The Chiemgau impact event in the Celtic Period: evidence of a crater strewnfield and a cometary impactor containing presolar matter.

by

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Abstract

A report on the newly discovered large meteorite crater strewnfield in southeastern Germany is given. More than 80 craters with diameters between 3 m and 500 m, excavated from Quaternary moraine sediments, have been identified to form a scattering ellipse with axes of 58 km and 27 km. The craters are related with heavy destructions of the rocks. Evidence of a strong thermal event (thermal shock, melt glass) is ubiquitous. Moderate shock in minerals from shock-wave propagation can be observed. The strewnfield is associated with extensive occurrences of peculiar metallic and non-metallic material frequently shaped aerodynamically. Among this material, ferrosilicides (including gupeiite and xifengite), titanium carbide, α-Fe, aluminium silicide (Al_XSi_Y) and peculiar element enrichments play an important role suggesting that the impactor was a comet containing presolar matter. A computer modeling of the impact arrives at reasonable results compared with the observations. Archaeological finds prove the event to have happened in historical time, and the Celtic period seems to be most probable.

Zusammenfassung

Wir berichten über ein neu entdecktes riesiges Areal von Meteoriten-Einschlagskratern im Südosten von Deutschland. Bisher wurden mehr als 80 Krater mit Durchmessern zwischen 3 m und 500 m registriert. Eingetieft in quartäre Moränen-Sedimente bilden sie eine Streuellipse mit Achsen von 58 km und 27 km.

Die Krater sind mit heftigen Gesteinszertrümmerungen verknüpft. Hinweise auf ein durchgreifendes thermisches Ereignis (thermischer Schock, Schmelzgläser) sind allgegenwärtig. In Mineralen sind moderate Schockeffekte als Folge von Stoßwellen zu beobachten. Ausgedehnte Vorkommen von eigenartigem metallischem und nichtmetallischem Material, häufig mit aerodynamisch geprägten Formen, sind mit dem Kraterstreufeld verknüpft. In diesem Material spielen Eisen-Silizium (Ferrosilizide; darunter die Minerale Gupeiit und Xifengit), Titankarbid, α-Eisen, Aluminium-Silizide und eigenartige Elementanreicherungen eine wesentliche Rolle, was dafür spricht, daß der Impaktor ein Komet mit Gehalten an präsolarer Materie war. Eine Computermodellierung des Impakts kommt zu Ergebnissen, die verhältnismäßig gut mit den Beobachtungen übereinstimmen. Archäologische Funde zeigen, daß der Impakt in historischer Zeit erfolgte, wobei gegenwärtig viel für die Keltenzeit spricht.

1 Introduction

Since 2000, a German research group discovered pieces of metal (ferrosilicide Fe_3Si, mineral gupeiit, and Fe_5Si_3, mineral xifengite), hithertho unknown in the region between the rural district of Altötting and Traunstein near the lake Chiemsee (Chiemgau, southeastern Bavaria) (Beer et. al. 2003). The team of amateurs (leader Werner Mayer, Bergen) who had an official instruction to look for archaeological relevant relics in the area, 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 done an extraordinary field work over three years till 2004 and having suspected some kind of extraordinary events, they decided to ask Dr. Michael A. Rappenglück, astronomer/archaeoastronomer, INFIS, Bavaria, Prof. Dr. Kord Ernstson , geologist, geophysicist, University of Würzburg, Bavaria and Dr. U. Schüssler, mineralogist, University of Würzburg, Bavaria for further support. Some investigations in the Burghausen area ran parallel (Fehr et al. 2002, 2004, Hoffmann et al. 2004). Here, we present the first comprehensive report on the unusual phenomena revealing a cometary impact in historical time with the formation of a giant crater strewnfieled associated with abundant relics of pre-solar matter.

2 Scattering ellipse and crater dimensions of the Chiemgau strewnfield

On earth, six meteorite crater strewnfields 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 del Cielo in Argentina, and the Wabar field in Saudi Arabia (see Hodge 1994, Krinov 1963 a,b, and others; for details see below).

Compared with these known occurrences, the newly discovered crater strewnfield in the Chiemgau (Bavaria), a region in southeastern Germany (Fig. 1), is exceptional.

Fig. 1. The location of the Chiemgau strewnfield in Germany.

Up to now, 81 craters have been identified, measured and catalogued on the basis of topographic mapping, satellite imagery, systematic aerial photography and ground inspection [6] establishing the scattering ellipse shown in Fig. 2. The size of the ellipse is given by a major axis of ca 58 km and a minor axis of ca 27 km. The strewnfield covers an area of about 1,200 km² between 47.8° to 48.4° N and 12.3° to 13.0° E. The craters are situated at altitudes ranging from 362 m to 560 m asl.

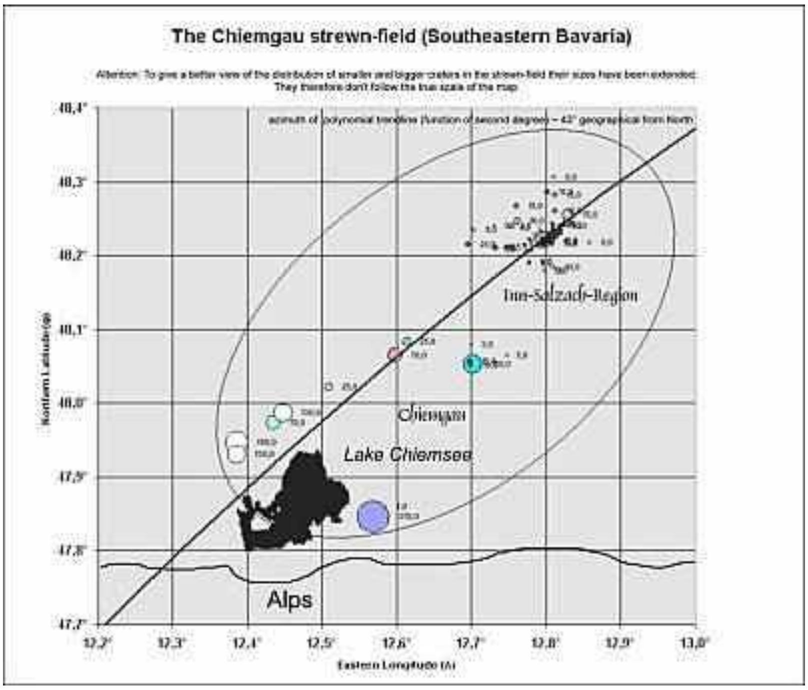

Fig. 2. Distribution and size of craters in the Chiemgau strewnfield.

The preservation of the craters is quite different depending on their location on, e.g., farm land or in forests. On farm land, many of the craters recorded on older topographic maps have meanwhile been leveled out. Despite the levelling, they are frequently visible by satellite imagery or on aerial photographs (Fig. 3). On the other hand, many well-preserved craters are probably if not certainly hidden in forests that cover large areas of the scatter ellipse. These undetected craters as well as craters that have been destroyed and, therefore, are completely unrecognizable, may account for estimated roughly 40 – 50 % of the original number of craters.

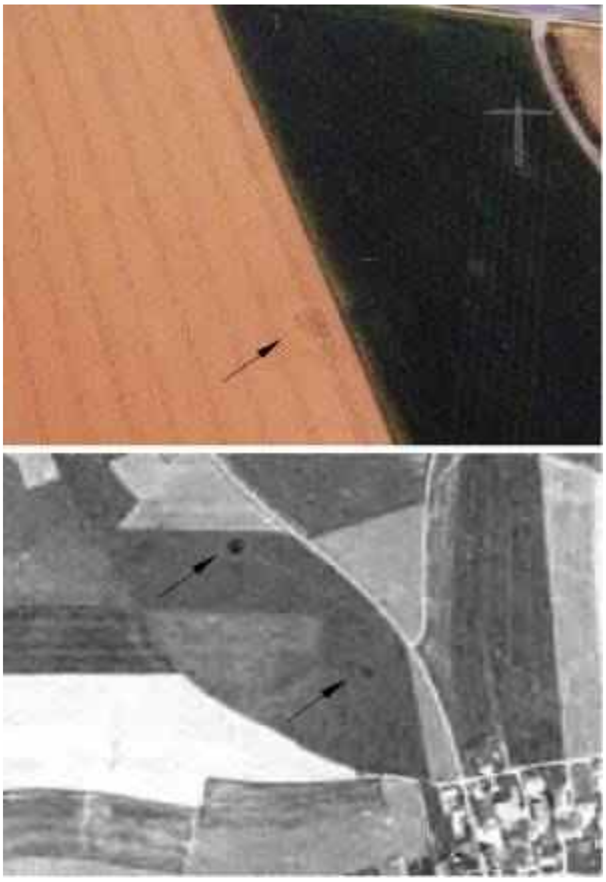

Fig. 3. Craters having been leveled out by farming. Aerial photograph (Gerhard Benske) and satellite imagery (D-SAT).

The diameter of the documented craters ranges between 3 m and several 100 m (Fig. 4 - 9). Some of them are permanently filled with water. There is a large number of craters and depressions having diameters below 3 m. They have so far not been documented, and in many cases the origin of the smaller pits from meteorite impact may be questioned without closer inspection. The other end of the scale shows craters having diameters as large as 200 m or more. At present, a lake named Tüttensee and located near the well-known Chiemsee and the town of Traunstein, proves to be the largest crater (Fig. 9). The lake is surrounded by a more or less continuous ring wall and has a maximum diameter of about 400 m. Taking into account the size of the ringwall, a rough diameter of 500 m for the Tüttensee crater may apply. As Fig. 9 shows, the shape is far from being circular, but in parts, the shore matches exactly a circle. We suggest therefore that the Tüttensee was formed by the impact of a fragmented projectile similar to the irregularly shaped craters of the Kaalijarvi and Henbury meteorite crater fields. More evidence for the impact nature of lake Tüttensee is given below.

Fig. 4. This crater at Murshall (near Tyrlaching) is permanently filled with water. It is 16 m across and shows a clear wall.

Fig. 5. This 55 m crater is located at an ancient bank of the river Alz near the hamlet Dornitzen (near Marktl). It is conserved only at half, because of the influence of the nearby Alz and agriculture. Originally there had been a wall. But it was destroyed by plowing. In the centre of the crater pieces of the peculiar Fe_xSi_y-phases had been found. Aerial photo: Gerhard Benske.

Fig. 6. The crater close to the hamlet Bergham (near Tyrlaching) today has a diameter of about 150 m, a depth of 15 m and a small wall. Before 1960 the hollow hosted a lake. Later it was dewatered and filled up with gravel and soil. Originally the crater had a wall of at least 2 m high. The slope had been steep enough and the lake was sufficiently deep (more than 25 m), that children and adults sprang from the rim headlong into the water without any risk. Photo: Mathias Wurm, farmer of Bergham.

Fig. 7. 6 m-diameter Hohenwart crater exhibiting a distinct wall.

Fig. 8. The deep 15 m-diameter Einsiedeleiche crater.

Fig. 9. The hitherto biggest crater is the lake Tüttensee close to the hamlet Marwang (near Grabenstätt). The water surface measures about 370 m. But the original hollow probably had a diameter of about 500 m. Today the walls are 8 m high. At a depth of ca 17.5 m a layer of trees fallen down from the walls was discovered. Divers noticed that there are some gaps in this swimming ground. They took soundings through these blanks, but didn't reach the ground at a depth of 70 m. Aerial photo: Gerhard Benske.

