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A Prominent Iron Silicides Strewn Field and Its Relation to the Bronze Age/Iron Age Chiemgau Meteorite Impact Event (Germany)

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Abstract: About 20 years ago, amateur archeologists and local history researchers discovered the iron silicide (FESI) strewn field measuring about 60 km x 30 km in the districts of the Chiemgau and the Inn-Salzach region in southeast Germany. They evidenced the connection between the FESi distribution and the pervasive rim wall craters and suggested a meteorite impact event, now widely recognized under the name of the Chiemgau impact. Widespread in the strewn field and in individual finds far beyond it they recovered and documented thousands of FESI particles of millimeter to centimeter size with a total mass of more than 2 kg, whereby a large lump of 8 kg stands out as a single find. The find layer is largely uniformly located at a depth of 30 - 40 cm in a glacial loose sediment soil. Microprobe, SEM-EDS, TEM and EBSD analyses determined as main minerals gupeiite and xifengite, subordinately hapkeite, naquite and linzhite. Besides the main elements Fe and Si of the matrix, more than 30 other chemical elements have been addressed so far, including uranium and various REE. Incorporated into the FESI matrix are the carbide minerals moissanite and titanium carbide as superpure crystals, and khamrabaevite, zirconium carbide, and uranium carbide, furthermore CAIs. SEM images indicate shock metamorphism. The present article describes the discovery history of this worldwide unique FESI occurrence with the exact find situations, as well as the very varied morphologies of the find particles with the macroscopically recognizable components and SEM EDS examples.

Keywords: Iron Silicides, Gupeiite, Xifengite, Hapkeite, Meteorites, Chiemgau Meteorite Impact Event, Germany

1. Introduction

The crater strewn field of the "Chiemgau Impact" shows a large meteorite impact in the southeast Bavarian foothills of the Alps [1-3], is dated to the Bronze Age/Celtic era (900-600 B. C. [4]) and comprises more than 100 mostly rimmed craters scattered in a region of about 60 km length and ca. 30 km width (Figure 1). They were determined, surveyed, mapped, and continuously subjected to geological mineralogical, petrographic, geomorphological, and geophysical investigations of varying intensity by means of site surveys, the study of aerial photographs and historical maps as well as the Digital Terrain Model (LIDAR) [5]. The crater diameters range between a few meters and several hundred meters. A doublet impact at the bottom of Lake Chiemsee is considered to have triggered a giant tsunami evident in widespread tsunami deposits around the lake [6], and a 1.3 km-diameter crater has recently been evidenced [7]. Geologically, the craters occur in Pleistocene moraine and fluvio-glacial sediments. The craters and surrounding areas are featuring heavy deformations of the Quaternary cobbles and boulders, impact melt rocks and various glasses, strong shock-metamorphic effects, and geophysical (gravity, geomagnetic, sediment echo sounder, ground penetrating radar) anomalies. Impact ejecta deposits in a catastrophic mixture contain polymictic breccias, shocked rocks, melt rocks and artifacts from Stone Age and Bronze Age/Celtic era people [8]. The impact is substantiated by the abundant occurrence of metallic, glass and carbonaceous spherules, accretionary lapilli, microtektites [9], and of accompanying epiphenomena, e.g., acid effects, widespread rock liquefaction [10], and a new kind of carbon impactite containing diamonds and carbines [11]. The cosmic body that caused the catastrophe in the Chiemgau region was probably a rather porous object consisting of various components that broke apart in the atmosphere [2].

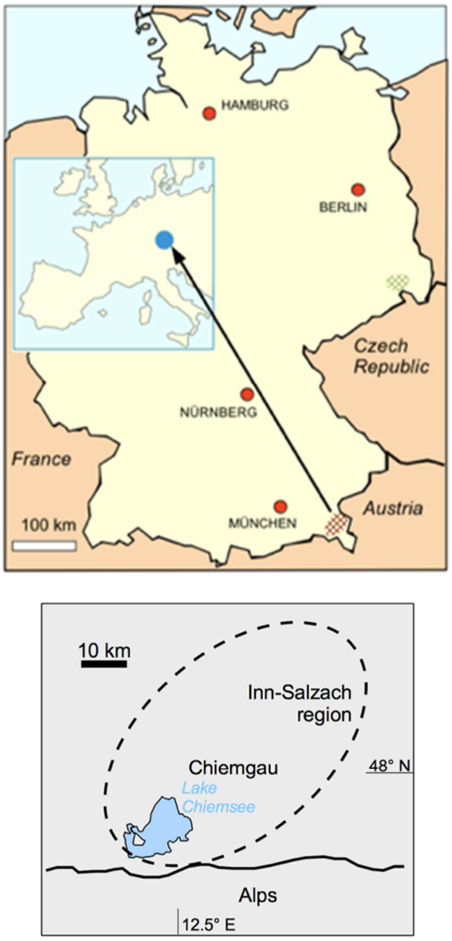


Figure 1. *Location map for the Chiemgau impact crater elliptical strewn field and iron silicide concentrations according to current (2022) documentation.*

The discovery of the crater strewn field some 20 years ago by a team of local history researchers and amateur archeologists was, apart from the large number of craters, essentially the unearthing of unknown, sometimes clustered metallic particles in the soil that appeared to be widely associated with the craters and were quickly revealed to be iron silicide minerals gupeiite and xifengite virtually absent on Earth. These findings marked the beginning of research on the Chiemgau impact [12-15], and over the years and, in the course of comprehensive analyses, have increasingly turned out to be more than one of the keys to events.

This article reports on the very eventful history of the discovery and study of the iron silicides, unique in the world in this massing [16], which had to fight against many adversities, but ultimately led to the present state of research with compelling features of a new class of iron silicide meteorites.

For simplicity, we will use the abbreviation FESI for the term iron silicide(s) in the following where it seems appropriate.

2. Materials and Methods

The discoverers, convinced after the finding situations of an extraterrestrial origin of the iron silicides, continued their systematic terrain investigation also in the following time and extended random sampling far beyond the elliptical scattering field into France and the Czech Republic (see 3. Results). In addition to the finds of the local researchers, contributions came from the population, which had become aware of the peculiar material through lectures and publications. The extensive mineralogical-petrographic-geochemical investigation of the impact-associated materials was accompanied in particular by a thorough analysis of the iron silicides with optical microscopy, SEM, TEM and EBSD at the institutes of Oxford Instruments and Zeiss [17, 18].

3. Results

3.1. Find Situations - Regional and Local

Figure 2 shows the maps of the areas where the local researchers have extended their search for iron silicides. In France they did not find anything at five test sites, and towards the east there was a rare find near the city of Ansbach, which continued on a line to a certain accumulation near the city of Regensburg and then to the crater strewn field of the Chiemgau impact. In the crater strewn field itself the iron silicides are consistently well detectable. Three test sites beyond the Czech border also yielded iron silicide accumulations in the already known soil depth with particle sizes up to 2 mm after a short time.

Given the size of the field in which the iron silicides occur (Figure 4), it is understood that there is no area-wide sampling of the subsurface and different criteria of selection were used. From the beginning, a major criterion was based on the observation of the local researchers that iron silicides were increasingly concentrated near the approximately 80 craters initially documented, which originally gave rise to the assumption of a common origin in a meteoritic impact event in the first place. Confronted with an initial rejection of a meteoritic origin and declaration of the finds as pseudometeorites and originating from industry, the local researchers spent a lot of time on careful sampling at selected sites, which in many cases made such an explanation absurd. Apart from the very special find situation in the deep soil as shown in Figure 5, iron silicides were found directly under a medieval silver hoard, which the amateur archeologists had initially recovered after their metal detector signal, under the wall remains of the medieval castle of the town of Burghausen, under the roots of ancient trees in the so-called 1000-year-old forests near Burghausen, in meadowlands at the height of the first Alpine foothills and fished from bog waters. The "red layer" in Figure 5 is significant for several find situations, which excluded a human deposition, in so far as the main mass of the iron silicide particles was covered by this extremely compacted layer, which had a hardness comparable to clinker and could only be scratched by the plow on the field. An explanation sees an extreme airburst frying of the uppermost loamy layer in the context of the impact event.

