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The Chiemgau Crater Strewn Field: Evidence of a Holocene Large Impact Event in Southeast Bavaria, Germany

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The Chiemgau strewn field in the Alpine Foreland discovered in the early new millennium comprises more than 80 mostly rimmed craters in a roughly elliptically shaped area with axes of about 60 km and 30 km. The crater diameters range between a few meters and a few hundred meters. Geologically, the craters occur in Pleistocene moraine and fluvio-glacial sediments. The craters and surrounding areas so far investigated in more detail are featuring heavy deformations of the Quaternary cobbles and boulders, abundant fused rock material (impact melt rocks and various glasses), shock-metamorphic effects, and geophysical anomalies. The impact is substantiated by the abundant occurrence of metallic, glass and carbon spherules, accretionary lapilli, and of strange matter in the form of iron silicides like gupeiite and xifengite, and various carbides like, e.g., moissanite SiC. The hitherto established largest crater of the strewn field is Lake Tüttensee exhibiting an 8 m-height rim wall, a rim-to-rim diameter of about 600 m, a depth of roughly 30 m and an extensive ejecta blanket. Physical and archeological dating confine the impact event to have happened most probably between 1300 and 300 B.C. The impactor is suggested to have been a low-density disintegrated, loosely bound asteroid or a disintegrated comet in order to account for the extensive strewn field.

Keywords: Chiemgau crater, shock-metamorphic effects, geophysical anomalies, Chiemgau material, Chiemgau impactor.

1. Introduction

In the last decade, an increasing interest in Holocene catastrophic impact events is documented by numerous international meetings, workshops and publications [1, 4, 28, 36, 56, 57, 65]. This interest reflects the public awareness of a realistic cosmic threat, and the centenary of the Tunguska event with

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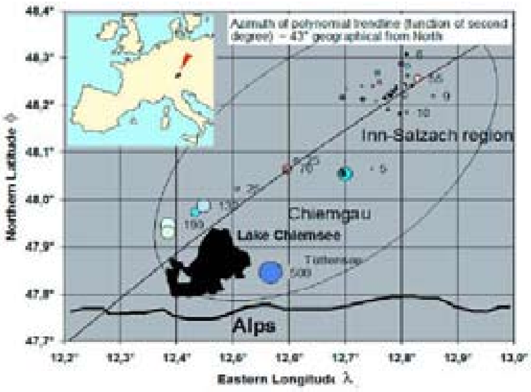


Fig. 1. The Chiemgau crater strewn field. The craters are not drawn to scale, but the relative sizes more or less hold true. The numbers attached to a few craters are the true diameters (in meters).

worldwide considerable resonance in the media underlines the importance of the subject matter. The real threat to Earth and possible defense strategies [12, 60, 61] are controversially disputed, and here statistics and impact probabilities play a major role [5, 7, 52]. While in general the threat by asteroid impact is considered much larger than by comet impact [60], there are scientists who suggest the probability of cometary impacts is largely underestimated [62]. The debate demonstrates that statistics has limited importance only and that a sound and complete as possible record of young impact events based on thorough field observations and precise dating are fundamental.

Here we report on a large impact event some 2,500 years ago in the Celtic period that produced an unusually large crater strewn field that was discovered in the early new millennium by a group of local history researchers (W. Mayer and co-workers). In the subsoil they detected pieces of metallic material (ferrosilicides Fe_3Si, mineral gupeiite, and Fe_5Si_3, mineral xifengite) hitherto unknown in the region of the rural districts of Altötting and Traunstein near Lake Chiemsee (Chiemgau, southeastern Bavaria) [2]. They noticed that the material was regularly associated with striking craters, which mostly showed a clear rim, though some of them had been leveled by plowing. After having performed an extraordinary field work over three years till 2004 they came to the conclusion that both the peculiar metallic matter and the craters could be related with the impact of an extraterrestrial object and that the impact must probably have happened in historical time. Their discovery in the Inn-Salzach region (Fig. 1) widely raised skepticism, but they nevertheless were able to interest scientists e.g., from the Munich and Tübingen universities resulting in a few early publications [25-27, 41, 67, 78]. In the year 2004, W. Mayer and co-workers entered into a new cooperation constituting a group of researchers (Chiemgau Impact Research Team, CIRT) that now comprises the early discoverers together with earth scientists, astronomers, impact researchers, archeologists and historians. The constitution of the CIRT went hand in the insight into a much larger dimension of the proposed impact event comprising both the areal dimension (Fig. 1) and the host of related phenomena. The present paper intends to give an overview of the research as it now (late 2008) stands.

2. Scattering ellipse and crater dimensions of the Chiemgau strewn field

On earth, seven meteorite crater strewn fields are known. These are the Kaalijarvi field in Estonia, the Morasko field in Poland, the Sikhote Alin field in Russia, the Henbury field in Australia, Campo

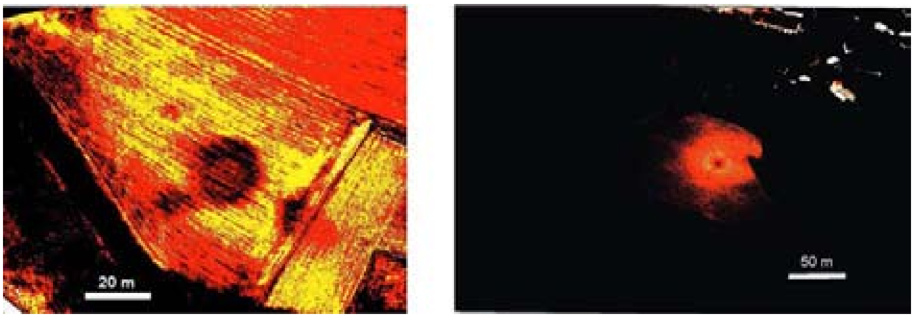


Fig. 2. Aerial photographs of leveled craters on farmland (near Mehring, left, and Perach) after image processing. The Perach crater exhibits a distinct ejecta blanket and, although leveled by farming, a clear concentric zoning. Photos by courtesy of G. Benske and Bayer. Landesamt f. Denkmalpflege


Fig. 3. The 6 m-diameter Hohenwarth and 11 m-diameter # 004 craters

del Cielo in Argentina, the Wabar field in Saudi Arabia [39], and the Macha meteorite crater field in Yakutia [35]. Recently, a group of a few young meteorite craters with diameters of the order of 300 m has been discovered in Russia east of Moscow [17].

Compared with these known occurrences, the newly discovered crater strewn field in southeastern Germany (Fig. 1) is exceptional. Our investigations up to now count more than 80 craters that have been identified, measured and catalogued on the basis of topographic mapping, satellite imagery, systematic aerial photography, and ground inspection establishing the scattering ellipse shown in Fig. 1. Recent sonar soundings in Lake Chiemsee and relevant deposits in and around the lake [85] suggest impacts to have happened also in the water. Most conspicuous is a rimmed doublet crater of the size roughly 900 m x 400 m.

The preservation of the craters varies depending on their location on, e.g., farmland or in forests. On farmland, many of the craters recorded on older topographic maps have meanwhile been leveled out. Despite the leveling, they are often visible by satellite imagery or on aerial photographs especially when image processed (Fig. 2). On the other hand, many well-preserved craters are probably if not certainly hidden in forests that cover large areas of the scattering ellipse.

The diameters of the documented craters range between 3 m and several 100 m (a few of them shown in Figs. 3, 4). At present, Lake Tüttensee, located near the well-known Lake Chiemsee, proves to be the largest crater (Fig. 1; more about the Lake Tüttensee crater below (chapter 12.1)). The depths of the craters range between 0.4 m (for the smallest 3 m-diameter craters) and an estimated depth of about 30 m for the largest crater, Lake Tüttensee. In Fig. 5, the depths and diameters for 42 fully preserved smaller craters are plotted exhibiting a general increase of the depths with increasing diameters. On

Fig. 4. The 16 m diameter Murshall crater and the 55 m-diameter # 024 semi-crater (punched out of the Inn river embankment; to the right). The # 024 crater is conserved at half only (see the broken line encircling the crater) because of the destruction by the nearby Inn river erosion. Aerial photo: G. Benske

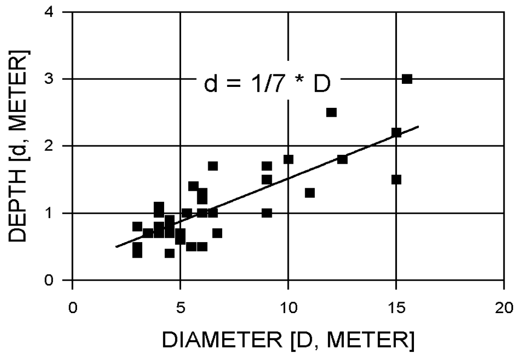


Fig. 5. Diameters and depths for 42 fully preserved smaller craters of the Chiemgau strewn field. On average, a diameter-to-depth ratio of 7 has been determined (given by the straight line)

an average, a diameter-to-depth ratio of $r = 7$ applies. Depth determinations for the larger craters is in general problematic because of lacking soundings in water-filled structures and frequent back filling.

On average, the diameter of the craters increases from the northern end of the strewn field to its southern end (Fig. 1). This is remarkably similar to other meteorite crater strewn fields (Morasko, Henbury, Kaalijarvi, Sikhote Alin) showing a comparable distribution [39]. Such a distribution is generally assumed to be related with an atmospheric break-up of the impactor implying a rough grading of the fragments and of the diameters of the associated craters.