From Fig. 2 it is evident that the average diameter of the craters increases from the northern end of the strewnfield to its southern end. This is remarkably similar to other meteorite crater strewnfields (Morasko, Henbury, Kaalijarvi, Sikhote Alin) showing a comparable distribution (Fig.10). 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.

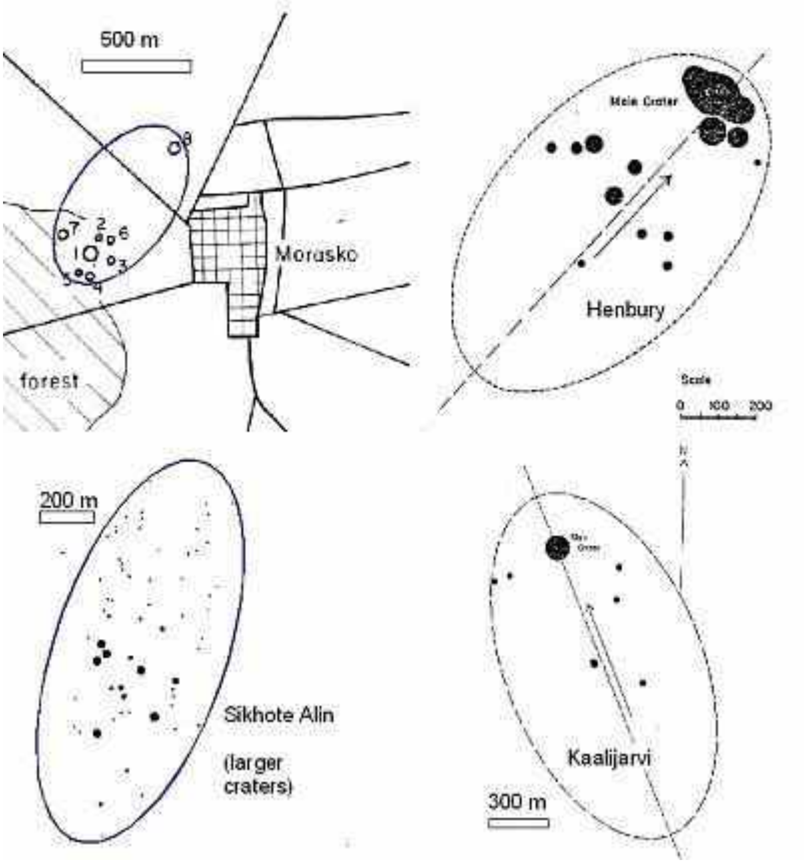

Fig. 10. Scattering ellipses for meteorite crater strewnfields. Modified from Krinov (1963) (Henbury, Kaalijarvi) and Hodge (1994) (Morasko, Sikhote Alin).

The depths of the craters range between 0.4 m (for the smallest 3 m-diameter craters) and about 70 m for the largest lake Tüttensee crater. In Fig. 11, the depths and diameters for 46 fully preserved craters are plotted exhibiting a general increase of the depths with increasing diameters. On average, a diameter-to-depth ratio of r = 6.7 applies.

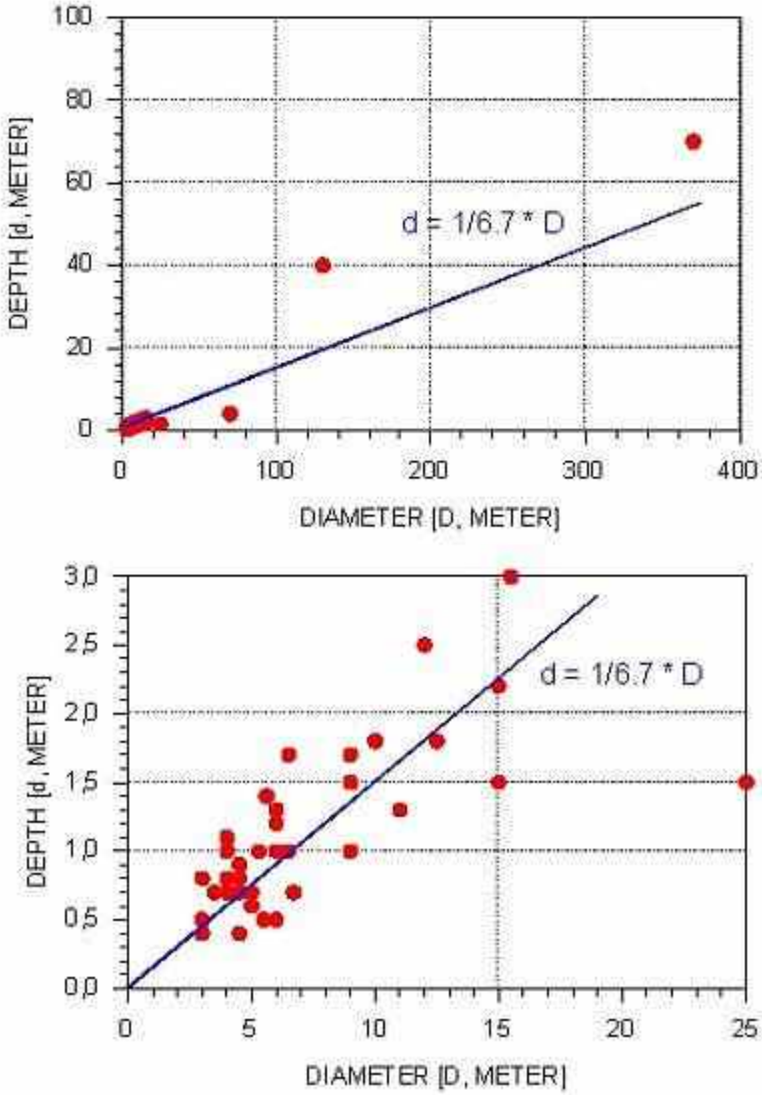

Fig. 11. Diameters and depths for 46 fully preserved craters of the Chiemgau strewnfield. On average, a diameter-to-depth ratio of 6.7 has been determined (given by the straight line).

3 The Chiemgau strewnfield compared to others worldwide

The Chiemgau strewnfield has an amazing number of craters, in particular larger ones, and covers a larger territory, compared with others well-known in Europe or worldwide [3].

At *Kaalijarvi* (on Saaremaa Island, Estonia; φ: 58.40° N, λ: 22.67° E), the strewnfield measures ca 1 km in size. 9 craters with diameters from 13 m up to 110 m are distributed across an area of 0.5 km².

The largest of them, which originally had an estimated depth of 22 m, contains a small lake. There are several estimates for the age of the craters ranging from 2,370 to 8,500 years ago. The 6,600 years old crater field of *Ilumetsa* is also situated in Estonia (φ: 57.97° N, λ: 25.42° E). There are five depressions known, but only two of them are established meteorite craters. The dimensions of the two craters, some 900 m apart, are 75-80 m diameter, 12.5 m depth, 4.5 m hight of the wall, and 50 m/4.5 m/1.5 m, respectively.

The strewnfield at *Morasko* (near Poznan, Poland; φ: 52.48° N, λ: 16.90° E) comprises 8 craters, which have diameters from less than 18 m (3 m deep) up to 95 m (11.5 m deep). They are located in an area of ca 460 m by 300 m (Fig. 10). Only one of the craters is always dry. Three of them host permanent lakes, while the others are seasonally filled with water. The impact of Morasko is estimated to have happened less than 10,000 years ago.

In 1947, people observed the breaking up of a meteoroid falling down in the western slopes of the Sikhote Alin mountains (between Ulunga and Iman, Russia; φ: 46.16° N, λ: 134.65° E). The multiple fragmentation of this object started at an altitude of about five kilometers and created an elliptical strewnfield with a major axis of ca 2 km and a minor axis of only 1 km (Fig 10). 158 craters had been preserved. The most prominent 68 craters have diameters between 1.1 m and 26.5 m. The largest one is 6 m deep. At Sikhote Alin, the classic distribution pattern occurs in the strewnfield: The largest masses are concentrated at one end of the ellipse where they made the largest craters.

At Henbury (Northern Territory, Australia; 24.58 S, 133.15 E), 13 craters are known which form a classic distribution ellipse (Fig. 10). The largest crater, probably produced by the impact of a fragmented projectile, measures 216 m by 108 m, being approximately 15 m deep. The other craters range in size between 10 m and 60 m. The Henbury crater field is assumed to be about 5,000 years old.

At Campo del Cielo (Gran Chaco Gualamba, Chaco, Argentina; φ: 61.70 S, λ: 27.63° W), 9 craters have been found with diameters ranging from 5 m to 100 m, and up to 5 m deep. The long axis of the crater scattering ellipse measures 17.5 km. The meteorite strewnfield associated with the craters is about 55 km wide. The Campo de Cielo impact is estimated to have happened 4,000 years ago.

At Wabar (Saudi Arabia; φ: 21.5° N, λ: 50.67°E), probably 4 craters set up the distribution field. The largest one is 116 m across. There is another one being 64 m wide, and a third having a diameter of 11 m. It is estimated that the Wabar impact happened 135-450 years ago.

A large strewnfieled is reported for Jilin (Manchria, China; φ: 44° N, λ: 126° E). The area of the scattering ellipse is 10 km by 67 km. Some fragments of the meteorite penatrated the ground down to a depth of 6 m.

A very large strewnfieled was discovered in 1836 at Gibeon (Great Namaqualand, Namibia; φ: 25.33° S, λ: 18° E). It has a major axis of 390 km and a minor one of 120 km (30,000 km²). But not any craters have been discovered yet.

4 Geology of the target

Apart from the most northern part of the strewnfield, where Miocene gravels, sands and marls are exposed in the hilly terrain, the target is predominantly composed of Pleistocene and Holocene moraine sediments. Pebbles, cobbles and boulders up to the size of 20 cm are intermixed with sands and clays. The components represent Alpine material in the form of sediments (mostly limestones and sandstones), magmatic rocks (mostly granitoids) and metamorphic rocks (mostly gneisses, amphibolites and schists). Occasionally, larger blocks of cemented conglomerates (Nagelfluh) are observed. Locally, loess and loamy soils may contribute to the uppermost target layers.

5 Crater structure and material

Only a few craters have so far been examined in more detail. A study of some hollows by 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. On aerial photographs (partly taken in infrared light), the zone of ejecta around some craters becomes visible (Fig. 12). Often, the craters show a slightly assymetrical, mostly elliptical form.

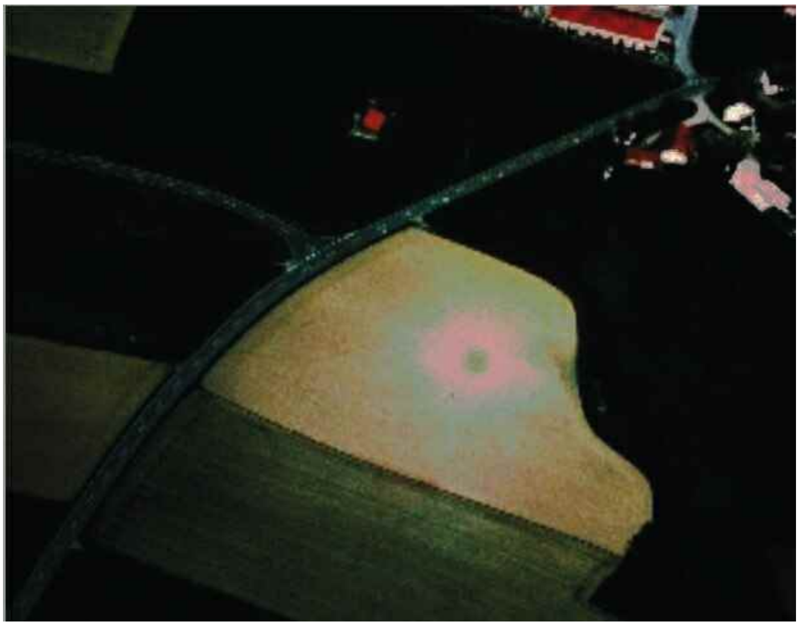

Fig. 12. This photograph taken in infrared light shows clear the zone of ejecta around a 15 m crater at Perach (379 m above msl). Aerial photo: Bay.LfD.