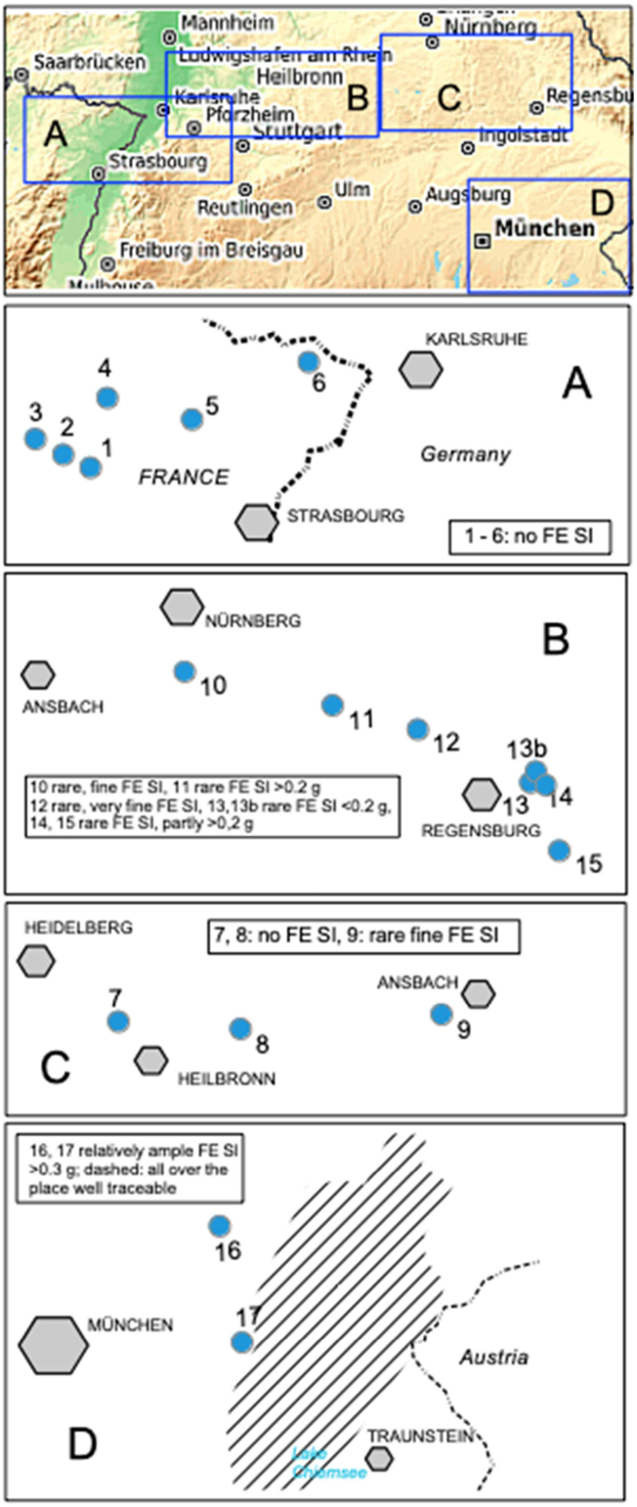


Figure 2. Site plans for the local historians' search areas on iron silicides.

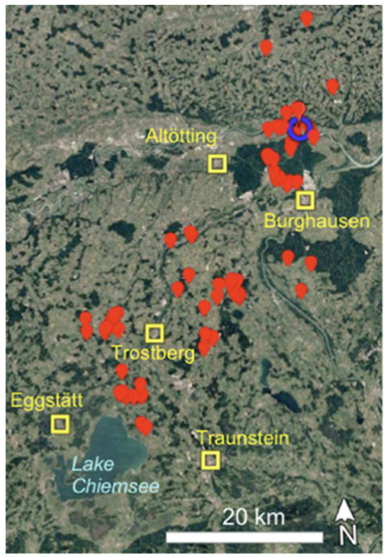


Figure 3. *Site plan (Google Earth) for the main FESI concentrations. Blue circle: Find of the most prominent FESI accumulation. Also see Figures 4 and 5.*

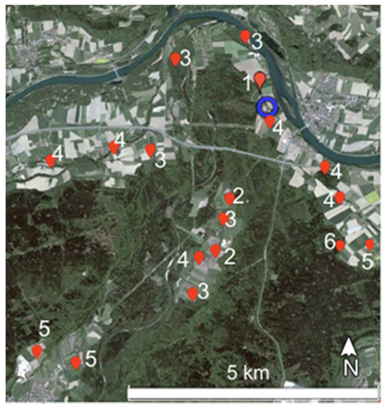


Figure 4. *Selected section of the map in Figure 3 with a (subjective) classification of the importance of the sites from 1 = faint to 6 = excellent.*

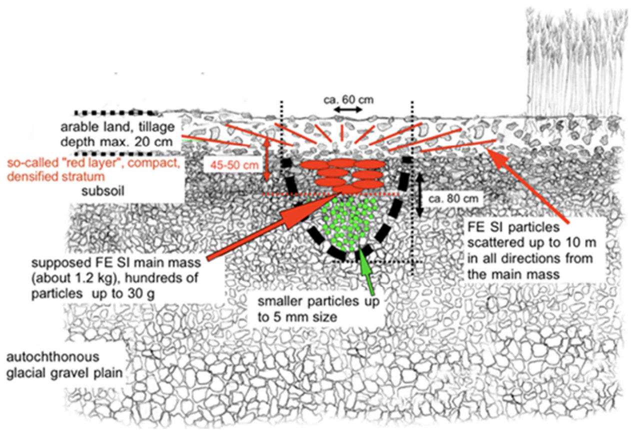


Figure 5. *Finding sketch showing the main parameters of the most significant FESI enrichment to date, marked with the blue circle in Figures 4 and 5. This find (#4) includes some 1000 particles up to 2 mm in size and some 100 up to several centimeters maximum with a total weight of 2,100 g. Green particles up to 0.5 cm in size, red particles up to 5 cm in size.*

Farmers were likewise helpful when they used tractors to pull off the topsoil layers of the field and expose iron silicide particles in larger craters, e.g., the 50 m-diameter Aiching semi crater at the valley edge of the Inn River [7]. The strong magnetism of the particles was also helpful in excavation by a powerful magnet.

3.2. The Chiemgau Impact Iron Silicides – Sizes and Shapes

The total yield of several 1000 iron silicide particles recovered by the local researchers is over 2 kg, including the smallest particles of less than 0.2 g. The surfaces show metallic luster and lack practically any corrosion. They often occur in aerodynamically shaped forms such as spheres, buttons and drops, but also as splinters and pieces, up to a chunk weighing 8 kg.