3. Target geology

Apart from the most northern part of the strewn field, where Miocene gravels, sands and marls are exposed in the hilly terrain, the target is predominantly composed of Pleistocene and Holocene moraine sediments and fluvial deposits (Fig. 6). Pebbles, cobbles and boulders up to the size of 30 cm are intermixed with sands, clays and loamy material. The components represent Alpine material in the form of sedimentary rocks (mostly limestones, dolostones and sandstones), magmatic rocks (mostly granitoids) and metamorphic rocks (mostly quartzites, gneisses, amphibolites, serpentinites and schists). Occasionally, meter-sized erratic blocks and larger blocks of cemented conglomerates (Nagelfluh) are observed. Locally, lacustrine clays, peat, loess and loamy soils contribute to the target layers.

Fig. 6. Rim zone of the # 024 semi-crater (located to the left) exposing typical gravelly target rocks in the Inn river embankment (see Fig. 4). Note that the layers are markedly folded probably due to the impact excavation flow field

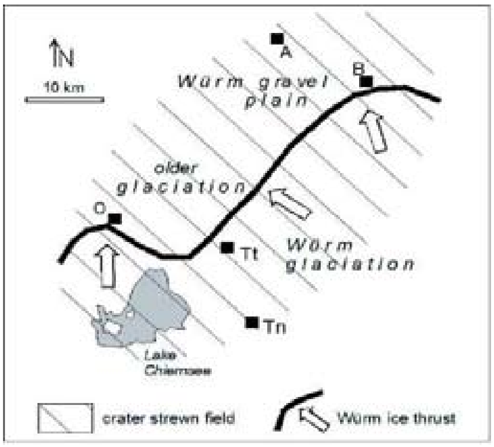


Fig. 7. Simplified sketch map of glacial signature in the crater strewn field area. Note that a large part of the crater distribution is located outside the most recent Würm glaciation not allowing a confusion of the craters with young dead-ice depressions there. A = Altötting, B = Burghausen, O = Obing, Tn = Traunstein, Tt = Traunreut

Because of the glaciation-dominated target geology, confusion has been introduced by critics of the impact hypothesis. Most commonly, the craters are claimed to be dead-ice depressions [16, 76, 91] without stating any reasons. As shown in Fig. 7, the crater strewn field is to a large extent located in the gravel plains outside the ice thrust of the latest Würm glaciation basically excluding a dead-ice origin for the numerous craters found here. Because of the markedly fresh shape of the craters an interpretation as remnants from earlier glaciations can likewise be excluded. With regard to other geological processes to have possibly formed the craters, we find that neither volcanism nor tectonics are known for the region under discussion and for the Holocene geological time of the phenomenon. Deep-seated dissolution and collapse processes like karstification may account for those depressions lacking a ring wall but can be excluded for all the craters exhibiting such a wall. Recent ideas and investigations [24] suggest that some of the smaller craters may have been formed indeed in the impact event, however from beneath instead of from above. Like strong earthquake shocks, impact shock may lead to liquefaction of water-saturated soft rocks causing sand explosion craters as happened wide-spread in the strong 1811/1812 New Madrid earthquake series [83].

4. Crater structure and material

Only a few craters have so far been examined in more detail. Digging vertical trenches through them reveals the typical bowl-shaped profile well known from meteorite craters of comparable size. The majority of the craters have clear walls, with a steep gradient inside towards the center and a flat one outside. Ground penetration radar (GPR) measurements [79] across a 11 m-diameter crater reveal strong reflexions from the crater floor, and the layering down to a depth of several meters continuously reflects the rim wall morphology. Often, the craters show a slightly elliptical form. On aerial photographs, the zone of ejecta around some craters may become visible (Fig. 2).

The gravel in the center of the craters studied so far is sharp-edged broken and looks basically different compared with the usually well-rounded pebbles found in the field (Fig. 8). At the rim of the craters, strongly deformed cobbles and boulders are regularly observed. They may be accompanied by melt rocks, pumice-like stones and low-density, foamy, vesicular carbonate material (for more details of the deformations and the melt rocks see below).

Fig. 8. Broken, sharp-edged clasts from within the craters (to the left) sharply contrasting with well-rounded clasts from the Quaternary material in the field

5. Macroscopic deformations

Craters having so far been investigated in more detail exhibit strong mechanical deformations at the floor and the walls and in the ejected material forming the rim (Figs. 9, 10). Heavily fractured but coherent cobbles and boulders (Fig. 9) prove *in situ* high-pressure/short-term deformation. A deformation by Alpine tectonics or by glaciers can be excluded, because the clasts would not have survived any significant transport. Comparable *in situ* high-pressure/short-term deformation established by Ernstson and Claudin [20] and Ernstson [23], have also been reported earlier for the Ries impact structure (Nördlinger Ries) [11, 15, 70, 71].

Likewise, the widely open fractures in the otherwise coherent cobbles with smooth surface and without any shearing (Fig. 10, upper) cannot possibly have originated from tectonics. Instead, these so-called spallation features are the typical result of dynamic shock deformation well known from shock experiments in fracture mechanics (Fig. 10, lower right) and also observed in conglomerates near large impact structures [22-23], (Fig. 10, lower left). We emphasize that the examples shown in the figures do not represent scarce finds but regularly occur in and around the strewn field craters. In the wall surrounding the largest crater, Lake Tüttensee, estimated 40-50% of the so far examined larger cobbles and boulders exhibit strong deformations, whereas all gravel pits next to the crater are void of these characteristically deformed rocks.

Fig. 9. Strongly deformed cobbles from the Chiemgau crater field. The cobble to the left has completely been crushed to form a monomictic movement breccia [75] partly exhibiting mortar texture. The heavily squeezed and sharp-edged fractured however coherent cobbles sampled from a soft matrix prove high-pressure/short-term deformation and exclude any significant transport

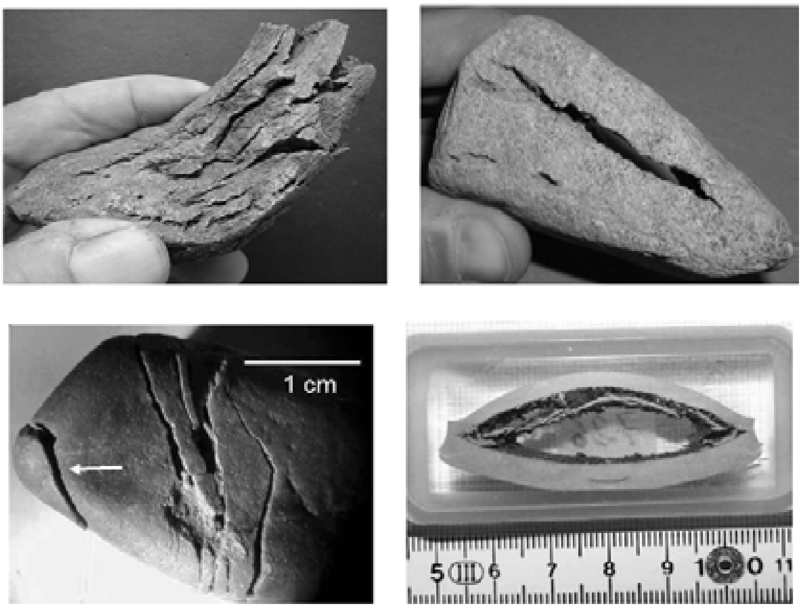


Fig. 10. Shock-induced spallation fractures in cobbles from the Chiemgau crater field (upper). For comparison, widely-open spallation fissures in a shocked quartzite cobble from the Azuara-Rubielos de la Cérida impact structures ([23]; lower left) and in an experimentally shocked ARMCO iron (courtesy M. Hiltl)

More impact-related deformations are observed in the form of heavily striated and polished cobbles found in various craters (Fig. 11). It is true, striated and polished clasts are well-known from glacier transport, the clasts shown here, however, originate from craters formed in fluviatile gravel deposits outside the Würm glaciation (see Fig. 7), and the striae and the polish would not have survived any water transport. Striated and polished clasts are moreover well-known from other impact sites like the Ries impact structure [11], the Azuara-Rubielos de la Cérida impact structures [20, 23] and the Chicxulub impact ejecta [54, 64].

In the fluviatile gravel material from craters in the Chiemgau strewn field, distinct concussion marks have been observed to occur on the surfaces of quartzite cobbles (Fig. 12). They strongly resemble similar deformations reported for shocked conglomerates near the Azuara-Rubielos de la Cérida impact structures [20-21], and a comparable formation for both, that is a highly energetic shock acceleration of cobbles in contact, is suggested.

