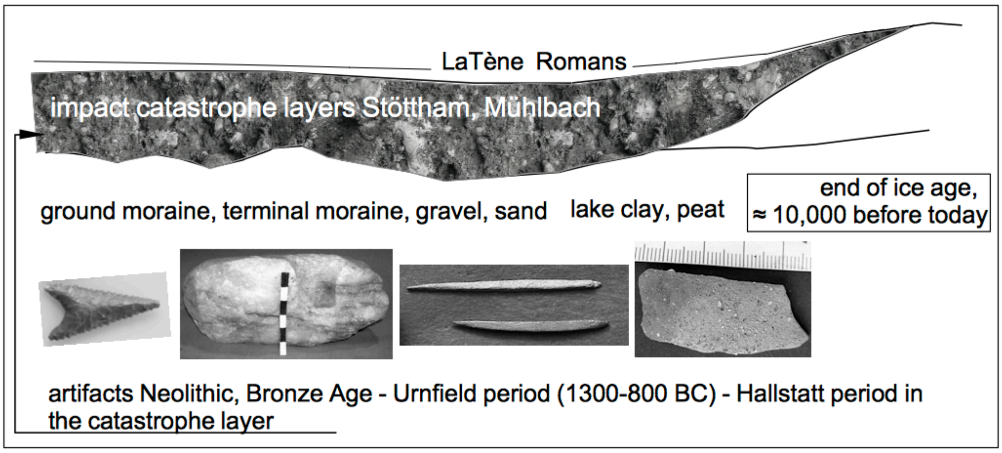

Fig. 8: The most reliable dating of the impact event to date results from archeological finds and features. It must be younger than the most recent finds in the disaster layer and older than the oldest finds directly above the disaster layer.

The stratigraphic situation encountered during an excavation at Chieming-Stöttham, on the eastern shore of Lake Chiemsee, was unique worldwide: There the impact disaster layer was embedded in archeological layers. The complex geological-archeological situation was interpreted by Völkel et al. (2012: 376-377) as a chronologically continuous colluvium in a paleo-channel, and the formation of the catastrophic layer in the context of a meteorite impact was denied. However, the evidence (Ernstson et al., 2012: 252-254) of different forms of impact diagnostic shock metamorphism proves that the material of this layer was affected by the impact. OSL dating, performed by Völkel et al. (2012: 371) as well as by CIRT (Liritzis et al., 2010: 17), dated the layer to the Bronze Age around 2000 B.C., but is discussed regarding its significance in the situation of impact and tsunamis (Liritzis et al., 2010: 29-30). The strata are strongly mixed with finds of different time positions - a circumstance that is possibly due to the ground movements caused by the impact. The excavating archeologist concluded that the layer "must have been deposited after the beginning of the Late Neolithic and at the latest during the Urnfield Period" (Möslein, 2009).

All in all, the dates obtained so far using various methods are sufficient to classify the Chiemgau impact with certainty in the Bronze Age/Iron Age. Since the archeological finds provide the most reliable clues - despite all the situation-related uncertainty - it is to be hoped that further excavations will be carried out in which the disaster layer can be found and the timing determined even more precisely.

In view of the dating of the Chiemgau impact and the proven settlement of the area at the time in question, the question of eyewitnesses and traditions of the event arises. Unfortunately, apart from Celtic inscriptions, the cultures that shaped the region at the time in question did not leave any written evidence. But the ancient myth of Phaethon, who crashed as son of the sun god with the sun chariot and set the world on fire, has been interpreted in detailed investigations as mythical processing of the Chiemgau impact (B. Rappenglück & M. Rappenglück, 2007; B. Rappenglück et al. 2010). The myth must have originated between around 2000 BC and 428 BC, when it was first clearly documented in writing. Some of the ancient authors locate the events in the "Celtic Land", which would agree well with the Chiemgau in the core region of Celtic culture. Not only in the dating and the scene, but also in essential further details (B. Rappenglück & M. Rappenglück, 2007: 103-105; B. Rappenglück et al., 2010: 431-435) the myth of Phaethon and the Chiemgau impact show unusual agreement, of which only some examples are mentioned: The breaking apart of the solar carriage can be compared with the fragmentation of the Chiemgau impactor; the countless coalification products described above are evidence of burnt vegetation as described by the myth; the Chiemsee impacts triggered tsunami waves, and correspond to Phaethon's fall into a lake and the fact that the god Neptune rose three times from the water and withdrew again; acid exposure, as evidenced by the violently decomposed rocks, may also have produced toxic fumes, of which the myth speaks.

If one interprets the details portrayed in the myth as the processing of concrete observations in the Chiemgau impact, one proceeds from eyewitnesses. During the Tunguska event of 1908 - the massive explosion of an unknown celestial object over Siberia - people survived the event at a distance of 10-60 km from the epicenter and reported on it. Also in the hilly landscape of the Chiemgau with its numerous waters and the nearby Alps, the event will have had very different local effects and the survival of eyewitnesses will have been possible. Various phenomena of the Chiemgau impact were perceptible over large parts of Europe (cautious estimates): the trajectory of the object could be observed at least over the whole of northern Eurasia. The explosion(s) in the atmosphere could be seen over a radius of at least 500-600 km and probably heard over a distance of 1,000 km and more. Depending on the fragmentation of the object, parts did not only settle in the Chiemgau. A fallout of carbon spherules occurred over large parts of Europe. The vibrations caused by the impact could still be felt at a distance of several hundred kilometers. The observations and experiences will have spread quickly - also through well-established trade contacts. An unpredictable event of such magnitude and impact required an explanation. A myth served this purpose at that time.

Summary

The above mentioned criteria for a meteorite impact are met by the Chiemgau impact, as shown here, in a comprehensive way. It stands out from other Holocene impacts by some pre-eminent features:

- the impact as such is clearly proven by shock metamorphism;
- find of meteoritic material,
- the size of the crater strewn field (approx. 60 km x 30 km),
- the number of craters (approx. 80), - the size of the Lake Tüttensee crater (600 m Ø),
- the variety of side effects and secondary effects,
- the direct embedding of the impact layer in an archeological stratigraphy,
- the comparatively exact dating.

Research into the Chiemgau impact is exemplary of how years of meticulous interdisciplinary scientific research involving the interested public and amateur researchers lead to unexpected, fascinating but well-founded results that break new scientific ground and open up new perspectives for research.

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