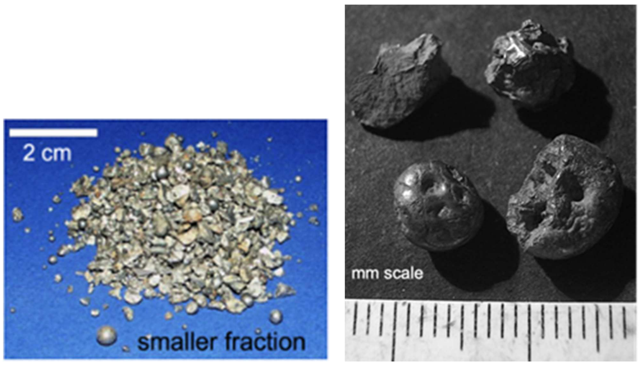


Figure 6. *The smaller fraction of the iron silicides from the Chiemgau impact strewn field. In addition to a large number of splintered particles, perfect spherules also appear.*

Figure 7. *Left: Aerodynamically shaped FE SI particles in splash form. Right: FESI particle with regmaglyptic surface reminding of ablation structures of meteorites.*

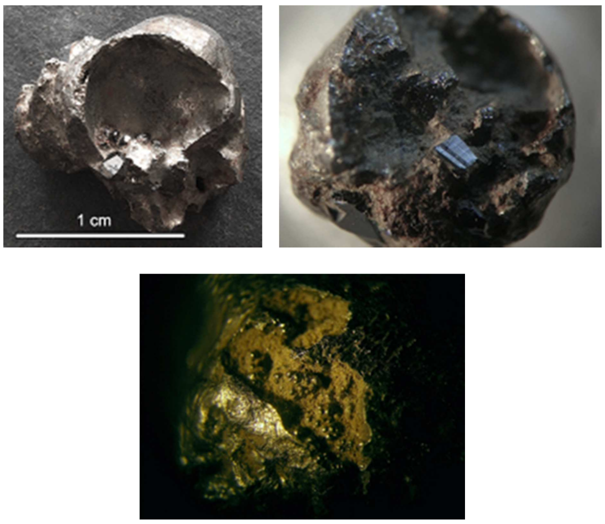


Figure 8. *Iron silicide particles with attached mineral crystals (upper) Lower: Iron silicide with attached micro-spherulitic particles. Specimen size 8 mm.*

Figure 9. *The 8 kg iron silicide chunk from the Chiemgau impact strewn field.*

The 8 kg lump was excavated about 30 years ago during excavation works near the municipality of Grabenstätt at Lake Chiemsee, was forgotten by the family of the finder as a strange object and was given to the impact researchers for investigation, after the relationship to iron silicides, which became known in the meantime, was suspected. The FESI composition was quickly confirmed with the detection of the minerals xifengite, gupeiite and hapkeite and other exotic components.

So far not further investigated are finds that were described by the original discoverers as a combi-material containing iron particles and FESI particles as platelets and spherules in a porous matrix of the elements Ca, Fe, subordinate Si and Al (Figure 10). Also not yet further investigated are limestone cobbles with externally visible FESI inclusions (Figure 10).

Accretionary lapilli (Figure 11) can easily be extracted from a loose soil with a strong magnet because of their magnetic FESI content.

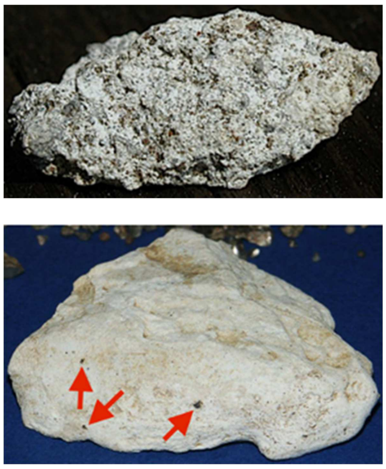


Figure 10. *Upper: The so-called combi-material of the early investigations containing FESI platelets and spherules. Lower: A limestone block with inclusions of tiny FESI particles (arrows).*

Figure 11. *Accretionary lapilli from the Chiemgau impact strewn field and a cut lapillus with a core of iron silicide.*

3.3. Iron Silicide Particles Under the SEM

In fact, the aspects shown here (Figures 12, 13) are giving only a strongly limited insight into the immense diversity of textures and components of the sampled iron silicides.

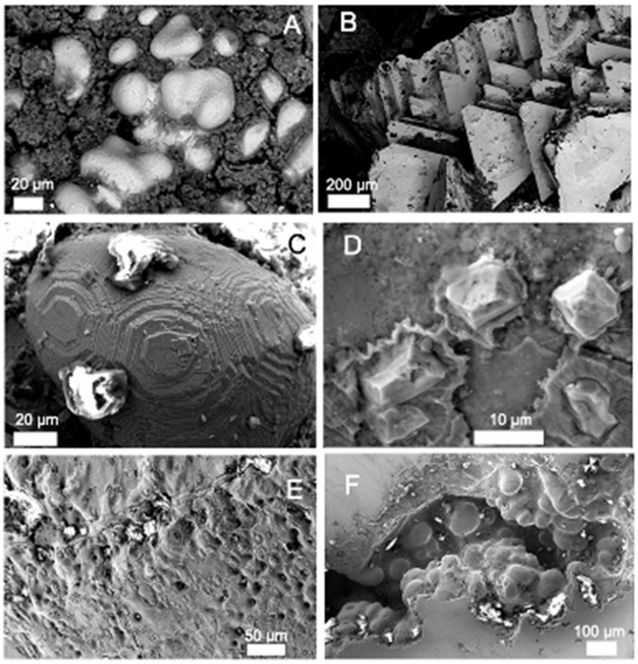


Figure 12. *Selected SEM images of multi-variant features of FESI particles. A, B: Amoebae-like and pyramidal-shaped iron silicides in widely unstructured FESI. C: Spheroidal FESI particle with strange crystal form. D: Zircon crystals obviously having impacted a plastic or liquid FESI matrix that seems to have been frozen during the disturbance. E: Micro-impacts into a plastically deformed matrix. F: FESI possibly with beginning (and then stopped) secession of spheroidal melt particles.*

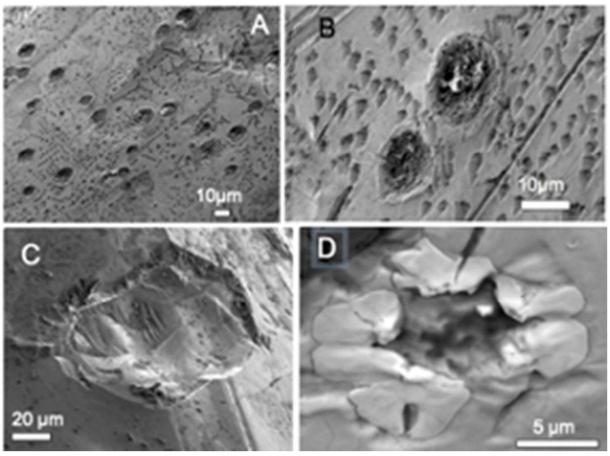


Figure 13. *A, B: The occurrence of the many micrometer-sized rimmed craters on the surface of an iron silicide particle may point to a highly energetic cosmic bombardment, and the supposed open imprints of lost zircon crystals could possibly be witness of a shock collision in space. C: A tiny impact spallation crater in a brittle FESI surface. D: An impact micro-crater in a softer FESI target.*

3.4. The Iron Silicides Mineral Assemblage in the Chiemgau Impact Strewn Field

The unusual metallic finds associated by local researchers with documentation of the initial 80 or so craters were quickly recognized as iron silicides with the minerals gupeiite (Fe_3Si) and xifengite (Fe_5Si_3) [12] (Figures 14-16). Later detailed analyses of various FESI samples added naquite (FeSi), linzhite ($FeSi_2$), and hapkeite polymorphs (Fe_2Si) (Figure 17, Figure 18). In particular, hapkeite was given special attention [19] after it was first detected on Earth in the lunar meteorite Dhofar 280 [20, 21]. From the SEM, TEM and EBSD investigations the existence of the iron silicide Fe_2Si, mineral hapkeite became evident as a very important mineral contributing to the Chiemgau iron silicides.

Like the hapkeite, the gupeiite also shows a relationship to meteoritic minerals, which is shown by the comparison with the composition of the suessite in two meteorites (Figure 19).