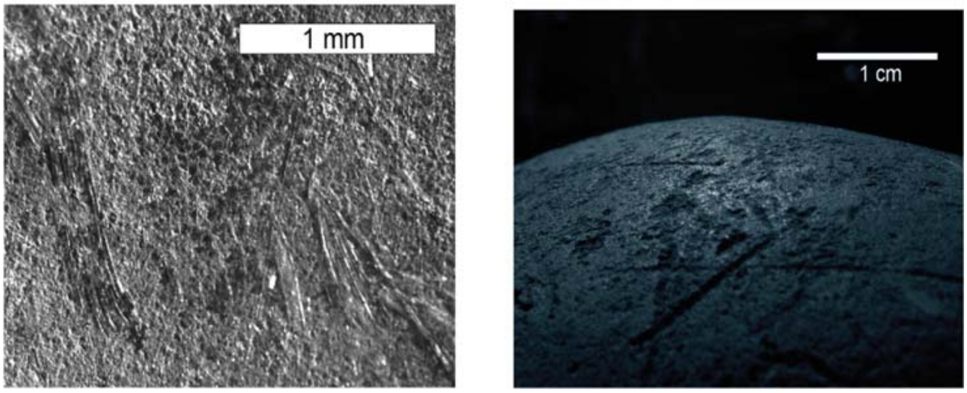


Fig. 11. Striation and mirror polish on quartzite clasts from # 024 semi-crater (to the left) and the Einsiedeleiche crater. The craters are located in fluvial deposits and, therefore, the deformations cannot be confused with a glacial signature

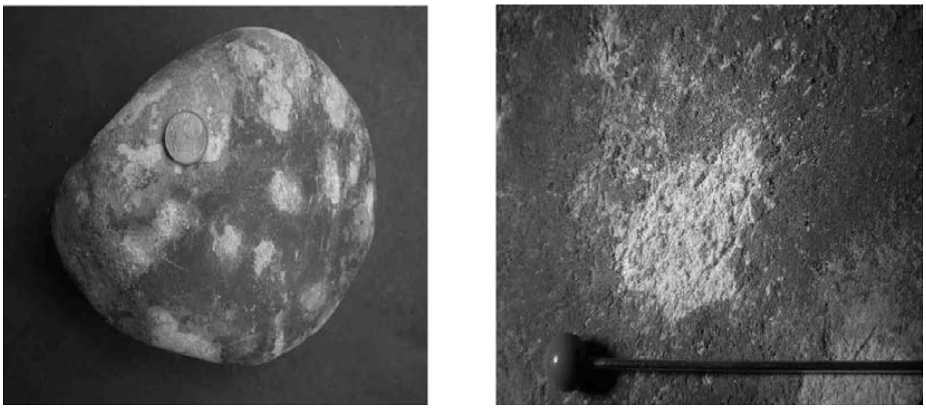


Fig. 12. Probably shock wave-induced concussion marks on the surface of a quartzite cobble from the # 024 semi-crater (Fig. 4). The close-up shows the strong microfracturing of the quartz grains causing a whitish color of the otherwise grayish stone

6. Rock corrosion

One of the most remarkable observations in the Chiemgau strewn field is the abundant heavy corrosion of Alpine cobbles and boulders of both carbonate and silicate lithology including, e.g., sandstones and amphibolites. They are observed to occur on the surface, in the shallow subsurface and within ejected material. The corrosion, abundantly deep-reaching to the point of residual rock skeletons (Fig. 13) is explained by decarbonization/melting and/or nitric-acid dissolution of carbonate rocks (limestones, dolostones) and by nitric-acid corrosion of silicate rocks. The production of considerable amounts of nitric acid (and other acids) in the explosion cloud of large impacts has repeatedly been proposed [53, 55, 66, 93], and precipitation of acid rain has also been suggested for the 1908 Tunguska event [50, 74].

7. Melt rocks and glass

Pumice-like melt rocks constitute striking impact rocks (impactites) in the strewn field (Fig. 14). They occur around the Lake Tüttensee crater and have been observed at the Lake Chiemsee shore. Near the Lake Tüttensee crater and north of Lake Chiemsee they have been used as building stones for the construction of 18th and 19th century farmhouses. Around the Lake Tüttensee crater, the melt

Fig. 13. Deeply corroded clasts from the Chiemgau crater strewn field

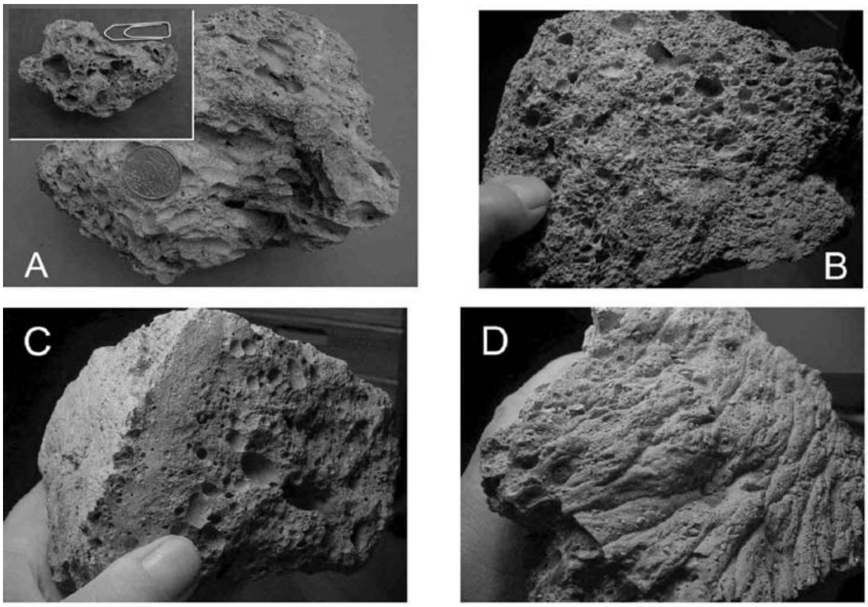


Fig. 14. Melt rock as occurring around the Lake Tüttensee crater and near lake Chiemsee. A, B: Various aspects of the strongly vesicular melt rock show analogy to the Chapadmalal (Argentina; [81]) impact melt rock (image inserted in Fig. 14 A). Superficially, the vesicular melt rock may pass over into a dense glass (C), and a «ropy pahoehoe» (D) reminds of well-known lava flow features

rocks must have been abundant in the past, but now they are rare. The reason is a popular game played by children some 50 years ago. They threw melt rock clasts («swim stones») into the Lake Tüttensee water betting on whose stone would sink last. The rock reflects an in general volatile-rich melt (Fig. 14 A, B) with frequent superficial transitions to a dense, often greenish glass (Fig. 14 C). Flow texture is indicated by alignment of elongated vesicles and a kind of «ropy pahoehoe» (Fig. 14 D) otherwise well known from volcanic lava flow. Frequently, melt rock clasts are superficially caked with gravel reflecting the emplacement of the melt. The macroscopically fairly homogeneous melt rock may be deduced from a homogeneous parent rock, for example from Lake Chiemsee lacustrine clays. In an experimental approach, wet lacustrine clay could be transformed to a vesicular glass on exposing the clay to some 2,500 °C for only a few seconds.

A second group of wide-spread melt rocks comprises cindery glass fragments in most cases interspersed with small rock fragments (Fig. 15). Among impact melt rocks the vesicular glass melt rocks from the Henbury (Australia) meteorite crater strewn field are most similar to this Chiemgau cindery glass.

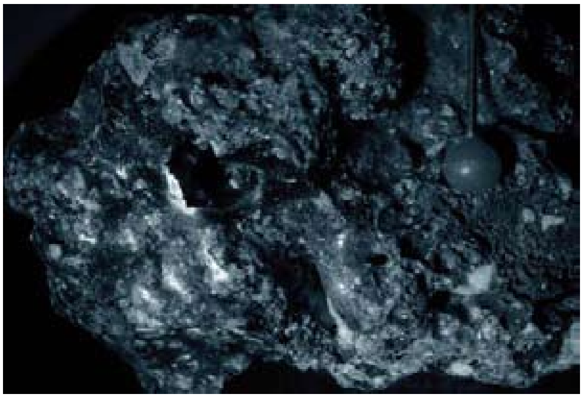


Fig. 15. Cindery glass fragment interspersed with quartzite splinters. This type of melt rock is widespread found in the Chiemgau strewn field

Fig. 16. A large sandstone boulder from the Lake Tüttensee crater completely coated by a thin film of glass. The darker spots show the original rock where the glass has flaked off

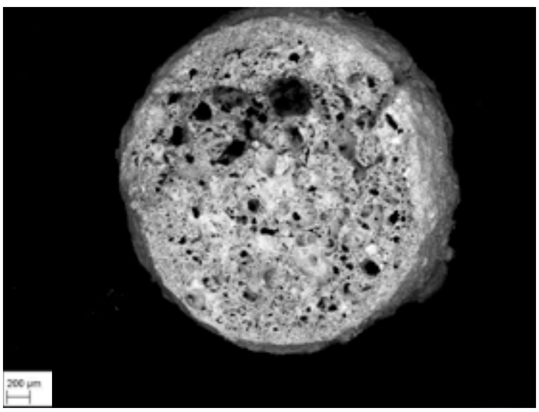


Fig. 17. SEM image of a broken vesicular glass spherule; Stöttham impact layer

A further variety of melt glass is found to in most cases completely coating silicate cobbles and boulders (Fig. 16). For the # 004 crater in the northern part of the strewn field, the cobbles and boulders more or less completely transformed to glass are a special characteristic that will be discussed in a separate chapter (12.3). More glass in the form of small glass spherules is found in the subsoil and embedded in impact breccia layers (Fig. 17).

8. Shock metamorphism

It is generally accepted that shock metamorphism in rocks must be considered as in proof of meteorite impact [31-32, 34]. Depending on their intensity, shock waves leave quite different traces in a mineral. Planar deformation features (PDFs) belong to the most important ones. Fig. 18 shows photomicrographs of PDFs in quartz from the Chiemgau strewn field. At least two (left) and five (right) sets with varying orientation are occurring.

These peculiar structures are closely spaced parallel, optically isotropic lamellae following crystallographic planes in the quartz grain. According to current knowledge [84], multiple sets of these closely spaced isotropic lamellae can originate from extreme shock pressure only. The mottled appearance of the quartz in Fig. 18 (right) can also be attributed to shock. This so-called «toasted quartz» is well known from shocked quartz from other impact structures and is explained by extremely tiny fluid inclusions [88]. PDFs in quartz have been shown to exist in several samples from crater # 004 (Fig. 18), from the Lake Tüttensee rim wall (Fig. 18) and in rocks from the Lake Tüttensee ejecta layer (see 12.1). In quartz from the # 004 crater diaplectic glass as a further strong shock indicator could be established. More distinct shock metamorphism in the form of PDFs and glass (probably maskelynite) is found in feldspar from the Lake Tüttensee melt rock (Fig. 19).