The gravel in the center of the crater is sharp-edged broken and looks basically different compared with the usually well-rounded pebbles found in the landscape (Fig. 13). On the crater floor, immediately on top of the target gravel, an ash layer peppered with small charcoal fragments is regularly observed (Fig. 14).

Fig. 13. Typical material sampled from crater floors (to the left) strongly contrasting with target material from outside the craters.

Fig. 14. Ash layer from a crater floor. The test pit is about 20 cm wide.

Near to the main craters, a prominent kind of secondary cratering can be observed. After removing the upper soil layers down to about 0.5 m, sharp-edged rock fragments sized 0.2 - 0.3 m occur to be stuck in the otherwise untouched ground. They are surrounded by a striking ring-shaped discoloring of the host material up to the diameter of 1 m (Fig. 15).

Fig. 15. Uncovered secondary cratering. Projectile (to the left) and halo of discolored host rock.

Peculiar metallic material (Fig. 16) is accumulated around all the craters at a certain depth, 0.3-0.4 m below the top soil. Occasionally, it has penetrated the target gravels. In majority, it is found concentrated northeast of each crater, while with increasing crater size the distance increases, too.

Fig. 16. Fine fraction of peculiar metallic material concentrated near the large Bergham crater. Note the many perfect spheres contributing to the material. Ferrosilicides (FeSi, Fe_3Si, Fe_5Si_3) are found distributed over a much larger area of about 3,000 km² besides the corridor set by the strewnfield. Following, from north to south, the major axis of the scattering ellipse, the material is traceable in the promontory of the Alps south of lake Chiemsee up to an altitude of 1,200 m.

6 Geophysical signature

Geophysical earth magnetic field measurements (Fehr et al. 2002) across smaller craters reveal faint anomalies that could not be related with definite causative bodies so far. Soil magnetic susceptibility measurements in the Burghausen area (Hoffmann et al. 2004) reveal substantially increased susceptibilties in the soil lacking typically industrial or geogenic signature. Preliminary pulse-electromagnetic soundings across a 20 m-diameter crater show a signature of larger metallic objects in the center of the structure.

Outside the craters, the abundant occurrence of strongly magnetic rocks of quite different lithologies among the target rocks is conspicuous. The high, dominantly remanent magnetization seems to be unusual compared with typically magnetic rocks from the Alps (e. g., amphibolites, serpentinites). We suggest that these rocks might have acquired their magnetization as a thermoremanent magnetization in contact with the super-heated impact explosion cloud (also see below).

004.

7 Macroscopic deformations

Some of the smaller craters have been investigated in more detail exhibiting strong mechanical deformations at the floor and the walls and in the ejected material forming the ring (Figs. 17, 18) [5].

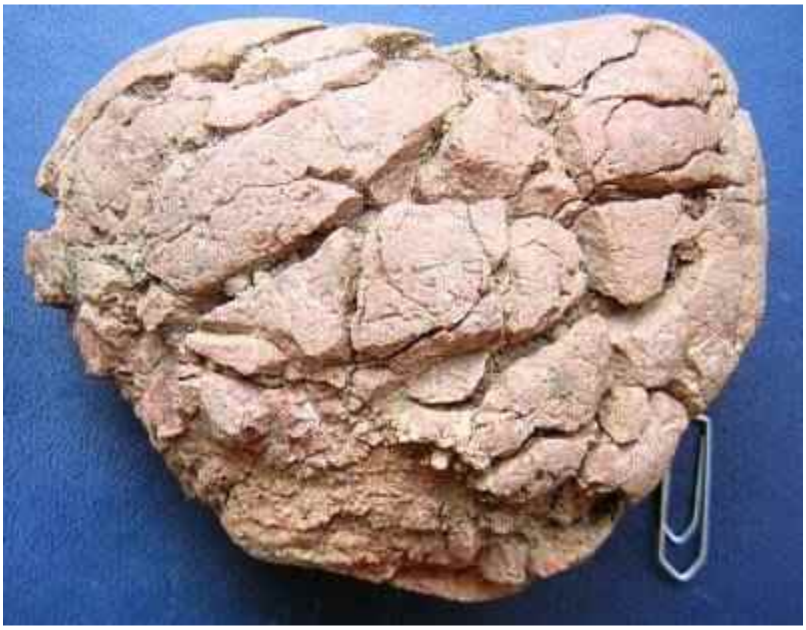

Fig. 17. Example of a heavily fractured sandstone cobble typically found in the craters of the strewnfield.

Fig. 18. Grit-brecciated quartzite clast (monomictic movement breccia) from crater 004.

Heavily fractured but coherent boulders (Figs. 19 - 23) prove *in situ* high-pressure/short-term deformation. A deformation by Alpidic tectonics or by glaciers can basically be excluded, because the boulders would not have survived any significant transport. For comparison, we show in Fig. 24 a similarly deformed boulder from the Pelarda Fm. ejecta of the Azuara/Rubielos de la Cérida impact structures in Spain (Ernstson & Claudin 2002). Rotated fractures and bread-cut-to slices features, special deformation types established by Ernstson & Claudin (1990, 2002), have also been reported earlier for the Ries impact structure (Nördlinger Ries) (Chao 1977; also see Rampino et al. 1996, 1997 a, b, and Claudin et al. 2001) [4].

Fig. 19. Heavily fractured quartzite block from the ringwall ejecta of the Tüttensee crater. Note the multiple sets of closely spaced fractures and the distinct displacements. The clast remains coherent and is not broken into pieces indicating high-pressure/short-term *in situ* deformation.

Fig. 20. From the Tüttensee ringwall ejecta.

Fig. 21. From the Tüttensee ringwall ejecta.

Fig. 22. From the Tüttensee ringwall ejecta. Note the coherence of clast and extended fragments (arrows).

Fig. 23. From the Tüttensee ringwall ejecta.

Fig. 24. Strongly fractured quartzite block from the ejecta of the Azuara/Rubielos de la Cérida impact structures. Note the remarkable coherence of the sample.

Likewise, the widely open fractures in the otherwise coherent cobble with smooth surface and without any shearing (Fig. 25) 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. 26) and also observed near large impact structures (Fig. 27) (Ernstson et al. 2001 a, b) [1].

Fig. 25. Spallation fractures in a sandstone cobble from crater 016 in the Chiemgau strewndfield.

Fig. 26. Spallation fractures in experimentally shocked ARMCO iron (by courtesy of M. Hiltl).

Fig. 27. Spallation fractures in naturally shocked quartzite cobble. Buntsandstein conglomerate near Rubielos de la Cérida impact basin.

Abundantly, strongly deformed components appear to have aerodynamically been deformed plastically (Fig. 28), similar to volcanic bombs. The formation process of the peculiar crackling or bread-crusting features exhibited by the sandstone cobble in Fig. 29 and by others is not clearly understood so far.

We emphazise that the examples shown in the Figures do not represent scarce finds but regularly occur in and around the strewnfield 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. 28. Banana-shaped sandstone clast (viewed side-on) similar to volcanic-bomb form. From crater 004.

Fig. 29. Sandstone cobble showing typical crackling or bread-crusting features. From the ringwall ejecta of the Tüttensee crater.

8 Petrographical and geochemical evidence

A program of petrographical and geochemical investigations (thin-section inspection, microprobe and x-ray analyses, etc) has been initiated. With respect to the host of material with quite different composition and texture, preliminary results are presented here.

Fig. 30. Sandstone cobble completely coated by silica glass. Note the smooth surface without any sinter traces. From crater 004.

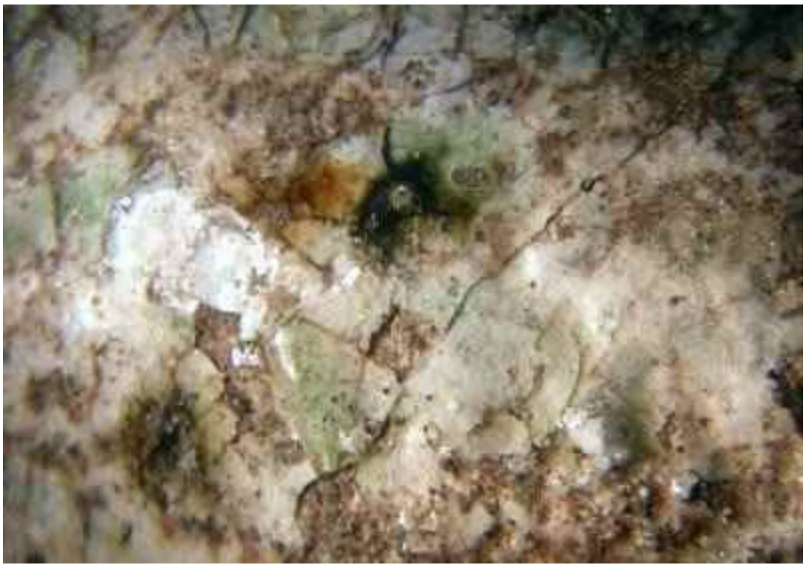

Fig. 31. Detail from Fig. 14 in close-up. The colourless to greenish glass exhibits many minute vesicles. The field is 22 mm wide.

Evidence of unusually high temperatures is given by the occurrence of sandstone boulders and cobbles in and around craters completely coated by silica glass (Figs. 30, 31) [11]. The cobble in Fig. 32 is similarly coated by silica glass but, moreover, is homogeneously interspersed with feldspar melt glass (the dark strings, close-up in Fig. 33) embedded in quartz (white). In thin section, the feldspar glass is in most cases associated with feldspar crystals dispaying multiple sets of so-called planar deformation features (PDFs; Fig. 34) which are considered to be indicative of shock deformation (Engelhardt et al., 1969, French & Short 1968, and others).

Fig. 32. Sawed surface of a thermally shocked sandstone cobble completely coated by silica glass. Note the dark strings of partly recrystallized feldspar glass giving a gneiss-like aspect to the rock. From 11 m-diameter crater 004.