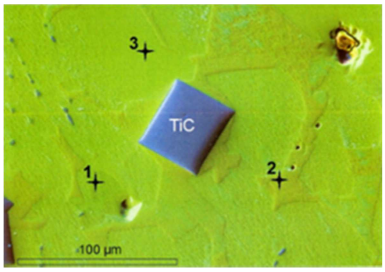


Figure 14. *Titanium carbide (TiC) crystal in a matrix of iron silicides; 1: FeSi (naquite), 2: Fe_3Si (gupeiite), 3: Fe_5Si_3 (xifengite). For TiC see 3.4.2.*

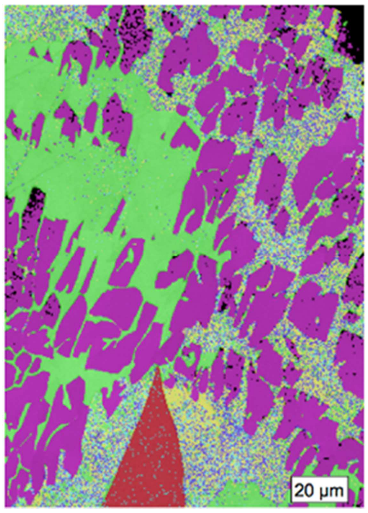


Figure 15. *EBSD image of a FESI minerals assemblage; red = fersilicite (naquite, FeSi), green = ferdisilicite (Linzhite $FeSi_2$), yellow = gupeiite, magenta = xifengite as the principal phases in an iron silicide matrix.*

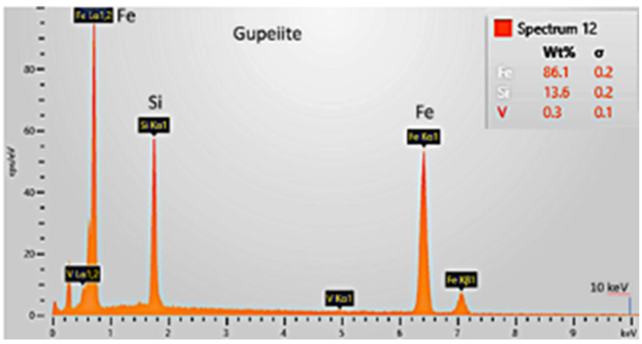


Figure 16. *EDS spectrum of gupeiite in a FESI particle.*

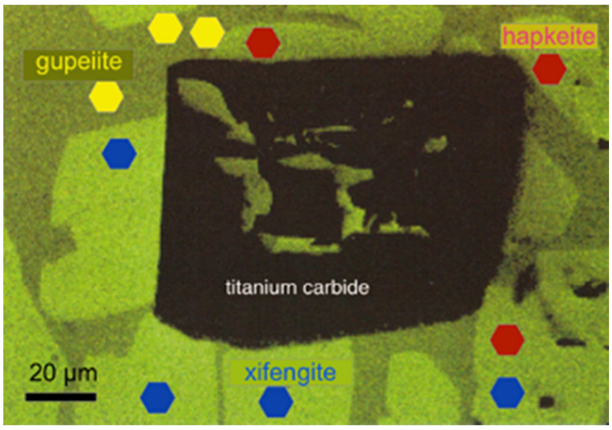


Figure 17. *Hapkeite in FESI mineral assemblages. The hapkeite shows intergrown with gupeiite and xifengite to form the iron silicide matrix that is hosting a titanium carbide (TiC) crystal.*

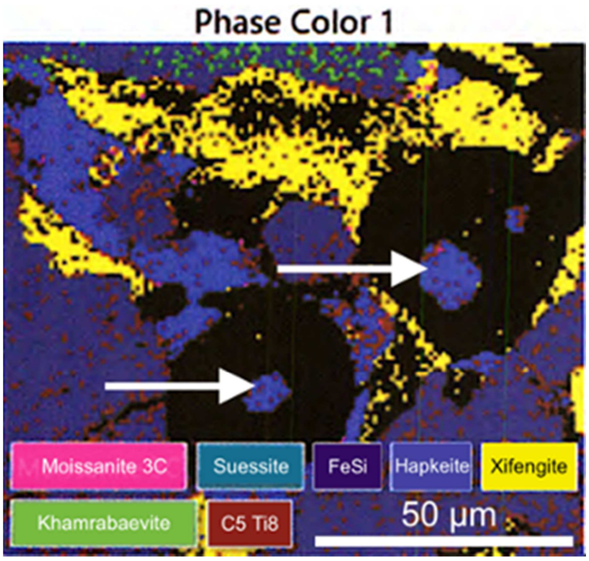


Figure 18. *The hapkeite phase is also clearly documented (arrows) and in part appears like the yolk of fried eggs within a so far unidentified calcium silicate phase, possibly a wollastonite polymorph. In the literature two hapkeite polymorphs, a cubic and a trigonal modification, have been reported [18], and here the trigonal polymorph (S. G. P3m1, No. 164 [22, 23]) has been established. - Suessite is represented by only few counts.*

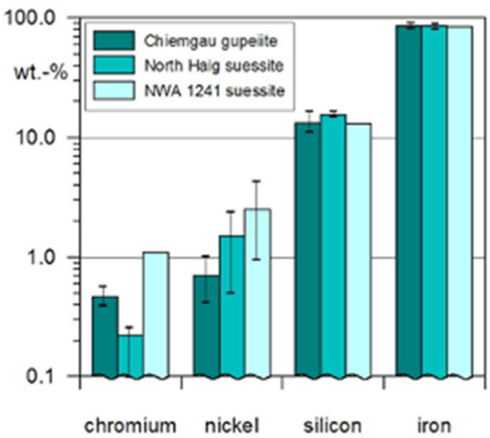


Figure 19. *A gupeiite particle from the Chiemgau impact strewn field with very similar composition as the suessite of the meteorites North Haig and NWA 1241. Data from [24].*

3.5. The Chiemgau Impact Iron Silicides – Companion Minerals and Elements

3.5.1. Special Elements

More than 30 chemical elements have been detected so far with the EDS in iron silicide samples from the Chiemgau impact strewn field. They include the REE yttrium, lanthanum, cerium, praseodymium, neodymium, gadolinium and ytterbium, but only few nickel (also see Figure 19). Some more elements that increase the total number to about 40 elements are statistically less reliable. Uranium is fairly common frequently associated with zirconium and cerium/neodymium (Figure 20).

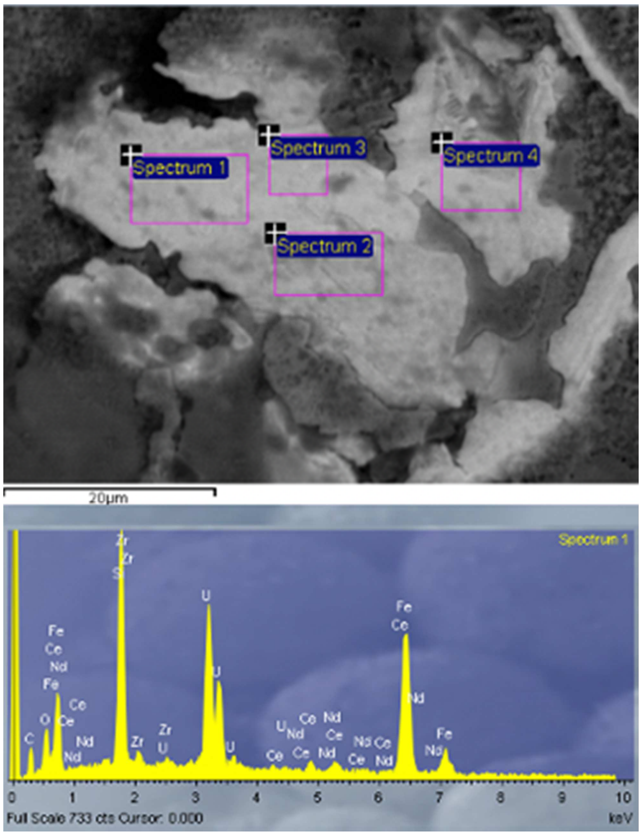
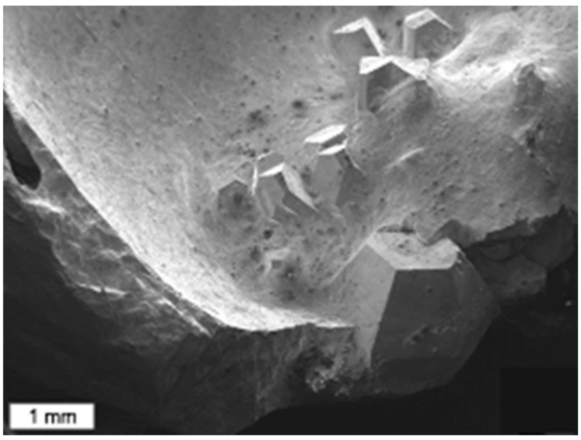