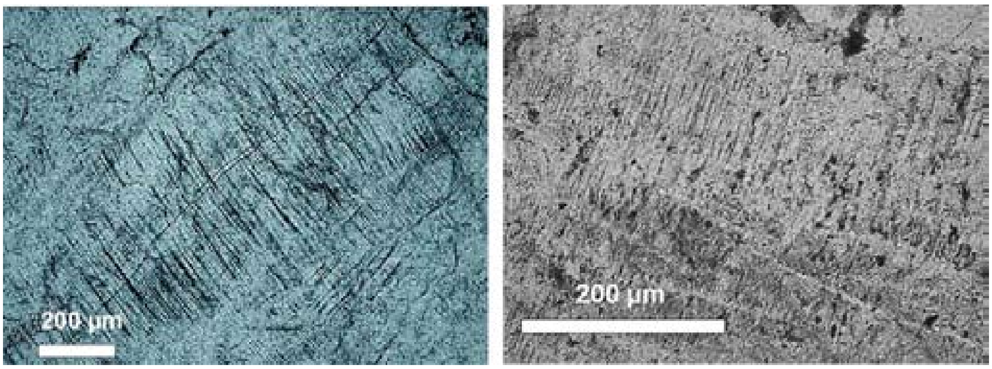


Fig. 18. Planar deformation features (PDFs) in quartz from the Chiemgau strewn field; photomicrographs crossed polarizers. Left: Two sets of PDFs in quartz, quartzite clast from crater # 004. Right: Five sets of PDFs in «toasted» quartz, quartzite cobble from the Lake Tüttensee crater rim wall. Not all sets can be seen on the image, but they become visible on rotation of the thin section on the microscope stage

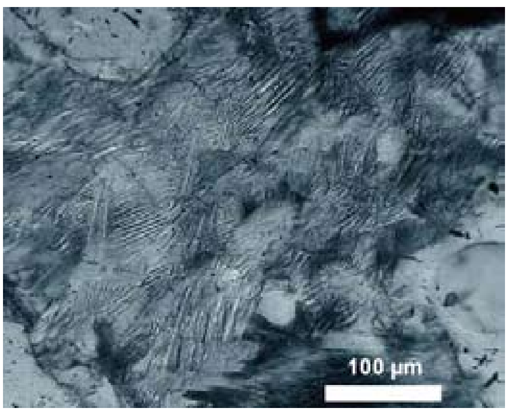


Fig. 19. Twin lamellae, multiple sets of PDFs partly showing «ladder» texture [31], and spots of glass (probably maskelynite) in plagioclase; photomicrograph, plane-polarized light. Melt rock from the Lake Tüttensee crater

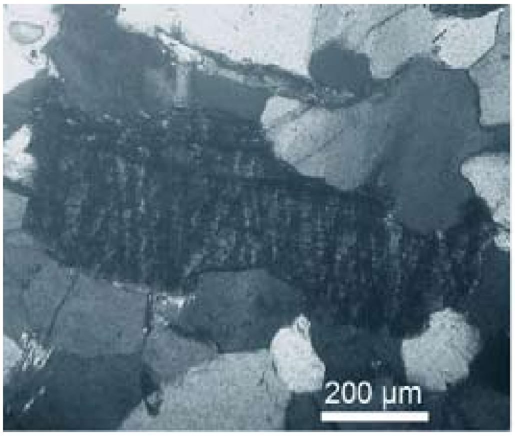


Fig. 20. Two sets of closely spaced kink banding in biotite (NNW – SSE and NNE – SSW trending); photomicrograph, crossed polarizers. Gneiss clast from the Lake Tüttensee ejecta layer (excavation pit # 10)

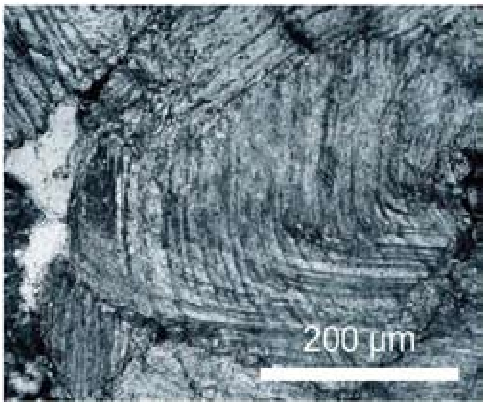


Fig. 21. Five sets of closely spaced and partly curved deformation features in calcite; photomicrograph, crossed polarizers. The spacing of the microtwins is in part 2 µm only. Calcite dikelet in quartzite, Lake Tüttensee crater excavation pit # 21

Apart from the PDF signature in quartz and feldspar and the diaplectic glass in quartz, the study of thin sections from 31 rock samples taken from seven different excavations at Lake Tüttensee establishes a rich inventory of mineral deformations that with reasonable certainty have also originated from shock load. The shock effects are moderate and comprise planar fractures (PFs; cleavage) in quartz, extreme and abundant kinking in mica (Fig. 20) [31, 43], and regularly occurring multiple sets of microtwinning in calcite (Fig. 21) [58]. With regard to the relatively small impact crater, the frequency of occurrence of the presumed shock deformations, although of moderate intensity, is conspicuous. Therefore, the special target conditions, that is hard and dense cobbles and boulders in an uncemented soft matrix, are discussed to have enabled a focusing of shock intensity as has earlier been considered for the Barringer crater Coconino sandstone [48] and for a shocked conglomerate [22].

9. Geophysics

Anomalous magnetic signature of craters and the subsoil have been revealed in the early phase of the investigations restricted to the Burghausen area in the very north of the strewn field. While Fehr et al. [27] considered inconclusive the measurements across a few craters, Rösler et al. [79] and Hoffmann et al. [42] discussing the strong magnetic signature of an 11 m-diameter crater (crater # 004 in our nomenclature; also see 12.3) favored a relation to an impact event. Extensive soil magnetic susceptibility measurements in forests in the northern part of the strewn field [40] revealed significantly enhanced values at depth. The authors exclude industrial and geologic delivery, but they avoid to discuss a third possibility. Meanwhile, we were able to show that the anomalous magnetic signature extends also to the most southern part of the strewn field. A rimmed 6 m-diameter crater some 2 km north of the Lake Tüttensee crater is characterized by a 15 m-diameter halo of enhanced soil magnetic susceptibility up to one order of magnitude larger than the normal soil susceptibility outside the halo. Also, the subsoil enhanced magnetic susceptibility as recorded in the northern strewn field [40] has been found to have its counterpart in the southern crater strewn ellipse. In a forest about 1 km north of the Lake Tüttensee crater we measured several soil susceptibility profiles regularly showing a peak at some decimeter depth (Fig. 22). The magnetic peak is related with a horizon enriched in fractured pebbles, cindery glass and carbonaceous spherules. Rock-magnetic studies remain to be done. More evidence of anomalous rock-magnetic behavior in the strewn field is given by the abundant occurrence of strongly magnetic rock clasts of quite different lithologies. The high, dominantly remnant magnetization seems to be unusual compared with typically magnetic rocks from the Alps (e. g., amphibolites, serpentinites). Although a systematic investigation has not been done so far, the cobbles and boulders thus featured seem to be confined to a superficial deposition, while lithologically comparable rocks sampled from e.g. nearby gravel pits are lacking this property. More geophysics in the form of a gravity survey is discussed in a special section on the Lake Tüttensee crater (12.1).

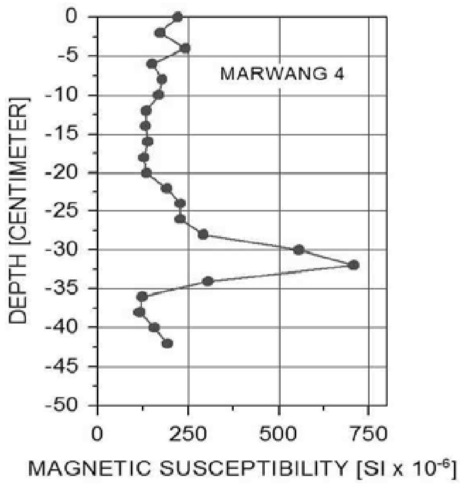


Fig. 22. Soil magnetic susceptibility profile near Lake Tüttensee revealing an anomalous peak at 30-35 cm depth. Comparable anomalous soil susceptibility has been shown to exist also in the northern part of the crater strewn field

10. Strange matter

The discovery and investigation of the Chiemgau meteorite crater strewn field is inextricably related to the occurrence of widespread peculiar matter that may generally be classified into metallic and carbonaceous matter. Since early analytical results from the northern crater strewn field have been published elsewhere, the present article confines to a short summary of the existing data and to a few exemplarily discussed new findings.