Fig. 33. Detail of Fig. 16: Feldspar glass embedded in quartz. Note the many spherical bubbles in the glass. The field is 3 mm wide

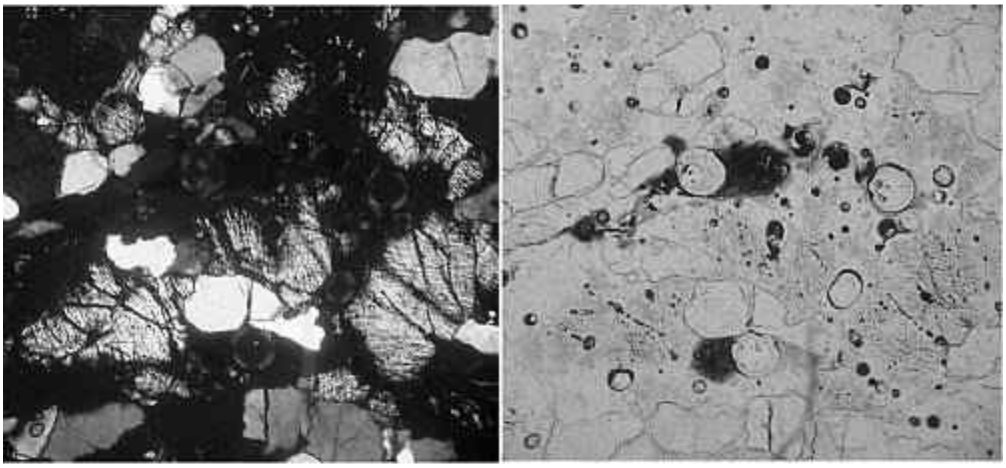

Fig. 34. Feldspar glass in sandstone cobble from Fig. 16. Photomicrograph, crossed polarizers and parallel light. The fields are 1.4 mm wide. Note the vesicular glass (black under xx nicols) and the multiple sets of planar features in the feldspar grains. Quartz grains are whitish to greyish.

Because of the smooth surface of the glass-coated cobbles lacking any traces of sinter processes from contact with neighboring rock material, an *in situ* origin of the glass, from human activities, can be clearly excluded. Instead, we have to assume that the cobbles were ejected and entered the super-heated impact explosion cloud where they became thermally shocked and partly melted. Moderate mechanical shock by impact shock waves is indicated by the occurrence of planar deformation features and multiple sets of planar fractures (cleavage) in quartz (see e.g., Stöffler 1972, Stöffler & Langenhorst 1994) from sandstone and quartzite cobbles and boulders (Fig. 35). Whereas PDFs in quartz are relatively rare in the samples so far examined, multiple sets of planar fractures (PFs) are abundant. Cleavage is normally absent in quartz and may only occasionally be observed in rocks from very strong regional metamorphism. In impact cratering, however, PFs belong to the regular shock inventory. Since the Mesozoic sedimentary rocks from the moraine material in the Chiemgau region underwent Alpidic tectonics only and were not subjected to any significant regional metamorphism, an origin of the PFs from shock is highly probable.

Fig. 35. Shocked quartz grain in sandstone cobble from crater 004: planar deformation features (NNE - SSW trending) and multiple sets of planar fractures (cleavage). Photomicrograph, crossed polarizers; the field is 560 μm wide.

Fig. 36. Highly porous carbonate clasts assumed to be crystallization products from a carbonate melt

More evidence of high temperatures is given by white, low density, highly porous carbonate clasts (Fig. 36). We suggest them to be the crystallization product of a carbonate melt from the melting of limestone cobbles. Very similar vesicular carbonate material to be also relics of carbonate melt is reported for the Azuara and Rubielos de la Cérida impact structures (Ernstson & Claudin 2002; also see Grieve & Spray 2003). Different from silicate rocks, carbonates may melt but cannot be chilled to form glass. Instead, upon cooling, the melt rapidly crystallizes to form again carbonate. Relics of calcite crystals in these clasts may show microtwinning which is assumed to be also a shock effect (Metzler et al. 1988, and references therein). Bluish-grey, dark green and black glass-like material abundantly exhibits "splash" shapes (tear drops, dumbbells, plates, etc.) indicating rapid cooling and solidification during flight (Fig. 37). The same matter, that has to be studied in more detail, may also coat rocks.

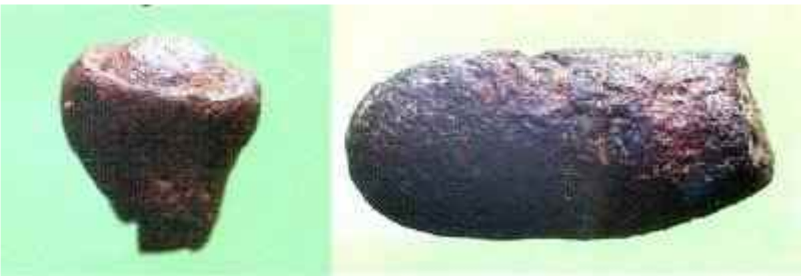

Fig 37. "Splash" shapes indicating rapid cooling and solidification of glass particles during flight.

More strange material extended over the area of the scattering ellipse comprises metallic matter of very different size, shape and composition (Figs. 16 ,38, 39) (Beer et al. 2003). Corroded metal fragments up to the size of 8 cm are composed of dominantly Fe, in two cases of Fe and C, together with Rb, Se, Cu, Na, Mn, Al, Zn, Si, S, Cl, Lu, P, Tl. Re, Ru, Ni, Cr in amounts between about 1 % and 0.01 %. Metallic fragments (< 10 cm) without any oxidation traces (density 6.3 g/cm³, Mohs hardness 6-8) prove to be ferrosilicides, Fe_XSi_Y, containing inclusions of TiC (titanium carbide), alpha-iron and Al_XSi_Y. Among the Fe_XSi_Y phases, Fe_3Si corresponding to the mineral gupeiite, and Fe_5Si_3 corresponding to the mineral xifengite, have been identified (Beer et al. 2003). The Fe_XSi_Y material finely intersperses also the carbonate clasts assumed to have originated from a carbonate melt (Fig. 40). It is also found, down to the fraction of fine sand, in a halo of more than 100 km length around the crater scattering ellipse.

Fig. 38. Different aspects of the peculiar metallic material.

Fig. 39. "Splash" shapes of metallic particles.

Fig. 40. Low-density carbonate material peppered with minute metallic particles. Arrows point to larger particles. The field is 5.5 cm wide

9 Discussion of alternate models

The craters

An origin other than from the impact of cosmic material has been discussed for both the craters and the peculiar matter. Neither volcanism nor tectonics is known for the region under discussion and for the Holocene geological time of the phenomenon. Moreover, the craters are found randomly distributed over areas of quite different surface geology. 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 [2].

Assemblages of apparently man-made depressions with a similar morphological signature are well known from other regions in Germany (German terms "Mardellen", "Mare" [Weber 1909, Stechele 1911]), and they have been reported also for regions in Belgium, Luxembourg and France (Van Werveke 1903; Barth & Löffler 1998, Barth 1996, Löhr 1985, 1986, Barth et al. 1996, Ginkel 1995, Wichmann 1903, and others). A clear and unambiguous explanation of origin and purposes is so far lacking. Apart from geological causes, exploitation of earth materials (gravel, loam, ores), use as reservoirs, charcoal piles, production of quicklime, glassworks and housing estates have been proposed. Obviously, in some cases a multiple use can be assumed. On the other hand and as far as we know, an origin of the crater fields from meteorite impact has so far not been considered.

In the Chiemgau strewnfield area, an interpretation of the craters as the result of human activities presents basic difficulties. Lots of the depressions are located midst of arable land speaking against exploitation and housing purposes. Apart from the craters filled with water, water reservoirs can in most cases be excluded because of the high permeability of the Quaternary gravel layers, and sealing by loam has never been observed in the depressions.

On cursory inspection, some of the craters show similarities with funnel-shaped pits well known from medieval limonite mining and smelting (e.g., Wolf 1986, Frei 1965/66). Some 40 km north of the Burghausen-Marktl strewnfield near Kelheim and Painten, these pits have diameters between 1 and 5 m, and related charcoal piles may amount to the size of 10 m diameter. The observations, however, don't explain the considerable number of much larger craters having diameters between 10 m and 400 m. Moreover, shafts have never be shown to exist and other man-made constructions in and outside the craters either. We also mention the complete absence of blocks of slag with charcoal imprints typically associated with smelting processes (Bielenin 1977). While regularly the magnetic signature of smelting activities (kilns, charcoal piles) is considerable (Bielenin 1977), the only faint magnetic anomalies in the strewnfield craters (see above) do not speak in favor of an anthropogenic origin. To the contrary, archaeological finds in and outside the craters are remarkably scarce. Neither oral nor written reports have ever mentioned mining and smelting activities related with the craters and depressions.

The observation of the heavy rock fracturing related with the craters implying evidence of strong dynamic deformation (spallation features; see above) may suggest explosion cratering from artillery fire or extensive bombing during World Wars One and Two. However, no metallic bomb splinters and no chemical matter from explosives have ever been found in the strewnfield. No aerial photographs typically taken from bombed areas in World War Two do exist. Even the giant World War One mortars (Lusar 2001) or the so-called "Grand Slam" or "Earthquake" bombs in World War Two produced craters not exceeding 66 m and 43 m, respectively (Battlefield Guide 2000). Moreover, neither eyewitness accounts nor archives have ever reported of any bombardment or artillery fire. Taking into account the 120-year age of lots of trees from within many craters (pers. comm. Altötting forestry office), their formation in World War One or later has to be excluded anyway.

In summary, for the most part of the craters under discussion a man-made origin can practically be excluded, and in rare cases, an exception may prove the rule.

The peculiar matter

Opposed to the hypothesis of cosmic matter obviously related with the craters, an origin from industrial and local smelting processes or/and fertilizer application has to be taken into consideration. From the above discussion of the crater formation we conclude that simple iron smelting to produce the slag-like matter does not apply to the observations. Moreover, it lacks high fayalite, wuestite and FeO contents to be expected in material from ordinary kilns (Bielenin 1977, Wolf 1986, Sperl 1981).

Ferrosilicide (Fe_XSi_Y). In nature, the ferrosilicides Fe_3Si (gupeiite) and Fe_5Si_3 (xifengite) are extremely rare, and only a few individual finds have been reported (Jambor et al. 2002, Rudashevskii 1995). Fe_3Si and FeSi were analyzed in fulgurite glass from lightning into the ground (Heinrich 2001; also see Sheffer et al. 2003). The authors suggest short-term formation temperatures in excess of 1710°C, and they refer also to the reported rare occurrences of natural ferrosilicides in Russia which have partly been confirmed only, or which are related with meteorite falls. The type locality of xifengite is the Yanshan area, Hebei Province, China, where the mineral was identified in the Yanshan meteorite. Because of the extensive distribution in the Burghausen-Marktl region, lightnings to have produced the ferrosilicides can reasonably be excluded.

The first artificial production of ferrosilica by J.J. Berzelius is dated the year 1810 (Reller et al. 2000). In the early 20th century, the large-scale production of FeSi began (Reller et al. 2000), and today it is used in steel alloying.

Different from Fe_3Si (gupeiite), Fe_5Si_3 (xifengite) has until today (October 2004) not been produced industrially in any notable extent, although its synthesis is possible and although its outstanding magnetic properties have become highly interesting (Hines et al 1976). Only 1997, the production of xifengite (together with gupeiite) from FeSi has been reported for the first time (Li et al. 1997).

Titanium carbide (TiC). - In the terrestrial lithosphere, pure titanium carbide is hitherto unknown. Since the early thirties of the last century, its artificial production, however, is possible (communication Treibacher Industrie, Austria) [7]. TiC is exceptional because of its remarkable high melting point of 3050 - 3230°C, its extreme hardness, and its resistance against corrosion and oxidation.