Figure 20. *Significant uranium in a FESI particle with some REE. The oxygen peak cannot be assigned for now; the carbon peak may belong with the uranium and zirconium to Zr and C carbides, which are discussed in 3.6.2.*



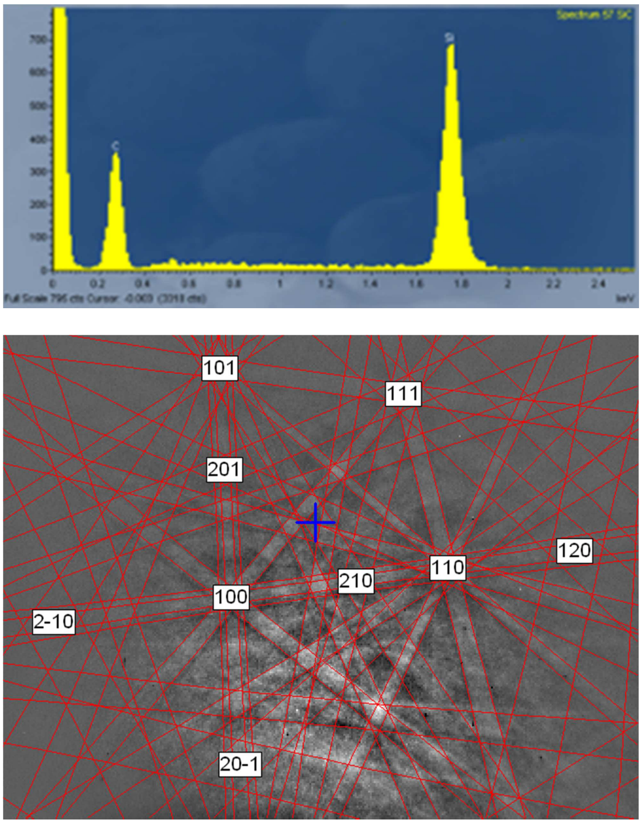


Figure 21. *Upper: SEM image of the moissanite crystals in Figure 8 (upper left) sticking out from the FE SI matrix. Middle: EDS spectrum of moissanite SiC in a FESI particle. The extreme purity is evident. Lower: Electron back scatter diffraction of cubic moissanite from the Chiemgau strewn field. Images: Carl Zeiss Microscopy and Oxford Instruments.*

The occasion for discussion is the observation that no uranium decay products including lead exist except for two EDS spectra showing traces of thorium and questionable polonium, respectively. The complete lack of lead in a very large number of EDS spectra is surprising and must be investigated further.

3.5.2. Carbides Moissanite, Titanium Carbide, Khamrabaevite, Zirconium Carbide, Uranium Carbide

A significant feature of all analyzed iron silicide particles is their content of titanium carbides and silicon carbides. They occur as extremely pure crystals (Figure 14, Figure 21) and more finely dispersed in the matrix (Figures 14, 22, 23). The SiC has been analyzed to be the cubic moissanite mineral – (b) 3C-SiC. Natural moissanite is extremely rare and is found only in few upper mantle rocks (e.g., kimberlites) and in meteorites. Thereby the cubic polymorph is again much rarer in comparison to the most cited hexagonal form.

The titanium carbide in general occurs as the (Ti, V, Fe) C mineral khamrabaevite (Figure 18, Figure 24), and also the off-stoichiometric form of TiC0.63 has been shown to exist (C5 Ti8, Figure 18). The crystals are abundant in FESI particles and can in some cases be identified in the field when they stick out from the FESI matrix (Figure 22). In SEM images they may occur as single individuum, joining moissanite crystals, or closely packed (Figure 23).

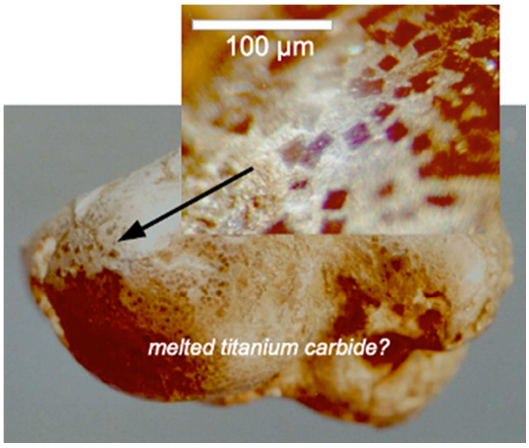


Figure 22. *FESI particle with titanium carbide TiC sticking out from the matrix - The melting temperature of TiC is 2,890 K. Modified from [12].*

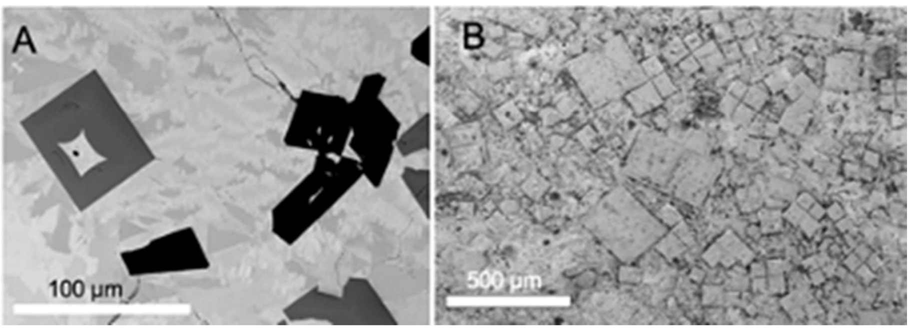


Figure 23. *SEM images: Various aspects of titanium carbide/khamrabaevite crystals in FESI matrix. To the left (grayish) in companion with moissanite (black); to the right closely packed.*

In a recent analysis of the 8 kg FESI boulder [18] zirconium and uranium carbides have been identified to add to the titanium and silicon carbides (Figures 25, 26).

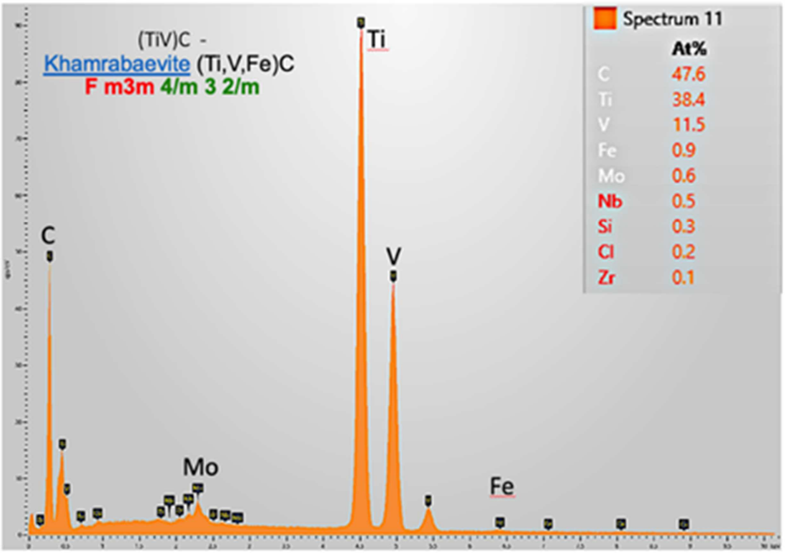


Figure 24. EDS spectrum of khamrabaevite in the 8 kg FESI block (Figure 12).