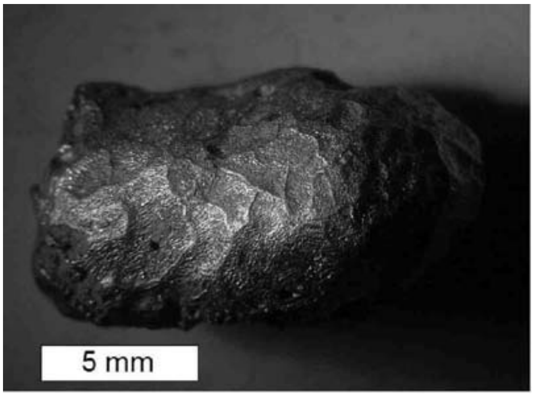


Fig. 23. Metallic iron silicide particle typically found in the Chiemgau impact strewn field

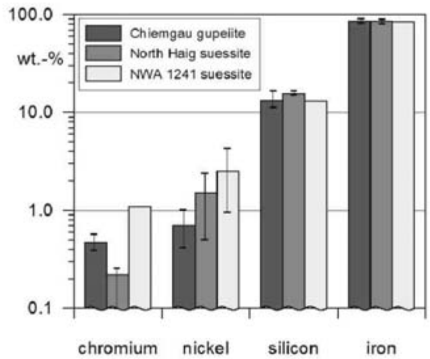


Fig. 24. Comparison of analyses of Chiemgau gupeiite and meteoritic suessite. Suessite data from [46] and [89]

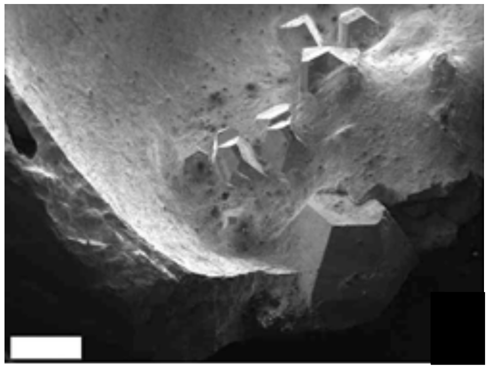


Fig. 25. SEM image of moissanite (SiC) crystals in iron silicide matrix. Scale bar 1 mm

Metallic matter. The first finds of peculiar metallic matter were often done near rimmed craters in the Burghausen area suggesting both occurrences were related to each other. The particles were millimeter to centimeter-sized forming spherules and irregular pieces, often seemingly aerodynamically shaped and with a peculiar surface sculpture reminding of regmaglypts (Fig. 23).

Surprisingly, these phenomena in turn correlated with anomalous data of a completely independent prospective biomonitoring campaign with honey bees over a considerable part of the sampling area [68] leading to the hypothesis both observations could be related to a possible cosmic impact. In early analyses, the metallic matter proved to be iron silicides Fe_xSi_y, among them the minerals Fe_3Si, gupeiite, and Fe_5Si_3, xifengite [80]. The similarity to gupeiite and xifengite occurences in cosmogenic globular particles from the Yanshan area in China [95-96] strengthened the hypothesis of an impact event in the Salzach-Inn region. A more recent electron microprobe analysis of a gupeiite particle from the Chiemgau strewn field showed clear affinity to meteoritic suessite (Fig. 24). The moissanite (SiC) crystals growing out of a iron silicide matrix (Fig. 25) also point to extraterrestrial origin of this Chiemgau sample if anthropogenic formation can be excluded.

Carbonaceous matter. Carbonaceous material of different, partly very peculiar character has abundantly been found in the Chiemgau strewn field. The most common occurrence is charcoal more or less regularly intermixed in the impact breccia layers from the Stöttham archeological excavation and the Lake Tüttensee crater ejecta blanket (see sections 12.1, 12.2). Moreover, carbonaceous

Fig. 26. Carbonaceous matter from the Chiemgau strewn field. Millimeter scale

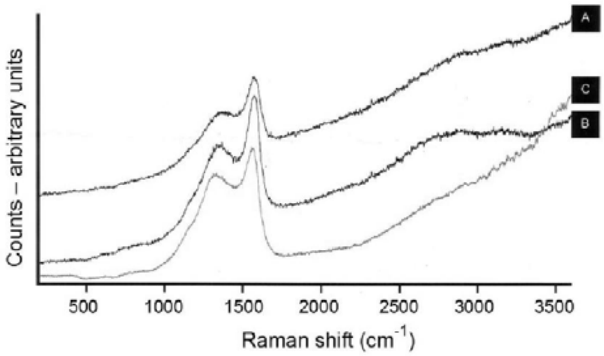


Fig. 27. Raman spectra collected from a carbonaceous piece sampled in the Chiemgau impact strewn field. The doublet peak at approximately 1360 cm^{-1} (D – disordered – band) and 1560 cm^{-1} (G – graphitic -band) indicates the matter to be mostly amorphous carbon

matter occurs in the form of black glassy fragments up to the size of a few centimeters (Fig. 26) and carbonaceous spherules with diameters of the order of millimeters (Fig. 28). The EDX analysis of a glassy fragment reveals mostly carbon, a high amount of oxygen (up to 25 wt. %), small amounts of Al, Si and Ca, and traces of Na, Mg, S, Cl, K and Fe. Raman spectra of the sample (Fig. 27) show greatly disordered elemental carbon mostly in an amorphous state. Similar Raman spectra of disordered carbon are known from, e.g., Allende carbonaceous chondrite, carbon matter from the Sudbury impact structure and artificially shocked graphite [38]. The inexplicably high oxygen content needs further analyses and may be related to a similar discovery of glassy amorphous particles of carbon and oxygen as the only major components in a microbreccia from the Mid-Tertiary Rubielos de la Cérida impact structure in Spain [23].

Like the unusual metallic matter, the carbon spherules (Fig. 28) have originally been discovered in the northern part of the strewn field and later also in the south when the much larger crater strewn field was established. Here they have been shown to be enriched in the layer of enhanced soil magnetic susceptibility (see above, Fig. 22).

For nanodiamond-bearing carbonaceous spherules sampled from the soil and embedded in the melt crust of rocks in the northern strewn field an impact-related origin has been suggested [92]. Both a formation in the impact process and constituents of the impactor are considered. Carbon spherules of similar qualities have been found also in soils widespread over Europe [92] and in an

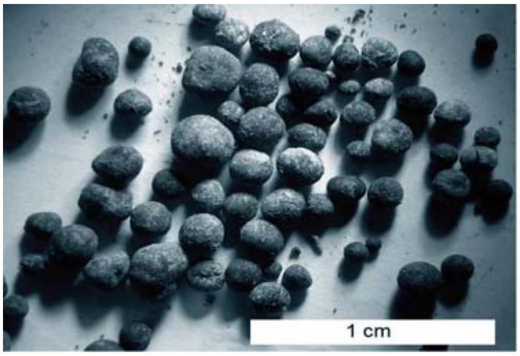


Fig. 28. Carbonaceous spherules

Fig. 29. Accretionary lapilli from the Chiemgau impact strewn field (left). Middle: A lapillo under the SEM showing the onion skin structure typically found in accretionary lapilli. Right: Cut lapillo composed of finegrained sandy matter hosting metallic particles (dark)

archeological context at the Dürrnberg (Austria) some 50 km off Lake Chiemsee thus pointing to a fallout phenomenon.

Accretionary lapilli. In the Chiemgau strewn field a special type of spherically shaped particles can abundantly be sampled from the ground that show the character of accretionary lapilli (Fig. 29). Although outwardly appearing very similar (Fig. 29 left), internal texture and chemical composition are quite different. Frequently they are composed of a dense fine-grained sandy material sometimes hosting a core of metallic matter (Fig. 29 right). Others show the sandy material to form a skeletal vesicular structure, and transitions to the vesicular glass spherules as shown in Fig. 17 can be observed. A broad spectrum from strongly magnetized to non-magnetic lapilli exists. Preliminary EDX analyses show strong elemental inhomogeneity even in one single lapillo.

Although accretionary lapilli are basically known from volcanism, they are more and more reported to have formed also in meteorite impacts, e.g. in the Ries [33], Azuara-Rubielos de la Cérida [21], Tookoonooka [6], Chicxulub [10] and in the Alamo [87] impacts. In the Chiemgau impact event the accretionary lapilli may attest a large explosion cloud. More analyses, however, are necessary.

11. The anthropogenic/industrial component

From the beginning, field and analytical work in the Chiemgau strewn field were confronted with the clear perception that there might be a strong anthropogenic signature concerning both the craters and the proposed impact-related material. In the region of the impact strewn field quite a few industrial firms are residing, and it is common knowledge that from the beginning of settlement human activities left various kilns, among them well-known lime kilns, glassworks and smelting works and related high-temperature material like various slags and glass always implying also carbonaceous matter. In addition, typical steel stabilizers are the same elements as are typical chemical elements in meteorites. In a few cases, after systematic inquiries in population and industry, a competition between proposed impact related findings and anthropogenic material clearly became evident. Thus, glass-coated silicate cobbles have convincingly been attributed to meteorite craters (e.g., crater # 004), but externally very similar cobbles are reported to may have casually been produced in lime kilns in earlier times. Much more problematic is the realization that in the Chiemgau industry the extremely rare iron silicide minerals gupeiite and xifengite are regularly produced as a hitherto completely unknown byproduct (Schüssler, written comm.), and from an enquiry it seems possible that iron silicides intermixed in fertilizer could be brought out on farmland during a few years after World War II. In this case, we have to explain why the particles under discussion are found also in many hundred years old forests, in peat mires at about two meter depth and in alp regions at more than 1,000 m altitude, unless also these areas, hardly imaginable, were fertilized in former times. Moreover, gupeiite and xifengite particles were detected below a medieval hoard of coins and below ground work of the Burghausen medieval castle. Hence, a so-called effect of convergence, that is the inserting of the same kind of ferrosilicide particles by fertilizing as well as by impact processes, cannot be excluded. As has been described above, impact melt rocks from Lake Tüttensee and Lake Chiemsee have been used as building stones for farmhouse construction in the 18th and 19th century. Likewise, true smelting slag served for the same purpose, and both were generally lumped together.