Aluminium silicide (Al_XSi_Y)*.* - Like titanium carbide, pure aluminium silicides are no naturally occurring minerals, but they are industrially produced in the form of $Al_{X=1}Si_Y$ (communication UMEC, Ukraine). In the last two or three decades, properties and production technologies have intensely been studied (Ejifor & Reddy 1997) [8]. With regard to the high purity of the Burghausen-Marktl aluminium-silicide matter, the usual admixture of elements like Cu, Mg, Fe, Ni, Zn, and others, in the industrial production process is worth mentioning.

Other elements. - The high amount of certain other elements in the Burghausen-Marktl matter (4% V, 3.5% Nb, 3% W, 1 % Ta, subordinate Zr, Mo) is remarkable and, in principle, may be related with industrial processes where they are used in alloying.

Summarizing and disregarding the FeSi and Fe_3Si occurrences in fulgurites and the disputed and partly unconfirmed other rare occurrences of Fe_5Si_3, we note that ferrosilicides, titanium carbide and aluminium silicides are unknown as terrestrial minerals but may be produced industrially. Here, it is important to also mention the in most cases enormous technical expenditure, which explains that the large-scale industrial production did not start before the middle of the 20th century. Assumed the peculiar material from the Burghausen-Marktl area is industrial waste, then, with respect to simple FeSi, it could not have been produced before the beginning of the 20th century, with respect to TiC not before the early fifties of the last century, and with respect to Fe_3Si and especially Fe_5Si_3 not before the end of the last century. With regard to these time limits, an anthropogenic deposition of this extremely rare and valuable material in large quantities, over large areas and at depths of several decimeters beneath the soil is basically inexplicable. The assumption xifengite is a waste product of some completely unknown industrial activities is incompatible with the growing interest in this peculiar material against a background of possible economic importance. We furthermore remind of the fact that, with regard to the age of the trees, the xifengite deposits in the southern Bavarian crater strewnfield must be older than 120 years. At the end of the 19th century, however, human activities to produce such enormous quantities of xifengite are absolutely unknown.

Consequently, we are forced to present the following scenario: The peculiar material from the crater area originates from a modern high-tech industry that produced it in an expensive process in order to remove it, gone unnoticed by the public, to an area of at least 3,000 square kilometers and to depths of at least 20 cm below the soil. We encourage the reader to assess the probability of such a scenario.

We may discuss the material to have precipitated from unknown sources, but the transport of the larger particles (several centimeters long) would have required strong winds, and it is inconceivable that this precipitation could have happened, escaped attention of the local population that well remembers the precipitation of, e.g., Sahara desert dust 25 years ago and of industrial dust from a defective filter some 40 years ago.

Finally, we asked some 50 farmers cultivating the fields and forests especially enriched in the strange material whether they used it for soil melioration or whether it is known to them at least. In unison they confirmed to have never seen those materials and, being aware of its extreme hardness, they said they would run the risk of damaging their farming machines.

At the final count we note that an anthropogenic origin of the peculiar material is beyond any reasonable argumentation. In combination with the crater assemblages for which we exclude an anthropogenic origin likewise, an extraterrestrial relation of the phenomenon is the simplest and most probable explanation.

10 Astronomical implications for the meteoroid and the impact event

Extraterrestrial ferrosilicides in meteorites

Regarding the peculiar matter found in the Chiemgau strewnfield, we notice striking correspondences to special kinds of meteorites and presolar grains. Only recently, different phases of Fe_XSi_Y, FeSi, Fe_2Si (hapkeite) and $FeSi_2$, have been found as new minerals in Dhofar 280 (Dh-280, Dhofar region, Oman, April 2001), a meteorite probably coming from the Moon (Anand et al. 2003). The meteorite FRO 90036 from Antarctica (Frontier Mountains) contains the mineral gupeiite (Fe_3Si) (Wlotzka 1994), which we were able to detect also in the Chiemgau strewnfield matter [9].
Another unique found verifies gupeiite and xifengite as substantial parts of a meteorite (type CV) that was discovered 1984 in the Yanshan Mountains (Hebei, China) (Yu Zuxiang 1984). The low percentage of Ni is striking and reminds of the low Ni content in the Chiemgau strewnfield matter. Moreover, TiC together with gupeiite (Fe_3Si) is the essential part of the centre of the spherules in the Yanshan meteorite (Yu Zuxiang 1984). A very similar composition is given in the Chiemgau impact samples [10].

α-Fe, Fe_xSi_y, TiC, and peculiar elements in presolar dust grains

We suggest that the peculiar material we found in the Chiemgau strewnfieled may be related with presolar matter. Quite recently, research work showed that α-Fe, Fe_XSi_Y, TiC, and certain peculiar elements are represented in grains of stardust coming from the primordial solar nebula and detected as well in primitive unaltered meteorites as in micrometeorites of the interplanetary dust, which had been collected in the stratosphere, in the ice sheet at the Earth's poles and in deep-sea sediments. The grain sizes range from 1 µm to 1 mm. (Ferrarotti et al. 2000, Gordon et al. 2000, Ferrarotti & Gail 2002, Clayton & Nittler 2003, Chigai et al. 1999, Rubin 1997, Kimura & Kaito 2002, Bernatowicz 1996 a,b; Croat et al. 2002, Nittler 2003, Jessberger et al., and many others)
The Chiemgau strewnfield is widely scattered with ferromonosilicide (FeSi). Now, FeSi was detected in grains of circumstellar dust clouds. Stars with initial masses < 8 M (M = mass of the sun) go through a special evolution at the so-called Asymptotic Giant Branch (AGB) of the Hertzsprung-Russel diagram (HRD). During their

transition from M-class to C-class stars, these S-class stars lose most of their originally mass by strong stellar winds (WN stars) or eruptions (LBV stars) into very thick dust shells. Among other materials, the dust condensates of these stars contain solid metallic iron (α-Fe) and FeSi. An important component assumed to trigger the nucleation of the dust is titanium carbide (TiC). In addition, dust grains consisting of β-$FeSi_2$, which had been discovered in the nebula NGC7023, support the idea that Fe_XSi_Y is a part of interstellar matter.

The analysis of the material in the Chiemgau strewnfield showed a high percentage of TiC. This is understandable regarding its formation during the final stages of post-AGB stars and its property to trigger the condensation of metallic iron (α-Fe) and FeSi. From an examination of the Murchison meteorite it is known that within graphite spherules, which are associated to supernova (SN) ejecta, pure metallic iron (α -Fe) is joined to cubic TiC in the grains (Croat et al. 2002; Stadermann et al. 2002). We found that in the Chiemgau impact material cubic TiC had been embedded in a Fe_XSi_Y-matrix, which contains additional pure metallic iron (α-Fe) and higher phases of ferrosilicides (Fe_3Si [gupeiite] and Fe_5Si_3 [xifengite] (analysis by Dr. Raeymaekers, InfraServ Gendorf). This is very similar to the composition of the matter associated with the star dust ejected by S-class stars and supernovae. We also observed significant values for V, Co, Zr, Nb, Mo, Ta, W in the material of the Chiemgau strewnfield. It is very interesting to note that the spherules embedded in interstellar dust grains contain Zr, Mo, Ru, which are related to the fractionating of elements during the condensation of the carbides (Bernatowicz 1991; Lodders 1996). V, Nb, Mo, Ru, Ta, W, Re are significantly present also in some types of carbonaceous chondrites (CV-class) (Rubin 1997).

Following these considerations we suggest that the meteoroid responsible for the Chiemgau strewnfield contained primordial matter from the time the solar system originated. We wouldn't be surprised if future research would reveal the existence of diamonds in the material, because these seem to play an important role in the nucleation process in a dust cloud and had been confirmed in carbonaceous meteorites, which represent a clue for presolar matter.

Modeling the impact

Together with the considerations mentioned before and available computer programs (http://www.lpl.arizona.edu/~marcus/crater2.html [Earth Impact Effects

Program]; http://www.lpl.arizona.edu/tekton/crater.html [Crater]; http://keith.aa.washington.edu/craterdata/scaling/index.htm [Crater Sizes from Explosions or Impacts]; http://janus.astro.umd.edu/astro/impact/ [Solar System Collsions]; software "Tunguska" (2002) by D. Neisius, based on Hills et al. 1993) we can try to get some impressions of the size, structure, and mass of the meteoroid. Within the limits of available data it is possible to describe the impact event itself . From the high quantity of larger craters in the strewnfield and the widespread distribution of heavy ferrosilicides we conclude that the original meteoroid must have contained large solid lumps of higher density embedded in matter of very low density, possibly the so-called methane ice. Because of its content of methane gas, methane ice becomes instable and is flammable above 18 °C. Upon atmospheric entry of the meteoroid, changes in temperature and pressure cause the methane to be set free in a giant explosion heating up the atmosphere along the entry channel. Thus the effects of high temperatures and pressures including thermal and mechanical shock we observe in the materials from the Chiemgau strewnfield are easily understood. The meteoroid responsible of this scenario could have been a planetoid or a comet of very low density. A candidate for an underdense body is a C-class (253) Mathilda type planetoid (density 1.3 ± 0.2 g/cm³) thought to be completely shattered however reassembled to form an aggregate rather than a solid. However, with respect to the unusual matter we found associated with the Chiemgau strewnfield and to the extension of the scattering ellipse, we suggest a cometary impactor that mainly consisted of ice (methane, ammonia, water) and a relatively small part of solid stony and iron material.

Whereas the impact cratering of individual asteroidal projectiles is largely understood (e.g., Melosh 1989), the behaviour of a comet and its nucleus on their passage through the Earth's atmosphere and the crash with the ground are still disputed. For the Chiemgau strewnfield, a rough approach to the suggested cometary impact cratering is given by some computations. To fit our observations, we estimate that the projectile had a diameter of about 1.100 m and a mean density of 1.3 g/cm³. It passed the Earth's atmosphere under an entry angle of about 7° at an entry velocity of ca 12 km/s implying a start of the breakup at an altitude of 70 km. The major mass of the projectile hits the ground at a velocity of 0.99 km/s, and the impact energy is calculated to be roughly 106 megatons equivalent. The fragmentation results in a scattering ellipse of 59.7 km by 7.3 km, and the largest fragment is estimated to produce a simple bowl-shaped crater with a final 832 m diameter and a final 177 m depth. Based on the size distribution of the craters - the larger ones in the southern, the smaller ones in the northern part - we conclude that the meteoroid moved from northeast to southwest keeping an azimuth of about 43 degree to north. These figures should be taken as a glimpse on the event only taking into consideration that the effects of a giant methane ice explosion are not well known yet. A multiple fragmentation of the impactor before its striking the Earth cannot be excluded either, possibly explaining the very long and broad strewnfield for the larger craters.

The age of the event and historical implications

Upper and lower limits for the age of the event are given by the dating of trees from within the craters and especially from archaeological finds indicating a recent event in historical time. Trees rooting in craters and on their walls are 120 years old on average, and in one case we found a tree that is about 400 - 500 years old. The upper limit of the impact event is further lowered by the find of the peculiar matter described above, embedded in an undisturbed layer of a 1000-years-old forest (information forestry office; also see Rugner 1956). The peculiar material has also been found beneath the big retaining walls of the Burghausen castle dated to 15th c. AD. At another place, we dug out a treasure of coins (dated to 1540 - 1572 AD) located above the layer containing the ferrosilicides.