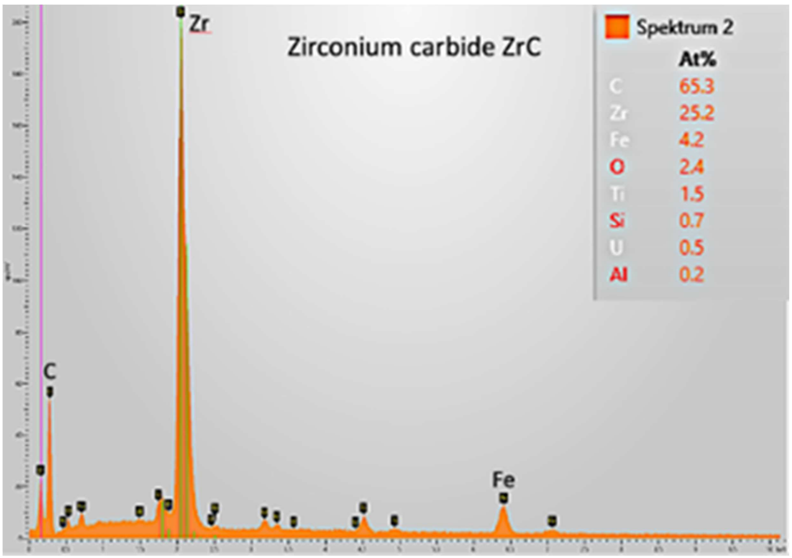


Figure 25. EDS spectrum of zirconium carbide in the 8 kg FESI boulder.

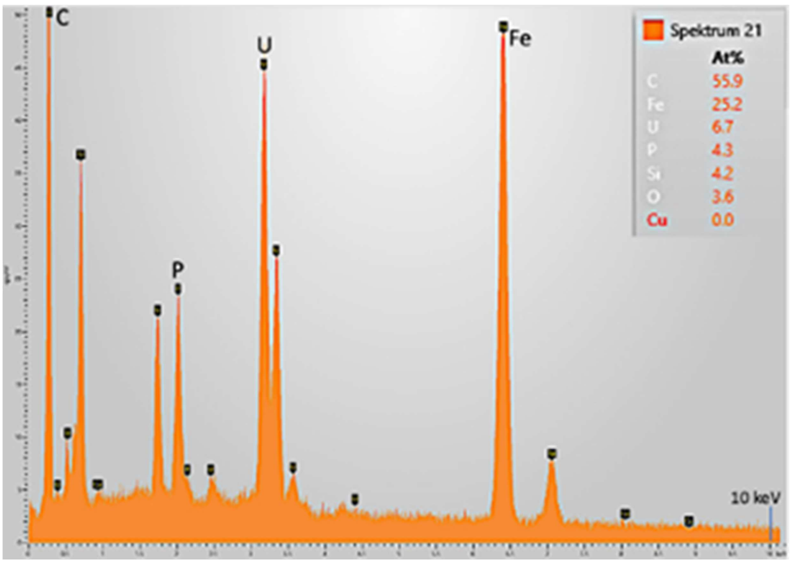


Figure 26. EDS spectrum of uranium carbide in the 8 kg FESI boulder. Phosphorus and iron as putative carbides may add to the carbide family.

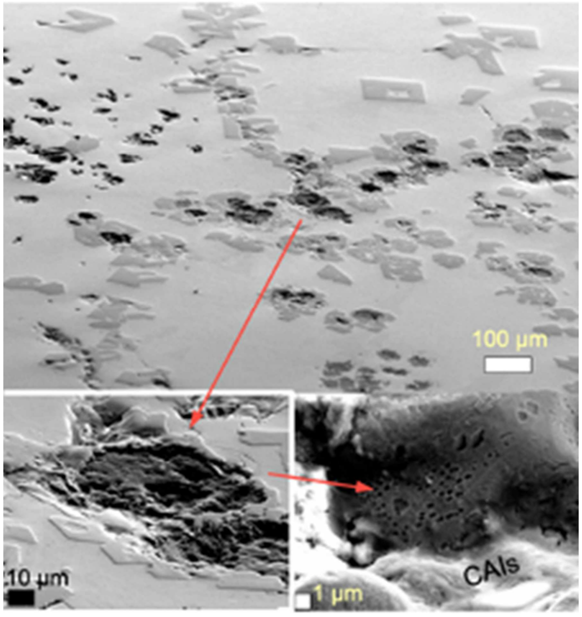


Figure 27. *Iron silicide matrix (light gray) with inclusions of titanium carbide TiC/khamrabaevite (Ti, V, Fe) C and moissanite SiC (dark gray), and black spots of C (graphite, amorphous carbon?) film and light edging CAIs.*

3.5.3. CAIs – Calcium Aluminum Inclusions

Recent analyses [17] have shown that the iron silicides from the Chiemgau impact strewn field contain CAIs with minerals $CaAl_2O_4$, calcium monoaluminate, and $Ca_2Al_2O_5$, dicalcium dialuminate (Figure 27). The monoclinic high-temperature (>1,500°C), low-pressure dimorph of $CaAl_2O_4$, mineral krotite, was first identified in a CAI from the CH chondrite NWA 470 [25] and later reported [26, 27] to exist in a CAI in the carbonaceous chondrite meteorite NWA 1934.

3.5.4. Zircon, Baddeleyite

The mineral zircon $ZrSO_4$ is a common constituent in the iron silicides of the impact strewn field (Figures 28-30) and can be identified in many cases based on the crystal shape in the SEM-EDS images. If only the element zirconium appears in the spectrum, other minerals with other elemental compounds are also possible, for which further investigations are currently underway. So far zirconium carbide ZrC (3.6.2) has been identified. Baddeleyite ZrO_2 would be a candidate, especially since the mineral is described as a widespread and sensitive indicator of meteoritic bombardment in planetary crusts [28]. Significantly, Zr occurs in FESI particles mostly in combination with uranium, which is known to be used for radiometric dating via the U-Th-Pb decay series of the oldest zircon-bearing rocks. The zircon-uranium combination here differs because the decay products thorium and lead surprisingly do not occur in the EDS spectra (see below). As mentioned above, uranium carbide has been identified as companion mineral of zirconium carbide (Figures 25, 26).

Zircon crystals are also conspicuous in the FESI in the SEM image, in which they have apparently impacted a strongly plastic or just melted FESI matrix (Figure 12 D), whereby the motion of the crater formation appears abruptly frozen. When and where this almost curious process took place remains unanswered, but a shock effect like freezing of water under shock wave compression [29] or generally phase changes in fluids exposed to shock (e.g., [30]) may be discussed (also see below).

Figure 29 points to exsolution lamellae of zirconium (zircon or/and baddeleyite) in FESI. More intergrowth of fan-like and wormy shape of zircon/baddeleyite in FESI are frequently observed (Figure 30].