An origin other than from the impact has been considered also for the craters, and especially a possible anthropogenic formation of the many craters (e.g., housing estates, exploitation of earth materials, water reservoirs, charcoal piles, production of quicklime and glassworks, medieval limonite mining and smelting, explosion cratering from artillery fire or extensive bombing during World Wars One and Two) has been investigated and discussed by us in very detail, and in summary, for the most part of the craters under discussion a man-made origin can practically be excluded.

12. Selected impact sites

12.1. The Lake Tüttensee crater.

Lake Tüttensee is located a few kilometers east-southeast of Lake Chiemsee and north of the Foothills of the Alps (Fig. 1). The main dimensions of the lake (Fig. 30) is roughly 400 m. A seismic survey conducted on the lake has revealed the maximum water depth to be about 16 m, however no clear reflection signals from deeper layers probably due to energy-absorbing thick mud (G. Daut, pers. comm.). A gravity survey on the frozen lake [19] suggests roughly 30 m total depth including this thick layer of organic material. The lake is surrounded by a rim wall merging in the north into a glacial moraine. About one hundred years ago, the 8 m-height rim wall continuously encircled the lake but now exhibits three artificial gaps (Fig. 30). The rim crest diameter amounts to roughly 600 m, which therefore is the diameter of the proposed meteorite impact crater. Apart from the artificial gaps, the rim and crater area have sustained significant morphological modifications probably beginning already in Roman times.

Fig. 30. The Lake Tüttensee crater and the 8 m-height rim wall exhibiting an artificial gap

Lake Tüttensee has always been considered a dead-ice relic from glaciation although the considerable size and the pronounced, originally continuous rim wall have never favored the interpretation of a kettle hole, the more so as there are not any exposures that have supplied the necessary geologic-sedimentological evidence. Moreover, outlet records of Lake Tüttensee [3] and dominating gravelly material reported for the peripheral lake bed are speaking against a bottom sealing otherwise typical for glacial lakes in the Alpine Foreland. Nevertheless, critics of the impact event maintain the dead-ice origin for Lake Tüttensee [16]. Planned boreholes into Lake Tüttensee have categorically been prohibited by the authorities because of feared negative impacts on nearby drinking water fountains. Consequently, the impact nature of Lake Tüttensee has been revealed by accessible geology of the rim wall and an extensive impact ejecta blanket.

The study of the rim wall is mostly restricted to the outcrops of the artificial gaps with in general poor insight into its structure and material, the latter in principle being Quaternary moraine and gravel material. From the gaps, and especially from quite a few additional superficial excavations into the rim wall, great quantities of pebbles, cobbles and boulders were sampled exhibiting the unusual strong deformations and peculiar textures already described in paragraph 5 and shown in Figs. 9, 10.

Ejecta blanket. – The most striking geological evidence of the Tüttensee impact cratering process, however, has been supplied by numerous excavation pits around Lake Tüttensee (Fig. 31). Modifications included, they exhibit in general a three-layer sequence of autochthonous target rocks (moraine material or lacustrine clay), a fossil soil and a diamictite layer that in general is overlain

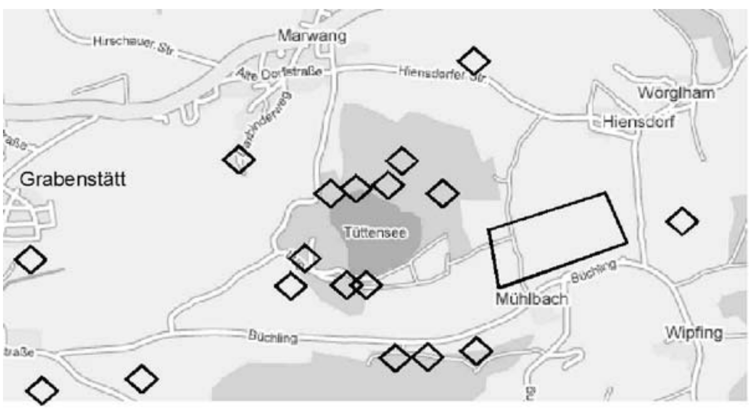


Fig. 31. Map of excavation pits around the Lake Tüttensee crater with a concentration of the excavations in the larger quadrangle

Fig. 32. A multicolored polymictic breccia constitutes a large part of the Lake Tüttensee crater ejecta layer. Note the heavily fractured however coherent quartzite clasts (to the right) proving deformation under high confining pressure and excluding any fluvio-glacial transport

Fig. 33. Organic material (splinters of wood, charcoal, bones, teeth; to the left) and Neolithic/ Bronze Age artifacts (a quartzite hammerstone and the fragment of a drilled quartzite boulder, possibly an inchoate stone ax) from the Tüttensee impact layer

by colluvium or immediately by the plowing horizon. The up to more than 1 m thick diamictite is interpreted to represent the Lake Tüttensee impact ejecta blanket that was in part overprinted and/ or reworked by tidal waves emerging from companion impacts into Lake Chiemsee [85]. The basal diamictite is dominated by sub-angular carbonate and silicate boulders in a muddy matrix which are in part strongly deformed plastically and are abundantly corroded down to a skeletal sculpture (Fig. 13). An intermediate bed, not always present, has the character of a polymictic matrix-rich breccia composed of heavily fractured cobbles and boulders of Alpine lithology (Fig. 32), while the uppermost part of the diamictite is especially enriched in humus material. The diamictite contains abundant splinters of wood and charcoal as well as fractured animal bones and teeth (Fig. 33). Tufts of hair from the base of the diamictite may be human hair. Thin-section analyses reveal abundant mineral deformations evident of shock metamorphism (see 8). From the matrix of the diamictites a couple of prehistoric artifacts could be recovered in the form of potsherds and Neolithic/Bronze Age stone tools (Fig. 33). A more comprehensive article on the Lake Tüttensee crater as matters stood in 2006 has been written by [13].

Gravity survey. – A gravity survey on the frozen lake and in its surroundings had the principal aim to get knowledge of the crater shape. The maximum gravity anomaly of Lake Tüttensee (Fig. 34) is about -0.8 milligals mainly resulting from the density contrast of water/mud and rock. Surprisingly, a ring of relatively positive anomalies is measured surrounding the Tüttensee negative anomaly (Fig. 34). The positive anomalies are modeled [19] by a 1000 m-diameter flat lens of slightly enhanced density. It is explained by a model of soil liquefaction and post-liquefaction densification well known from large

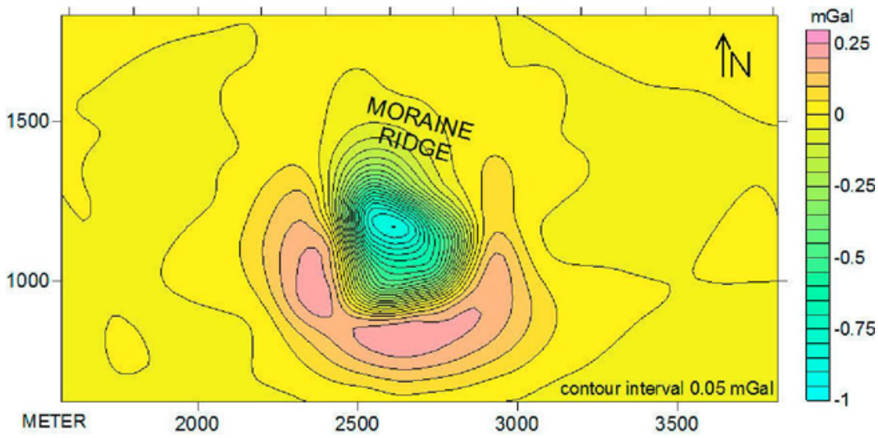


Fig. 34. Bouguer gravity residual anomaly for the Lake Tüttensee crater. Note the ring-like zone of relatively positive anomalies explained by impact densification

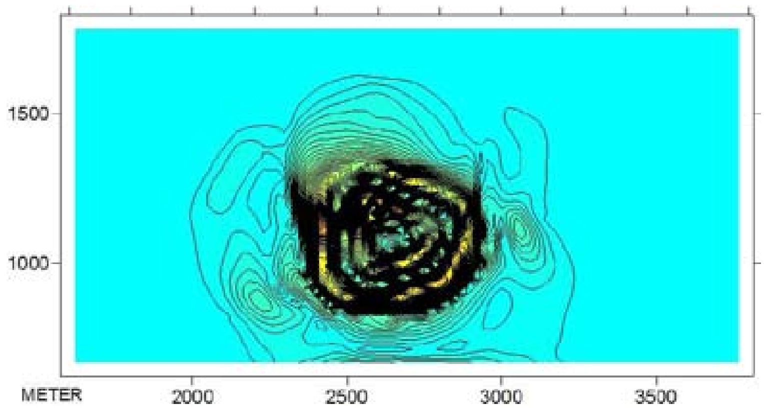


Fig. 35. Gravity horizontal second derivative of the Lake Tüttensee Bouguer residual anomaly suggesting interference of smaller circular features

earthquakes [51, 59, 86]. Moreover, mass flow behind the impact shock front could have contributed to the compaction of the loose, highly porous and water-saturated target rocks. The impact densification model is substantiated by a gap in the northern part of the positive ring-like anomaly (Fig. 34). Here, a moraine ridge of densified glacial rock material obviously resisted further densification upon impact, in contrast with the otherwise highly porous Quaternary fluvial sediments. More strong rock liquefaction suggested to be the result of the Chiemgau impact event is observed to occur widespread in the southern part of the strewn field [24].