A lower limit is given by archaeological observations. The excavation of one of the craters has clearly affected a large artificial dam (11 km long), which according to archaeologists has been constructed in the High Middle Age about 10th - 12th c. AD or may be Graeco-Roman, between 50 BC and 50 AD (Stechele 1911, Harlander 1983). Other scientists suggest an earlier construction of the dam, some centuries BC. At another site, finds from the Celtic culture together with the peculiar impact material exhibit strange surfaces pointing to sudden heating on one side only (Fig. 41). Thus, the late Latène period (480 BC to 30 BC) may be the earliest date for the impact. To get a more precise age, we took ash samples from the layers associated with the impact event in several craters for radiocarbon dating the result of which will be available soon.

Fig. 41. Celtic archaeological finds give evidence of a short but strong heat pulse experienced upon ejection from a crater

In any case, the insignificant erosion of the craters, with exception of their destruction by human influence, is remarkable once more pointing to a recent impact event in historical time. Thus we think that a date fore the impact event can be set between the 5th c. BC and the 9th c. AD. We also checked the historical and climatic records for exceptional events falling in this period. Quite recently (Rigby et al. 2004) a cometary meteoroid with a size about 500 m was claimed to be responsible for the AD 536 event. The dendrochronology of Irish oaks shows that the tree-rings had been strongly influenced by a climatic change between 536 and 545 but also at around 207 BC. Regarding the possible earlier date, is it only casual that at about 205/204 Roman authors handed down stories about several stone showers falling from the sky and terrifying the people? Because of those remarkable events, the Roman senate decided to bring back the conical shaped *Needle of Cybele*, a meteorite, which was recognized as the Great Mother Godess Cybele from Asia Minor to Rome. At present we can only speculate about an association with these both dates. Taking into account the sample of thermally shocked coins from the late Latène period, we tend to set the Chiemgau impact event into that period. At present we favor the early date, because of the fact that archeologists had already found roman relics at the rim of the big “Tüttensee” crater, which date about 200 AD.

In any case the effects on nature and people in the Altoetting-Chiemgau area, and probably in nearby regions must have been very strong. The big size of the meteoroid, which caused the Chiemgau strewnfield of craters, let us think that the area had been devastated for some decades. Therefore people should have avoided to settle down in this region over some decades. We are currently looking for gaps in the cultural tradition at the proposed earlier and later date. There are several blanks in the archaeological records which must be further evaluated, aided by the results of radiocarbon dating.

The effects of the impact

At a distance of 10 km people will feel the major seismic shaking as a quake of magnitude 6.0 on the Richter scale, two seconds after the fragments of the impactor hit the ground. It is expected that the damage is moderate regarding well-built structures, but is considerable with regard to poorly built objects. At 10 km distance, the air blast will arrive ca 30 s after the impact with a wind velocity of about 225 km/h. The excess pressure is estimated to have a peak at 142,000 Pa. This will cause collapsing of buildings, in particular wooden ones. Up to 90 % of the trees will be blown down, and 10 % should loose their branches and leaves.

But the effects could have been much stronger regarding the assumed explosion of methane ice in the atmosphere. The thermal shock, which we have observed in our material, supports such an expectation. A great radiant fireball should have been seen by the people. From this, the thin layer of ash is easily understood, which we found in and between the craters: The forest must have been ignited suddenly until the air blast had shut down the fires. In addition, we estimate that dust was blown up some kilometers high and transported around the world. Thus it will be possible to trace the event in the ice records of Greenland or Antarctica. People should have seen a big toroidal cloud. Finally, we checked what people would have heard in a distance of 10 km: The sound intensity would have reached about 103 dB, enough to cause strong ear pain.

References:

American Mineralogist (1976): 61, 184-185.

American Mineralogist (1986): 71, 228.

Anand, M., Tayor L. A., Patchen A. Cahill J., Nazarov M.A. (2002): New Minerals from a New Lunar Meteorite, Dhofar 280. 2002. Lunar Planet. Sci. XXXIII.

Anand, M., Taylor, LA., Nazaraov, M.A., Shu, J., Mao, H.-K., Hemley, R.J. (2003): New Lunar Mineral Hapkeite: Product of impact-induced vapor-phase deposition in the Regolith? -Lunar Planet. Sci. XXXiV.

Anthony J., Bideaux R., Bladh K., Nichols M. (1997): *Handbook of Mineralogy,* vol. 3, Halides, Hydroxides, Oxides.

Barth, B. (1996): Mardellen im lothringischen Gipskeuper. Abh. Delattinia, 22, Saarbrücken.

Barth, B., Löffler, E. W. (1998): Mardellen im Saar-Lor-Lux-Raum. In: Mosella, Eau de Morphologies, 23, Nr. 3-4, 75-94.

Barth, B., Schneider, C., Schneider, T.G., Dorda, D., Eisinger, D., Didion, A., Royar, H. (1996): Mardellen im saarländisch-lothringischen Schichtstufenland. Abh. Dilattinia, 22: 285 S.

Battlefield Guide (2000): Major & Mrs Holt's Battlefield Guide - Somme, Leo Cooper.

Beer, R., Benske G., Mayer W., Blienetsrieder T., Raeymaekers, B., Sporn, R. (2003): Beawatch und der Meteorit aus Oberbayern; nur eine Hypothese? Präsentation InfraServ, Gendorf.

Bernatowiiz T.J., Cowsik R., Gibbons P.C., Lodders K., Fegley B., Amari S., Lewis R.S. (1996): Constraints on Stellar Grain Formation from Presolar Graphite in the Murchison Meteorite. - Astrophysical Journal, 472, 760.

Bielenin, K. (1977): Frühgeschichtliches Bergbau- und Eisenhüttenwesen im Swietokrzyskie-Gebirge. In: Eisenverhüttung vor 2000 Jahren. Archäologische Forschungen in der VR Polen. Ausstellung des Pahstwowe Muzeum Archeologiczne Warszawa, Muzeum Archeologiczne Krakow, Muzeum Starozytnego Hutnictawa w Pruszkowie Pruszków, in Zusammenarbeit mit dem Museum für Vor- und Frühgeschichte Staatliche Museen Preußischer Kulturbesitz Berlin. 27. August 1977 bis 30. Oktober 1977 im Langhansbau Schloß Charlottenburg, S. 11-18.

Chao, E.C.T. 1977. The Ries crater of southern Germany. A model for large basins on planetary surfaces. Geol. Jb., **A43**: 81 pp.

Chigai, T., Yamamoto, T. Kozasa, T. (1999): Formation conditions of presolar TiC core-graphite mantle spherules in the Murchison Meteorite. The Astrophys. J., 510, 999-1010.

CIRT, Chiemgau Impact Research Team (2004): Did the Celts see a cometary impact 200 B.C.? (Sahen die Kelten einen Kometeneinschlag 200 v. Ch.?) http://www.astronomy.com/asy/default.aspx?c=a&id=2519

CIRT, Chiemgau Impact Research Team (2005): Kommentar zu: Der Tüttensee im Chiemgau - Toteiskessel statt Impaktkrater, von Gerhard Doppler und Erwin Geiss (Bayerisches Geologisches Landesamt). http://www.chiemgau-impact.com/kommentar.html.

Claudin, K., Ernstson, K., Rampino, M.R., and Anguita, F. (2001). Striae, polish, imprints, rotated fractures, and related features in the Puerto Mínguez impact ejecta (NE Spain). *Abstracts, 6th ESF IMPACT workshop, Impact Markers in the Stratigraphic record*, pp 15-16.

Clayton, D.D., Nittler, L.R. (2003): Astrophysics with Presolar Stardust. Annual Rev. Astron. Astrophys., Nov. 2003, 1-37.

Clayton D.D., Nittler L. R. (2004): Presolar Stardust Grains. - Carnegie Observatories Astrophysics Series 4: Origin and Evolution of the Elements (McWilliam A. Und Rauch M., eds. Cambridge University Press, p.1-20.

Croat T. K., Bernatowicz T., Stadermann F. J., S. Messenger S., Amari S. (2002): Coordinated isotopic and TEM studies of a supernova graphite. Lunar Planet Sci. XXXIII, Abstract # 1315, Lunar and Planetary Institute, Houston.

Croat T.K., Bernatowicz T.J., Amari S., Messenegr S. Und Stadermann F.J. (2002): Metallic Iron Condensed onto Titanium Carbides within Supernova Graphites. - Meteoritics, Abstract # 5089;

Ejifor, J. U., Reddy, R. G. (1997): Developments in the Processing and Properties of Particulate Al-Si Composites. - JOM (The Member Journal of The Minerals, Metals, and Materials Society), 49 (H), 31-37.

Engelhardt, W.v., Stöffler, D., Schneider, W. (1969): Geologica Bavarica, 61, 229-295.

Ernstson, K. & Claudin, F. (1990). Pelarda Formation (Eastern Iberian Chains, NE Spain): Ejecta of the Azuara impact structure. *N. Jb. Geol. Paläont. Mh.* 1990: 581-599.

Ernstson, K., Claudin, F., Schüssler, U. & Hradil, K. (2002): The mid-Tertiary Azuara and Rubielos de la Cérida paired impact structures (Spain). - Treb. Mus. Geol. Barcelona, **11**, 5 - 65.

Ernstson, K., Rampino, M.R. & Hiltl, M. (2001). Cratering of cobbles in Triassic Buntsandstein conglomerates in NE Spain: Shock deformation of in-situ deposits in the vicinity of large impacts. *Geology*. 29: 11-14.

Ernstson, K., Rampino, M.R. & Hiltl, M. (2001b). Shock-induced spallation in Triassic Buntsandstein conglomerates (Spain): an impact marker in the vicinity of large impacts, in: *Impact markers in the stratigraphic record, 6th ESF-IMPACT workshop Granada, abstract book*: 25-26.

Ernstson (2005): Gravimetrische Untersuchungen bei Grabenstätt: Anzeichen für einen Impaktursprung des Tüttensee-Kraters erhärtet. http://www.chiemgau-impact.com/.

Fehr, K.T., Pohl, J., Hochleitner, R. (2002): Meteoritenstreufeld Burghausen. Statusbericht August 2002.

Fehr, K.T., Hochleitner, R., Hölzl, S., Geiss, E., Pohl, J., Faßbinder, J. (2004): Ferrosilizium-Pseudometeorite aus dem Raum Burghausen, Bayern. Der Aufschluß 55, S. 297-303.

Fehr, K.T., Pohl, J., Mayer, W., Hochleitner, R., Faßbinder, J., Geiß, E., Kerscher, H. (2005): A meteorite impact crater field in eastern Bavaria? A preliminary report (Ein meteoritisches Kraterfeld in Ostbayern? Ein vorläufiger Bericht). Meteoritics and Planetary Science, 40, 187-194.

Ferrarotti A., Gail H.-P (1999): Dust condensation in S-Stars. Astronomische Gesellschaft Abstract Services,vol. 15.

Ferrarrotti A. S., Gail H.-P. (2001): Dust Condensation in LBV and WN Stars. Astronomische Gesellschaft Abstract Series, Vol. 18, abstract #P49.

Ferrarotti A.S., Gail H.-P. (2002): Mineral formation in stellar winds. III. Dust formation in S Stars. -Astron. Astrophys., 382, 256-281.

Ferrarotti, A. Gail, H.-P., Degiorhi, L., Ott, H.R. (2000): FeSi as a possible new circumstellar dust component. Astron. Astrophys., 357, L13-L16.