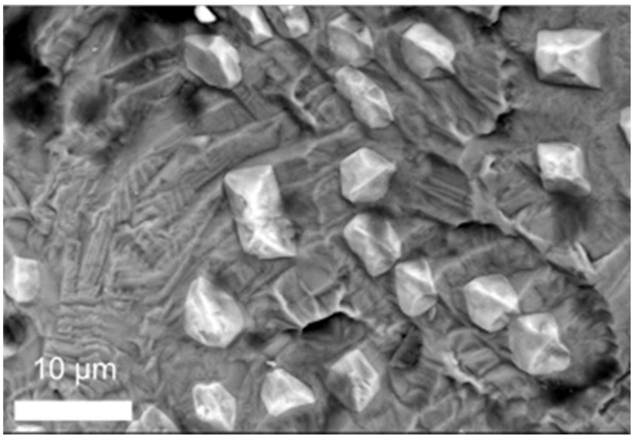


Figure 28. *Zircon or baddeleyite crystals in peculiarly textured iron silicide matrix.*

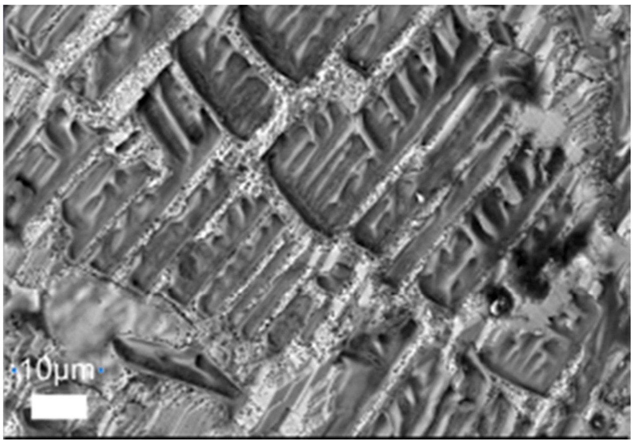


Figure 29. *Zirconium (zircon or/and baddeleyite) exsolution features in iron silicide.*

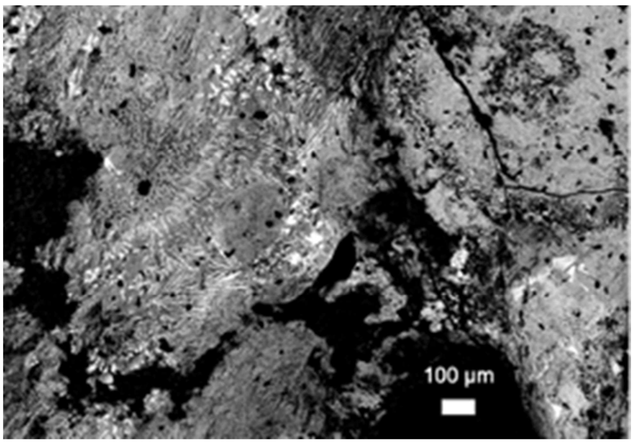


Figure 30. *Intergrowth of fan-like and wormy shape of zircon/baddeleyite in FESI.*

3.6. Evidence of Shock Effects

Figure 31. *Micro-breccia of fractured TiC and SiC components.*

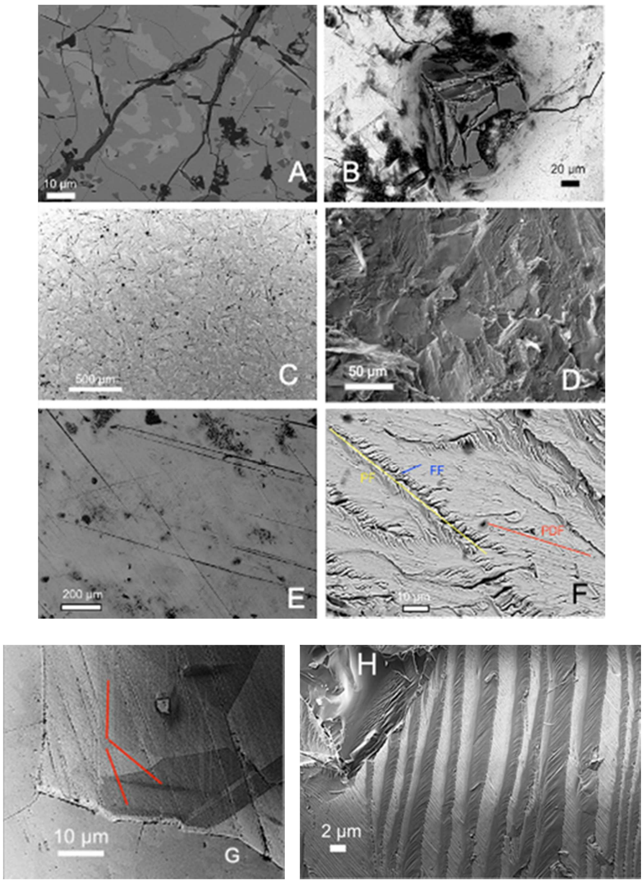


Figure 32. *Probable shock features in moissanite from the Chiemgau impact strewn field seen in SEM. A: Open fractures in irregular patterns. B: Strongly fractures TiC crystal. The open fissures point to tensile deformation, which is best explained by shock spallation. C: Multiple sets of sub-planar open fractures, which may also point to shock comparable to planar shock fractures (PF) in quartz. D: SiC fracture exhibits multiple sets of closely spaced (on the order of 1µm) planar de-formation features. E: On the polished SiC plane the SEM accentuates the great similarity with the well-known planar deformation features (PDFs) in silicate rocks as indicative of shock metamorphism. F: Only recently suggested as a shock effect in quartz: Possibly similar feather features FE (or feather lamellae) in SiC (see text) bordering planar fractures PF. A suggested shock inventory like in quartz is complemented by planar deformation features PDF. G: Stronger magnification of three sets of PDFs in a moissanite crystal with spacing down to less than 1 µm. H: Closely spaced kink bands in a moissanite crystal. All kink bands show distinct PDFs with spacing down to 200 nm.*

FESI particles from the Chiemgau strewn field show in general a strong mechanical overprint, which may be attributed to brecciation (Figure 31), thermal shock, shock pressure or dynamic shock spallation (Figure 32). Irregular cracks (Figure 32 A) remind of similar cracks and shock veins in meteorites. Open cracks in the FESI matrix and in mineral crystals (Figure 32 A, B) point to tensile deformation, which is best ascribed to dynamic shock spallation. Multiple sets of subplanar open fractures (Figure 32 C) may be crystallographically oriented and a shock effect like in shocked quartz.

Previously unknown, but in many ways very similar to the shock behavior of quartz, is the observation of planar deformation features (PDFs) in moissanite, of which Figure 32 D-H show examples in various constellation. The absolute similarity to multiple sets of PDFs in quartz is striking, as is the spacing and width of the elements down to 1 µm and less. Another remarkable similarity to shocked quartz is shown in Figure 32 F, which has become known as feather structures or feather lamellae [31]. Feather structures, as marked in Figure 32 for a moissanite, are attributed to low shock pressures in shocked quartz, are crystallographically oriented at the same spacings as the PDFs and are always observed in association with a planar fracture. This exactly can be seen in Figure 32 F, not to forget the simultaneously well-formed PDFs in the same section. The extent to which a comparable formation mechanism of the feather structures exists in quartz and moissanite is left to further investigation. Kink bands in silicate and carbonate rocks are likewise well known as shock effects and find here a nice counterpart in combination with densely spaced PDFs (Figure 32 H).