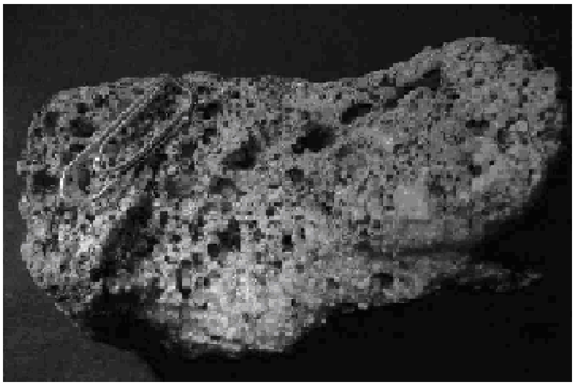
From the computed field for the horizontal second derivative of the Tüttensee Bouguer anomaly (Fig. 35), the circular shape of the crater anomaly becomes more accentuated, at the same time exhibiting an outline of interfering smaller circles. This may indicate a pre-impact disintegration of the Lake Tüttensee projectile.

12.2. The Stöttham exposure.

In the course of an archeological excavation at Chieming-Stöttham located a few hundred meters apart from the shoreline of Lake Chiemsee (47°54’25.3’’N; 12°31’28.5’’E), a diamictic layer very similar to the Lake Tüttensee impact diamictite has been encountered outcropping in a clear archeological stratigraphic context (see 13). The several decimeters thick diamictite is embedded in layers of colluvium contains brecciated and strongly corroded clasts, abundant organic material like wood, charcoal, fractured animal bones and teeth, and intermixed archeological artifacts. High-temperature signature is given by partly melted silica limestone, a typical rock from the Alps, and a sandstone clast with sporadically interspersed glass. A formation of the melt from shock release is possible. Moderate shock is indicated by abundant and strong kink banding of micas in gneiss clasts from the diamictite. Millimeter-sized glass and carbonaceous spherules were extracted from the diamictite mud. Lacking serious alternate explanations, the Stöttham layer must be considered an impact horizon belonging to the same catastrophic event as does the formation of the Lake Tüttensee crater. Different from the Lake Tüttensee crater diamictic ejecta no crater has so far been found as a source for ejected material constituting the Stöttham deposit. A nearby possible candidate is a 200 m-diameter depression that however was completely filled in the past not allowing simple geological access. A delivery of the Stöttham proposed impact ejecta material from craters located offshore in Lake Chiemsee is also discussed [85].

12.3. The # 004 crater.

In the first time of the strewn field investigations, the crater # 004 (Fig. 3) located in the northern part of the strewn field raised special interest because of its conspicuous deformation features and exceptional high-temperature signature. The bowl-shaped circular depression with a complete rim wall measuring 11 m in diameter was excavated from fluvial gravel material comprising common rocks from the Alps like quartzites or basic metamorphic rocks. Apart from a great number of mechanically deformed and fractured cobbles and boulders in and around the crater, a high-temperature process the crater area must have undergone is given by numerous clasts exhibiting a drastic melting signature up to practically complete transformation to glass. Rösler et al. [79] report temperatures that must have exceeded 1,500 °C across the crater area and a halo of about 20 m diameter. From these observations and additional geophysical radar and magnetic measurements, an impact-related origin of the crater is considered possible [79], although the authors were not able to establish shock metamorphism. From detailed petrographic and geochemical analyses of rocks taken from crater # 004, new insights into the cratering process are available. 17 cobbles of various lithology have been studied by thin-section inspection and microprobe analyses (Mineralogical Institute, University of Würzburg). The thin sections clearly show that the cobbles have experienced shock metamorphism at high temperatures and pressures. Apart from extreme fracturing of quartz and feldspar including multiple sets of planar fractures (PFs) in quartz, we observe multiple sets of planar deformation features (PDFs) in quartz and feldspar, diaplectic SiO_2 glass and extreme subgrain formation. Heavy tensile fracturing of whole rocks and quartz grains indicates spallation by dynamic shock pulses. Melt glass is in general found in five different occurrences: as nearly completely foamed-up cobbles (Fig. 36), as a thin crust often completely coating the cobbles, as vesicular, partly recrystallized feldspar glass interspersing quartzite rocks, as recrystallized glass filling open spallation fissures (Fig. 36), and as allochthonous melt lumps fused to the cobbles' surface. The field observations and the lab analyses exclude normal tectonic processes as well as human activities but, especially with regard to the shock metamorphism, clearly establish a meteorite impact event. Obviously, this event that formed crater # 004 must have been



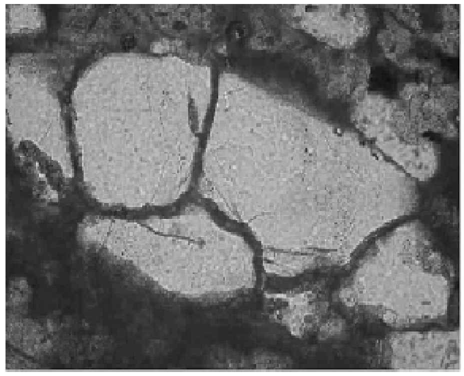


Fig. 36. Glass from crater # 004. Left: Cobble practically completely transformed to a foamy glass. Right: Glass filling tensile, probably shock spallation fissures in quartz grain. Photomicrograph, crossed polarizers; field width 0.8 mm

different from a normal solid-body impact shedding some light on the impactor(s) and the process of the Chiemgau impact event and the emplacement of the meteorite craters. From scaling laws and from comparison with the recent Carancas (Peru) meteorite impact that formed a roughly 14 m-diameter crater [37, 82], a solid projectile of the size of the order of 1 m could have formed crater # 004. This small size categorically excludes the formation of the abundant and widespread melt glass and the heating of the 20 m-diameter crater halo to more than 1,000 °C from shock release. Total-rock melting from shock release requires shock pressures of more than 50 GPa (= 500 kbar) [18] attained, if at all, at the impact point of crater # 004. Consequently, the crater formation must have been accompanied by a discrete strong thermal event independent of impact shock, and we suggest a local superheated gas explosion bubble near above or immediately at the ground surface.

For the present, details of this peculiar process have to remain unanswered, for example the question whether there was a solid impactor at all or whether the crater could have been formed solely by a near-surface extreme gas explosion. Assuming this to be true, the question arises whether the heavy mineral deformations in the crater # 004 cobbles could in part be produced by extreme thermal shock stress waves. The production of cleavage (PFs) in quartz by thermal shock has been reported earlier [29].

13. Dating the Chiemgau impact event

An approximation to the date of the Chiemgau impact is so far realized by quite different methods. The stratigraphic context of the Lake Tüttensee (12.1) and Stöttham (12.2) ejecta layers clearly establishes a post-glaciation, Holocene age. A thermoluminescence dating of a sample from crater # 004 revealed an age of a few hundred years BC (B. Raeymaekers, pers. comm.). Various radiocarbon (C14) datings supplied a broad time span and in part puzzling results that must still be analyzed thoroughly. Dating wood from an excavation into the Lake Tüttensee impact layer gave reasonable ages that places the impact to have happened after 2,900 BC. A radiocarbon age for charcoal from crater # 005 suggests the crater formed before 200 AD [27].

For the Chiemgau event, the currently most stringent age is given by archeological artifacts. Intermixed in the ejecta layer of Lake Tüttensee crater potsherds have been discovered. In temper and texture they show great similarity with the so-called «Kultplatz» ceramics found at the Durrnberg

(Austria) Celtic archeological site, only 50 km afar. Due to new dendrochronological data and the archeological context at the Dürrnberg, the «Kultplatz» ceramics can be dated between 470-430 (+/-10) BC. Unfortunately, the Lake Tüttensee potsherds lack important attributes that would enable to distinguish them with certainty from ceramics used in the Bronze Age. But from the mere existence of these potsherds in the impact-related layer a 1300 BC *terminus post quem* of the impact is warranted. Several artifacts of the Roman Imperial Period found at the rim wall of the Lake Tüttensee crater establish a *terminus ante quem* that can be further narrowed down by a potsherd of middle/late La Tene graphite ceramics found in the topsoil above the ejecta layer. It provides a *terminus ante quem* of about 300 BC further substantiated by abundant middle/late La Tène artifacts in the affected region excluding an impact later than 300 BC.

At the Chieming-Stöttham excavation site (12.2), the unique chance for studying the situation of an impact layer being embedded in an archeological stratigraphy was gambled away by the strict opposition of the excavating archeologist and the Bayerisches Landesamt für Denkmalpflege (Bavarian State Office for the Preservation of Historical Monuments) to cooperate and to establish a joint geological and archeological stratigraphy. Nevertheless, within the impact layer a slightly graphitized potsherd was found that may be ascribed to the late Hallstatt/early La Tène period thus possibly scaling up the *terminus post quem* to 700-500 BC when this kind of potsherd was used. The impact layer is overlaid by colluvium as bed of a Roman pavement (ca. 2nd century AD). Summarizing, archeological artifacts establish a date of the Chiemgau impact event definitely between 1300 and 300 BC and possibly narrowed down to 700-300 BC.

The Chiemgau impact may further be dated by analyzing traditions of ancient people. The Celtic fear of the collapsing sky is handed down to us as being mentioned in 335 BC (Strabo, Geography 7.3.8). In general, the respective story has been interpreted as an anecdote illustrating the fearlessness of the Celts. On the background of the Chiemgau impact we offer an alternative interpretation: The Celts did not point to a possible catastrophe in the future but reminded of a real event in the past that could recur anytime. The date of 335 BC is coherent with the *terminus ante quem* of 300 BC provided by the archeological data.