Florschütz (1896): Mardellen. Korrespondenzblatt des Gesamtvereins der deutschen Geschichts- und Altertumsvereine (KorrBlGesamtVGA) 44, S. 148.

Frei, H. (1965/66): Der frühe Eisenerzbergbau im nördlichen Alpenvorland. - Jahresber. Bayer. Bodendenkmalpflege, 5/6, 67-137.

French, B.M. & Short, N.M. (eds.) (1968). *Shock metamorphism of natural materials*. Mono Book Corp. Baltimore.

Ginkel, H. (1995): Die Mardellen der Seiters. - III. In: Heimatkalender d. Pirmasenser u. Zweibrücker Land. S. 62-68.

Gordon K., Witt A.N., Rudy R.J., Puetter R.C., Lynch D.K., Mazuk S., Misselt K.A., Clayton G.C., Smith Tr. L. (2000): Dust Emission Features in NGC 7023 between 0.35 and 2.5 Microns: Extended Red Emission (0.7 Microns) and Two New Emission Features (1.15 and 1.5 Microns). - The Astrophys. J., 544, 859-866.

Grieve, R.A.F., Langenhorst, F. and Stöffler D. 1996. Shock metamorphism of quartz in nature and experiment: II. Significance in geoscience. *Meteoritics & Planet Sci,* **31**: 6-35.

Grieve, F., Spray, J.G. (2003): Large Meteorite Impacts.

Harlander, J. (1983): Der Laubergraben in Schützing - ein Bodendenkmal aus der Römerzeit? Oettinger Land, 3, 31-38.

Heinrich, E. W. (2001): The Mineralogy of Michigan, 27 p., Lansing, Michigan.

Henning Th., Salama F. (2000): Carbon in the Universe. - Science, 282, 2207.

Hodge, P. (1994): Meteor craters and impact structures. Cambridge University Press, 124 pp.

Hills, J.G., Goda, M.P. (1993): Astron. J., 105 (3), 1114-1144).

Hines, W. A., Menotti A. H., Budnick J. I., Burch T. J., Litrenta, T., Niculescu, V., Raj, K. (1976): Magnetization studies of binary and ternary alloys based on Fe3Si. - Phys. Rev., B 13 (9), 4060-4068.

Hoffmann, V., Rösler, W., Schibler, I., 2004: Geophys. Res. Abstracts, 6, 05041.

Hoffmann et al. (2004): Evidence for an impact strewn field in SE Bavaria. Paneth-Kolloquium, Nördlingen.

Hoffmann, V., Rösler, W., Patzelt, A., Raeymaekers, B., van Espen, P. (2005): Characterization of a small crater-like structure in southeast Bavaria, Germany. Meteoritics and Planetary Science, 40, p. A129.

Melosh, H.J. 1989. *Impact cratering. A geologic process*. Oxford Univ. Press, Oxford, 245 pp.

Jambor, J.L., Grew, E.S., Roberts, A.C. (2002): New Mineral Names: Am. Mineralogist, 87, 181-184.

Jessberger E. K., Stephan T., Rost D., Arndt P., Maetz M., Stadermann F. J., Brownlee D. E., Bradley J. P., Kurat G. (2001): Properties of Interplanetary Dust: Info rmation from Collected Samples. In Interplanetary Dust (eds. E. Grün, B. Å. S. Gustafson, S. F. Dermott and H. Fechtig) pp. 253–294. Springer-Verlag, Berlin, Heidelberg, New York.

José, J., Hernanz, M., Amari, S., Lodders, K., Zinner, E. (2004): The Astrophys. J., 612, 414-428.

Keil, K., Berkley, J.L., Fuchs, L.H. (1982): Suessite, Fe_3Si: a new mineral in the North Haig ureilite. Am. Mineral., 67, 126.

Kimura, Y, Kaito, C. (2002): Titanium carbide partides as pre-solar grains.
Monthly Notices Royal Astron. Soc., 343 (2), 385-389.

Krinov, E.L. (1963): In: The solar system, vol. IV, pp. 183-187, 189-207, 208- 234, University of Chicago Press.

Li T., Li Y.Z., Zhang Y.H. (1997): Phases in ball milled Fe0.6Si0.4 - J. Physics-Condensed Matter, 9(6), 1381-1388.

Löhr, H. (1985): Maare, Märchen, Mardellen, wenig beachtete Bodendenkmäler? Funde u. Ausgr. Bez. Trier, 17, 3-9.

Löhr, H. (1986): Mardellen und ähnliche Sedimentfallen: eine spezifische Feuchtbodensituation im Mittelgebirgsbereich. Arch. Info rmationen, 9, 104-110, Berlin.

Lusar, R. (2001): Riesengeschütze und schwere Brummer, Bonn.

Melosh, H.J. (1989). *Impact Cratering. A geologic process*. Oxford Univ. Press. Oxford

Metzler, A., Ostertag, R., Redeker, H.-J. and Stöffler, D. 1988. Composition of crystalline basement and shock metamorphism of crystalline and sedimentary target rocks at the Haughton impact crater, Devon Island, Canada. *Meteoritics*, **23**: 197-207.

Mittler L.R. (2003): Presolar stardust in meteorites: recent advances and scientific frontiers. - Earth Planet. Sci. Lett., 209, 259-273.

Münster, A. (1957): Eigenschaften und Anwendungen von Titannitrid und Titancarbid. Angewandte Chemie, 69, 281-290.

Oberweis, C. (1992): Popokatepetl's auf der Ferschweiler Hochfläche? : Ein Beitrag zur Untersuchung der Märe, Maare, Mären, Märchen, Mertel bzw. Mardellen, III. In: Gester an Hätt. - Nr. 10=5, 6-16.

Osinski, G. R. and Spray, J. G. 2001a. Impact-generated carbonate melts: evidence from the Haughton structure, Canada. *Earth Planet. Sci. Let.*, **194**: 17-29.

Raeymaekers, B. & Schryvers, D. (2004): Iron silicides and other metallic species in the SE Bavarian strewn field). Paneth-Kolloquium Nördlingen.

Raeymaekers, B. (2005): A prospective biomonitoring campaign with honey bees in a district of Upper-Bavaria (Germany). - Environmental Monitoring and Assessment, 11 pp., in press).

Rampino, M.R., Ernstson, K., Fischer, A.G., King, D.T., Ocampo, A., and Pope, K.O. 1996. Characteristics of clasts in K/T debris-flow diamictites in Belize compared with other known proximal ejecta deposits. *Abstracts with Prog., Geol. Soc. Am.*, **28**: A-182.

Rampino, M. R., Ernstson, K., Anguita, F., & Claudin, F. (1997a). Striations, polish, and related features of clasts from impact-ejecta deposits and the "tillite problem". *Abstracts, Conference on Large Meteorite Impacts and Planetary Evolution, Sudbury, Ontario, Canada* p. 47.

Rampino, M. R., Ernstson, K., Anguita, F., Claudin, F., Pope, K.O., Ocampo, A., & Fischer A. G. (1997b). Surface features of clasts from impact-ejecta deposits and the "tillite problem". *Abstracts with Prog. Geological Society of America*. 29.

Rappenglück et al. (2004): The Chiemgau impact event in the Celtic Period: evidence of a crater strewnfield and a cometary impactor containing presolar matter. http://www.chiemgau-impact.com/.

Reiter, A., Braungart, M., Soth, J., Uexküll, 0. v.(2000): Silicone - eine vollsynthetische Materialklasse macht Geschichte(n). - GAIA 9 (1): 13-24.

Rigby, E., Symonds, M., Ward-Thompson, D.(2004): A comet impact in AD 536? Astronomy & Geophysics, 45, n 1, abstract.

Robertson, P.B., Dence, M. R. and Vos, M. A 1968. Deformation in rock-forming minerals from Canadian craters. In: French, B. M. and Short, N. M. (eds.), *Shock Metamorphism of Natural Materials*. Mono Book Corp., Baltimore, 433-452.

Rösler et al. (2004): Puzzling new carbon materials in forest soils: carbonaceous graphitic spherules (CGS) with diamonds). Paneth-Kolloquium, Nördlingen.

Rösler, W., Hoffmann, V., Raeymaekers, B., Schryvers, D., Popp, J. (2005): Diamonds in carbon spherules - evidence for a cosmic impact?. Meteoritics and Planetary Science, 40, p. A129.

Rubin, A.E. (1997): Mineralogy of Meteorite Groups. - Meteoritics & Planet. Sci., 32, 231-247.

Rudashevskii N.S., Kretser Y.L, Anikeeva L.I., Andreev S.I., Torokhov M.P., Kazakova V.E. (2001) Platinum minerals in oceanic ferromanganese crusts. - Doklady Earth Sciences 378 (4), 464-467.

Schryvers, D. & Rössler, W. (2004): Diamond identification by TEM in carbonaceous graphitic sperules. Paneth-Kolloquium, Nördlingen.

Schüssler, U. (2005): Petrographie und Geochemie von mechanisch und thermisch geschockten Geröllen aus dem nördlichen Bereich des Impakt-Areals. http://www.chiemgau-impact.com/petrographie.html.

Schüssler, U. (2005): New analyses - new photomicrographs: xifengite, gupeiite and titanium carbide. http://www.chiemgau-impact.com/analysis.html.

Schryvers, D. and Raeymakers, B. (2005): EM characterisation of a potential meteorite sample, proceeding of EMC 2004, Vol. II, p. 859-860 (ed. D. Schryvers, J.P. Timmermans, G. Van Tendeloo)

Sheffer, A.A., Melosh, H.J., Jarnot, B.M., Lauretta, D.S. (2003): Reduction of silicates at high temperature: Fulgurites and thermodynamic modelling. Lunar Planet. Sci., XXXIV, 110.

Speck A.K., Hofmeister A.M. (2004): Processing of Presolar Grains around Post-Asymptotic Giant Branch Stars: Silicon Carbide as the Carrier of the 21 Micron Feature. - The Astrophys. J., 600, 986-991.

Stadermann F.J., Bernatowicz T., Croat T.K., Zinner E., Messenger S., AmariS.,(2003): Nanosims Isotopic Measurements of Individual TiC Crystalls in a Single Presolar Graphite Grain. Ann. Lunar Planet. Sci. Conf., XXXiV, (Houston: Planetary Inst), A1627, 2003.

Stechele, K. (1911): Vor- und Frühgeschichtliches aus dem Heimatbezirke Burghausen. Druck W. Trinkl, vorm. Leo Russy, Burghausen.

Stöffler, D. (1972). Deformation and transformation of rock.forming minerals by natural and experimental shock processes, I. Behavior of minerals under shock compression. *Fortschr. Mineral*. 49: 50-113.

Stöffler, D. & Langenhorst, F. (1994). Shock metamorphism of quartz in nature and experiment: I. Basic observation and theory. *Meteoritics*. 29: 155-181.

UMEC "Ukrainian Electrometallurgical Company " Ltd, Kiev als AlSi (Si-38-42%), $AlSi_2$ (Si-42-60%), $AlSi_3$ (Si-46-50%), $AlSi_4$ (Si-33-40%); http://al-si.ukrbiz.net/eng.htm und Osprey Metais Ltd.,Millands, Neath, SAH 1NJ, UK; http://www.ospreymetals.co.uk/low-expansion/index.htm

US Pat. No. 5,417,952; Koc, Rasit, New Method for Synthesis of Metal Carbides, Nitrides, and Borides (http://mtc.engr.siu.edu/mtc/docs/research/koc.htm).

Van Werveke, L. (1903): Beitrag zur Kenntnis der lothringischen Mardellen. Zugleich ein Beitrag zur Kenntnis des lothringischen Diluviums. Mitteilungen der geologischen Landesanstalt von Elsaß-Lothringen, V, H. 4, 1903.

Von Helden G., Tielens A.G.G.M., Van Heijnsbergen D., Duncan M.A., Hony S., Waters L.B.F.M., Meijer G. Titanium Carbide Nanocrystals in Circumstellar Environments. - Science, 288, 313-316.

Wang, C. B., Wang Q. X., Shen, Q.,Zhang, L.M. (2003): Preparation of Fe-Si Composite Powders by Mechanical Alloying. In: Composite Materials III. KEM - Key Engineering Materials, 249, 311-314.

Weber, F. (1909): Die vorgeschichtlichen Denkmale des Königreiches Bayern, I. Band: Oberbayern. Nach den Ergebnissen der Inventarisierung von 1903-1908. München: Im Selbst-Verlag des Kgl. Generalkonservatoriums der Kunstdenkmale und Altertümer Bayerns, 1909, S. 4 (Altötting, K.BI.No.V.42;
Altöttinger Forst, K.BI.NO.IV.37), S. 5 (Altöttinger Forst, K.BL.NO.III. 38; Mering K.BI.NO.III.40), S. 6 (Burghausen K.BI.NO.II.40).

Weiland, F. (1996): Cerametal S.à.r.l., eine Spitzenadresse nicht nur in Europa. Hartmetall und Hartmetallwerkzeuge auf und mit Welt-Niveau. Revue Technique Luxembourgeoise, Kap. 3.1.2 und Bild 7.

Wichmann (1903): Ueber die Maren oder Mertel in Lothringen (Mit einem Bericht über die Ausgrabungen des Herrn Colbus in Altrip.) Jahrbuch der Gesellschaft für lothringische Geschichte und Altertumskunde (Annuaire de Societé d'Histoire et d'Archéologie Lorraine, Quinzième Année), 15. Jahrgang, Metz (Verlag von G. Scriba), S. 218-262.

Wolf, H. (1986): Eisenerzbergbau und Eisenverhüttung in der Oberpflaz von den Anfängen bis zur Gegenwart. Hefte Bayer. Geschichte und Kultur, Band 3 (Hg. Müller, R. A.). München: Haus der Bayerischen Geschichte, Bayerische Staatskanzlei, 1986, S. 15.

Wlotzka, F. (1994): The Meteoritical Bull., 77, Meteoritics, 29, 6.

Yu Zuxiang (1984): Acta Petr. Min. Analytica, 3, 231-238

Zinner E. (1998): Stellar nucleosynthesis and the isotopic composition of presolar grains from primitive meteorites. Ann. Rev. Earth an

Footnotes

[1]

Spallation is a well-known process in fracture mechanics as well as in impact cratering and has been investigated theoretically and experimentally by many researchers. Unfortunately, it is less well known that spallation can also be observed in nature as an actually existing geologic phenomenon in and around impact structures.

Spallation takes place when a compressive shock pulse impinges on a free surface or boundary of material with reduced impedance (= the product of density and sound velocity) where it is reflected as a rarefaction pulse. The reflected tensile stresses may produce widely open tensile fractures and may lead to the detachment of a spall or series of spalls.

Here, in addition to Fig. 25, we show a cobble from the rim of the Tüttensee crater exhibiting a prominent spallation fracture strongly reminding of the experimentally shocked ARMCO iron in Fig. 26.

More about impact spallation can be read here:

http://www.impact-structures.com/Archiv/archiv.html (Impact spallation in nature and experiment)

and here:

http://www.impact-structures.com/spain/shocked/spallation.htm .

[2]

Several of the larger craters in the Chiemgau strewnfield, e.g. the Tüttensee crater, are commonly interpreted as dead-ice moraines. Dead-ice depressions originate from the melting of buried glaciers involving the sinking of moraine material and, in general, do not exhibit a ringed wall. In rare cases, dead-ice depressions may be surrounded by hilly moraines arranged to roughly form a ring pattern. The pattern is usually explained by differential melting rates in the center and in the periphery of the buried glacier.

The wall around the lake Tüttensee crater is to a large extent composed of heavily fractured and deformed clasts (see Figs. 19 - 23) typical of impact ejecta and not at all compatible with a ring formation of a dead-ice depression.

[3]

A short description of each of the crater strewnfields is given by P. Hodge:

Hodge, P. (1994): Meteor craters and impact structures. Cambridge University Press, 124 pp.

More information can be found here:

Kaalijarvi:

http://gisp.gi.alaska.edu/craterbase/kaalijarvi.htm

Morasko:

http://gisp.gi.alaska.edu/craterbase/morasko.htm

http://www.inyourpocket.com/poland/poznan/en/feature?id=55559

Sikhote Alin:

http://www.alaska.net/~meteor/SAinfo.htm

Henbury:

http://www.marssociety.org.au/jnt-db/Australia-NT_S-Henbury.html

Campo del Cielo:

http://gisp.gi.alaska.edu/craterbase/campo.htm

http://www.fcaglp.unlp.edu.ar/~sixto/arqueo/w-6-ing.htm - an article on: Meteorites of Campo del Cielo: Impact on the indian culture

Wabar:

http://volcanoes.usgs.gov/jwynn/3wabar.html

http://www.saudiaramcoworld.com/issue/198606/the.wabar.meteorite.htm

Gibeon:

http://www.alaska.net/~meteor/GNinfo.htm

[4]

In the Ries impact structure (Nördlinger Ries), Bavaria's "big" meteorite crater, deformations like rotated fractures and bread-cut-to-slices features are abundantly exhibited by clasts from the Bunte breccia ejecta.

Characteristically deformed clasts from the ejecta of the Ries impact structure.

For comparison: Characteristically deformed clasts from the Puerto Mínguez impact ejecta (Spain) and from the rim of the Tüttensee crater (to the right).

The clasts shown here have in common that they were embedded in a soft matrix excluding a long-lasting, e.g. tectonic, deformation process. Instead, the deformations are considered diagnostic of short-term impact deformation under high confining pressure.

A more comprehensive discussion of these high-pressure/short-term impact deformations is found also here:

http://www.impact-structures.com/spain/ptominguez.htm

[5]

Comparison of the grit brecciation shown in Fig. 18 with a similar monomictic movement breccia from the Ries impact structure (Nördlinger Ries):

Ries impact structure

Chiemgau crater

Monomictic movement breccias are well-known to be exposed in and around impact structures. They may be related with giant rock falls and may in rare instances occur along tectonic fault zones. The observation of this grit brecciation in the Chiemgau craters is a strong clue to their impact nature. Evidently, an origin from Alpidic tectonics and a subsequent transport of the heavily fragmented clast can be excluded.

More about monomictic movement breccias can be read here:
http://www.impact-structures.com/breccia/monomictic.htm

[6]

For each crater a data sheet has been drawn up including location (village/town, field-name, field and/or topographic map, satellite imagery and/or aerial photograph, ground photograph, GPS coordinates), size, phenomenology, underground properties, geology, and special features (degree of destruction, possible risk of destruction, etc).

[7]

Industrial titanium carbide (TiC) is usually produced from a mixture of titanium dioxide and carbon in an induction heater: $TiO_2 + 3\ C = TiC + 2\ CO$ (Weiland 1996). Since 1995, there is an additional process (IMTA, US Pat No. 5,417,952) that starts at TiO_2 and C_3H_6.

[8]

Metallurgical studies of the properties of aluminium silicides (Al_XSi_Y) und their industrial production have been performed in the last 20 - 30 years (Ejefor & Reddy 1997). There are hypoeutectic, eutectic and hypereutectic Al-Si systems (T_{eu} = 577°C). As a rule, elements like Cu, Mg, Fe, Ni, Zn, and others are added in order to achieve the desirable material properties. Among the metallic matter from the Chiemgau strewnfield, a small piece of Al_XSi_Y , probably corresponding with $AlSi_2$ or $AlSi_3$ of a hypereutectic Al-Si system, has been analyzed to yield no other elements oxygen included. Because of the purity of the Al-Si compound an origin from industrial production is highly improbable.

[9]

Ferrosilicides (FeSi, Fe_2Si [hapkeite], and $FeSi_2$) as new minerals have been detected in the lunar Dhofar 280 meteorite (Dh-280; Dhofar region, Oman, April 2001) (Anand et al. 2002, 2003). At grain sizes of 2-30 µm, they are embedded in a regolith breccia. More than 95 % of the rock is composed of Fe (66 %) and Si (31 %) with subordinate amounts of Ni (1 %), P and Cr. But enrichments of Ti (4.6 %) and P (15 %) have also been observed. The Fe-Si phases in Dh-280 are in proof of extremely reducing conditions on the Moon or on a planetoid. It is assumed that the reducing conditions are related with extremely high temperatures like in the process of formation of Fe-Si phases in fulgurite glass.

A mineral with a structure very similar to gupeiite - suessite, $(Fe, Ni)_3Si$ - is extremely rare in the North Haig ureilite type meteorite (Sleeper Camp, Australia, 30°26' S| 126° 13' E) (Keil et al. 1982) and NWA 1241 (Libya, 27° N| 16° E).

Gupeiite (Fe_3Si) itself is contained in the FRO 90036 meteorite found in the Frontier Mountains (Antarctica, 72°59'27'' | 160°20'72'' E) (Wlotzka 1994).

[10]

The Yanshan meteorite having gupeite and xifengite as the main constituents is an individual find. The meteorite contains quite a few small iron spherules (0.1 - 0.5 mm diameter) composed of two or three shells of different phases. The inner shell is composed of Ni-Fe metal (kamacite and taenite) and the outermost shell of magnetite, wuestite and maghemite. On average, the analyses yield 84.8 % Fe, 0.8 % Ni, 14.1 % Si, 0.7 % Mn and traces of Cr, Cu, and Co. The low Ni content is striking. The core of the spherules predominantly contains cubic gupeiite (Fe_3Si) and hexagonal xifengite (Fe_5Si_3) (Yu Zuxiang 1984). The spherules show wrinkled and scaly surfaces and aerodynamically shaped splash forms pointing to an extraterrestrial origin (Anthony et al. 1986). It is interesting to note that hongquiite, originally though to be TiO but now shown to be in fact TiC, is found to occur together with gupeiite in the core of the spherules (American Mineralogist 1986).

[11]

Glass-coated pebbles, cobbles and boulders can meanwhile be said to belong to the regular inventory of the impact strewnfield. They may be associated with craters but can also be sampled in the open field. In one case, a small glass-coated sandstone pebble was found to have been dug out by a mole. Below we show different aspects of the "glass stones".

A 10 kg glass-coated sandstone boulder found in the field near Vachendorf, 2.3 km southeast of the Tüttensee crater (southern part of the strewnfield).

Close-up of the glazed surface of the 10 kg boulder.

Broken glass-coated sandstone cobble found near Emmerting village (northern part of the strewnfield).

Glass is also filling the open fissures within the broken cobble and occurs along the bedding planes (the dark veins). Note the distinct fitting (arrows) along the sharp-edged fissures proving tensile (?spallation) fracturing.

Glass-coated sandstone pebble from a molehill.

Brownish glass coating a sandstone cobble.