A thorough analysis [72-73] provides a good basis to interpret the Greek myth of Phaethon as an allegorization of the Chiemgau impact. Details of the mythical tradition handed down in classical texts can well be compared with astronomical, geological, geophysical and geographical details of the Chiemgau impact. The application of criticism of sources and text hermeneutics suggests to date the event reflected in the myth of Phaethon to 600-428 BC. Hence, the time frames provided by three different dating methods fit very well together, possibly narrowing down the date of the Chiemgau impact to 700-300 BC, if not to 600-428 BC.

14. The nature of the Chiemgau impactor

While for the known Holocene impacts iron meteorite projectiles are established, the nature of the Chiemgau impactor must for the time being left to assumptions. Preliminary computer modeling (by M.A. Rappenglück) of the impact that formed the unusually large crater strewn field yielded a low density (<1.3 g/cm^3), roughly 1,100 m sized projectile that fragmented on entering the atmosphere on a low-angle trajectory (~ 7°) at a velocity of about 12 km/s. Hence, a comet nucleus or a low-density asteroid like 253 Mathilde must be taken into consideration. The ~50 km-diameter asteroid

253 Mathilde probably is a kind of a gravity-bound rubble pile to account for the low density of 1.3 g/cm^3 only, and apart from a comet nucleus a fragment of such a cosmic body could have constituted the Chiemgau impactor. The discussion of the peculiar # 004 crater (12.3) suggesting a superheated gas explosion bubble near the ground may substantiate the idea of a complexly composed projectile comprising both solid meteoritic matter and explosive gaseous, possibly frozen methane constituents. So far, no material has been sampled from the Chiemgau strewn field that can unambiguously be attributed to the impactor. It is true, the strange matter (10), e.g., the nanodiamonds, the ferrosilicides xifengite and gupeiite, the latter resembling meteoritic suessite, and the silicon carbide moissanite have substantial extraterrestrial counterparts, and current SEM and TEM analyses of the Chiemgau material (M. Hiltl, F. Bauer, pers. comm.) are strengthening the idea of a cosmic source. A conclusive relation between the strange matter and the impactor has to be provided eventually.

15. Conclusions and final remarks

In meteorite impact research there are quite a few criteria as a base for the evaluation of a meteorite crater, and some of them are regarded as in proof of impact. Impact criteria, compelling and less compelling, as compiled by, e.g., Norton [63] and French [31] are morphology, geophysical anomalies, geologic evidence implying exotic layers, high-temperature evidence, high-pressure evidence, shock metamorphism, shatter cones, meteorite fragments or geochemical evidence of meteoritic matter, direct observation (historical record), and special evidence like spherules, accretionary lapilli and micro- and nanodiamonds. According to current understanding, shock metamorphism, shatter cones, meteorite matter, and direct observation are each one by itself accepted as a confirmation of an impact event. Beginning with shatter cone fracture markings, they are not expected to occur in the Chiemgau impact strewn field because of the unconsolidated target rocks. The other criteria are definitely, probably and possibly fulfilled. Morphologically significant are numerous bowl-shaped craters exhibiting clear rim walls. Geophysical anomalies are measured showing abnormal magnetic and gravity signature. Strong geologic evidence is given by exotic layers constituting polymictic breccias that could hardly have been formed by geologic processes other than impact. The abundant occurrence of impact melt rocks and various kinds of natural rock glasses proves a high-temperature overprint of the region. High-pressure effects are indicated by plastic and brittle strong deformation of cobbles and boulders including spallation, striations, polish and concussion marks definitely unrelated to glaciation. Abundant heavily fractured however coherent cobbles and boulders in a soft matrix prove short-term deformation under high confining pressure. Clear shock metamorphism, unanimously considered as in proof of impact, has been attested in form of planar deformation features (PDFs) in quartz and feldspar and diaplectic glass requiring shock pressures >10 GPa. More evidence of (moderate) shock (planar fractures (PFs) in quartz, strong kink banding in micas, multiple sets of microtwins in calcite has been shown to occur in Lake Tüttensee rocks in an intensity and frequency incompatible with deformation from possible Alpine tectonics. Various kinds of spherules, accretionary lapilli, nanodiamonds and strange metallic and carbonaceous matter can be considered a probable impact signature, while an unambiguous evidence of meteoritic matter remains to be given. Possibly, the geomyth of the fall of Phaethon allegorizes the observed Chiemgau impact [72-73].

Despite this clear, comprehensive and compelling impact evidence brought before the public by Internet presence and numerous website articles (on www.chiemgau-impact.com, www.chiemgau-impakt.de), notable magazines, many public presentations and lectures, and several TV documentary reports, the fact of the Chiemgau impact event has greatly been challenged by both a group of regional/local geologists ([16]; Darga, verbal messages; and others) and part of the so-called impact community [49, 76, 91]. The criticism of the first group is the criticism well acquainted in impact research. Whenever a new meteorite crater/impact structure is put up for discussion, there are geologists claiming the impact nature is not compatible with regional-geology features. These classic discussions are well known for the Ries, Sudbury, Vredefort, Azuara and a large number of other impact structures worldwide. In the case of the Chiemgau impact, this regional-geology context is the Alpine glaciation, and craters are said to be glacial kettle holes and dead-ice depressions, and all deformed cobbles were carried from the Alps where the rock experienced tectonic overprint. Moreover, all high-temperature signature is considered anthropogenic. While this discussion is in principle accessory only, the challenge of the impact event by part of the impact community is more crucial. Not a single one of the addressed impact community members has ever contacted our research group, has ever visited the Chiemgau impact sites or has ever been willing to jointly examine the impact exposures and impact rocks. The challenge is motivated by remote image diagnosis of our impact material, by theoretical computer modeling of impacts and by repeating the regional geologists' arguments of a glacial origin of the impact features [47, 49, 76-77, 91]. Among their arguments, the large size of the strewn field and the asserted impossibility of the formation of the smaller craters in a comet impact are most commonly used. The assertion [47] that according to numerical simulation the width of strewn fields cannot exceed 1 km is simply confuted by the dimensions of the Campo del Cielo (Argentina) crater field measuring 19 km x 3 km [90]. One order of magnitude larger (390 km x 120 km) is the Gibbeon (Namibia) strewn field of a fragmented iron meteoroid (however without the formation of craters). The argument [76-77] smaller craters cannot possibly have been formed in a comet impact because small-sized cometary fragments would not have survived atmospheric passage ignores that we don't exclusively consider a comet to have been the impactor (see 14) and that the old idea of comets mostly composed of ice [75, 76] is no longer maintained by astronomers and cosmochemists (e.g., [8, 9, 30, 44, 45, 94]. It is just the Chiemgau multiple impact with the in part unusual crater formation and the abundant strange matter that could possibly enormously contribute to the new understanding of asteroids, comets and the NEO threat.

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Note added in proof

In 2009, Acevedo et al. [Acevedo R.D. Bajada del Diablo impact crater-strewn field: The largest crater field in the Southern Hemisphere / R.D. Acevedo, J.F. Ponce, M. Rocca, J. Rabassa, and H. Corbella // Geomorphology, 110. – 2009 – P. 58-67] report on the discovery of an impact crater strewn field in the Chubut Province, Argentina. In an area of about 27 km x 15 km more than 100 crater-type structures occur with diameters ranging from 100 to 500 m. The proposed impact event is dated between Early Pleistocene and Late Pleistocene (0.78–0.13 Ma ago). According to the authors the extensive strewn field may have originated from multiple fragmentation of an asteroid that broke up before impact, perhaps traveling like a rubble pile. Alternatively, a collision of comet fragments is discussed. A relationship to the Chiemgau impact event is obvious, and the authors when considering the nature of the impactor explicitly refer to the Chiemgau impact.

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Кратерное поле Чимгау: свидетельство крупного импактного события в Юго-Восточной Баварии, Германия

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Кратерное поле Чимгау в Альпийском предгорье обнаружено в начале нового тысячелетия; оно состоит из более чем 80 кратеров, рассеянных в области примерно эллиптической формы с осями около 30 и 60 км. Диаметр кратеров колеблется от нескольких метров до нескольких сот метров. Геологически кратеры образованы в плейстоценовых речных моренных ледниковых отложениях. Кратеры и детально исследованные прилегающие к ним районы демонстрируют признаки сильных ударных деформаций гальки и валунов четвертичного возраста, следы сильного плавления материала пород (расплав породы и различные остекленения), ударно-метаморфических эффектов и геофизических аномалий. Ударные воздействия подтверждаются обильным появлением металлических, остекленненных частиц и углерода, аккреционных лапиллий и странным материалом в форме силицидов железа, таких как gupeiite и xifengite, а также различных сплавов, например moissanite SiC. Крупнейшим образованием в кратером поле является озеро Тютензее с восьмиметровым краевым валом диаметром около 600 м, с глубиной воды около 30 м и обширными отложениями импактных выбросов. Физические и археологические свидетельства позволяют предположить наиболее вероятную датировку события между 1300 и 300 гг. до н.э. Принимая во внимание обширное поле разброса, можно предположить, что импактор был низкой плотности, возможно, рыхлосвязанный астероид или комета, подвергшиеся дефрагментации в процессе падения, учитывая обширное поле разброса.

Ключевые слова: кратер Чимгау, ударно-метаморфические последствия, геофизические аномалии, материал кратера Чимгау, Чимгау-импактор.