4. Discussion

Iron silicide minerals are best known from industry as the iron monosilicide FeSi, which is used, among other things, to produce various alloys. Iron silicides in nature are very rare, little known, and have only become accessible to science in the last few decades. At the same time, much (origin, formation) is still unclear. The reason for the rare occurrence of iron silicide minerals on Earth is the formation conditions, which require extreme temperatures and an extremely reducing environment, which is hardly ever present in terrestrial processes. Accordingly, iron silicides have been detected in some fulgurites, including most recently (2020) in a Michigan fulgurite [32]. Eutectic intergrowth texture of two iron silicides revealed naquite and linzhite or naquite and xifengite. Iron silicide particles found in Southern Urals, Russia, up to 1 m deep in Pleistocene sediments, were studied as a possible new class of meteorites, but in the end, a terrestrial formation from a completely unknown process was favored. Cosmic connections however are more and more discussed, although opposition against extraterrestrial origin is maintained. Recently, hapkeite (1–2 µm) was found in a meteorite from Koshava, Bulgaria [33] and discovered in the meteorite DAG 1066 [34]; it also occurs in a grain from the FRO 90228 ureilite [35]. Fe_2Si reported for magnetic spherules in Hungary could be related to cosmic dust or a meteorite impact [36]. Hapkeite was found also in a 7 µm Supernova graphite (OR1d3m-18) from the Orgueil meteorite [37]. A few years ago, naquite, suessite, and xifengite were identified in the Khatyrka CV3 carbonaceous chondrite [38]. A recent article on iron silicide spherules [39] with partly astonishingly similar analyses as those presented by us here, denies again a cosmic origin, equally also an anthropogenic formation, and postulates a formation as a kind of fallout from impact ejecta from a sedimentary target). An interesting discussion was also triggered on the origin and formation of various iron silicide phases in the aerogel of the Stardust mission.

Nevertheless, it remains to be noted that naturally occurring iron silicides are found very sparsely and the scientific literature on them has remained manageable. Even more exciting proved to be the discovery of thousands of iron silicide particles in a large, scattered field over an area of a few thousand square kilometers in the southeast of Germany about 20 years ago, which were documented by local researchers and amateur archaeologists and associated with a meteorite impact.

The hypothesis of the connection of the iron silicide findings with the large scattering field of meteoritic impact craters, put forward by the amateur researchers, has been clearly manifested until today, which is explained in the introduction. From the beginning of the discovery there had been strong resistance against this spectacular new hypothesis, although the first analyses had quickly clarified that the metallic finds were the intergrowths of the iron silicides gupeiite and xifengite with titanium carbide, which practically do not occur on earth, and the find circumstances, which are described here, practically excluded a human, industrial origin. Resistance especially against the crater strewn field came from the regional ice age research [40, 41], which saw the craters as dead ice holes or simply as human constructs, but especially from the scene of established impact research. The main argument was that such small meteorite craters could not possibly form on Earth [42], which only a short time later proved to be a thorough scientific misjudgment, when as counterpart the Carancas stony meteorite formed an identical 13 m-diameter crater [43], as they abound in the Chiemgau [44].

For the iron silicides, the rejection fed on the fact that iron silicides of the same mineral compound could form for a short time after World War II on the electrodes of an industrial furnace used for fertilizer production and was claimed by opponents of the impact to be the source of the iron silicides when the fertilizer was spread. A comparative analysis was made [24], but neither pictures nor data of it were ever published. The characterization of the iron silicides by the local researchers as pseudometeorites was based on a lead isotope measurement [45] of a sample resulting in a typical terrestrial lead isotope, but this was shown to be incorrectly interpreted [24]. Unresolved to this day remains this lead isotope survey, as not even one of the SEM-EDS measurements on a myriad of iron silicide samples from the crater strewn field has yielded even the slightest evidence of lead.

Even if today the Chiemgau impact event with accompanying iron silicides is only sporadically questioned with the old known, meanwhile absurd counterarguments of the ice age researchers and advocates of the industrial iron silicides (e.g. [46]), the essential discussion about the origin of the iron silicides remains. For it here once again the findings are summarized, which can help clarifying:

1) Iron silicide minerals gupeiite, xifengite, fersilicite, ferdisilicite, hapkeite and stoichiometrically similar variants; traces of the meteoritic mineral suessite; the Chiemgau hapkeite is the trigonal polymorph (S. G. P3m1, No. 164).
2) An 8 kg iron silicide excavated block is exceptional.
3) More than 30 chemical elements so far established including six REE; few nickel. Uranium is fairly common, frequently associated with zirconium/zircon and cerium/neodymium; no uranium decay products including lead exist (except for two EDS spectra showing possible traces of thorium and polonium, respectively).
4) Extremely pure crystals of titanium carbide (TiC, (Ti, V, Fe) C, khamrabaevite) and silicon carbide (SiC, moissanite) interspersing the iron silicide matrix. Zirconium carbide and uranium carbide have been verified.
5) CAIs (calcium aluminum inclusions) in coexistence of the monoclinic high-temperature (>1,500°C), low-pressure dimorph of $CaAl_2O_4$, mineral krotite, and the orthorhombic $Ca_2Al_2O_5$ dicalcium dialuminate high pressure phase pointing to complex formation conditions.
6) Probably one or more shock events the iron silicides underwent:
7) moissanite showing multiple sets of closely spaced planar features (Figure 32) very similar to shock PDFs in silicate rocks, feather features and strong closely spaced kink banding.
8) uranium without its decay products (Figure 26) interpreted as the result of a shock event that could have led to complete resetting of the U-Pb isotopic system (see, e.g., [47, 48]).
9) Ubiquitous tensile open fractures traversing the iron silicide particles in irregular patterns (Figure 32) and as multiple sets of subparallel open fissures (Figure 32) interpreted by impact shock spallation.
10) Clusters of micrometer-sized rimmed craters on the surface of an iron silicide particle (Figure 13) interpreted by a highly energetic cosmic bombardment. The supposed open imprints of lost zircon crystals (Figure 13) could possibly be witness of a shock collision in space.
11) Impact of tiny zircons into a plastic or even liquid matter and the obvious sudden freezing of the expansion waves of the disturbance (Figure 12 D) pointing to abrupt change of the material's properties.

Based on this compilation and with respect to the impact event, two processes have to be discussed in principle: the iron silicides originate from the cosmos and belong to the projectiles of the impact, or they have newly formed during the high-energy impact from target material with or without participation of meteoritic material, as it is postulated e.g., for the iron silicide spherules of the work in [39]. The two possibilities need not be mutually exclusive. At least for a cosmic part of the iron silicides the established event of the Chiemgau impact would offer itself.

Very similar to meteoritic shapes, which the discoverers noticed early on and solidified their hypothesis of meteorite impact, were the typical regmaglypt surfaces (Figure 7) and the "splash" shapes of many FESI particles (Figure 7), which seemed to prove aerodynamic imprinting.

A new formation of an 8 kg heavy, all around metallic shining iron silicide boulder (Figure 12) composed of at least the iron silicide phases gupeiite, xifengite and larger portions of hapkeite [18] seems to be excluded from an impact cratering relation.

The formation of perfectly formed super-pure crystals of titanium carbide, khamrabaevite and moissanite (Figures 14 21), some of them densely grown in an iron silicide matrix, during or after a catastrophic large impact event does not really seem possible. Already in the very first EDS analyses of TiC [12] the extreme super-purity of the crystals without any admixture of other elements caused considerable sensation and led to statements that such TiC crystals could not be produced in this purity on earth (communication Dr. B. Raeymaekers). For the extreme purity of the moissanite crystals, which we measured later, the same might be true.

Also, the formation of the detected CAIs in the iron silicides seems to be practically impossible under terrestrial conditions. With regard to the direct coexistence of the high-temperature/low-pressure phase of the krotite with the high-pressure phase of the dicalcium dialuminate a common formation is not conceivable with a short impact event.

The postulated shock effects are of special importance. The absolute similarity of the shown planar deformation structures of planar fractures, PDFs, feather features and kink bands in moissanite with shock-produced analogous formations in quartz hardly allows another mode of formation for the moissanite, too. The frequently occurring networks of irregular cracks as open tensile cracks across the FESI matrix and the open fractures through individual titanium carbide crystals can be explained fracture mechanically most plausibly by dynamic shock spallation. With the fact that impact cratering in the first contact and compression stage with the propagation of shock waves into the hit target and back into the projectile produces the typical known shock effects in the minerals and rocks, the simple conclusion is that the iron silicides must have existed before the impact happened when they were reached and deformed by the shock waves.

Iron silicides with open spallation cracks and moissanite crystals with planar deformation structures cannot have formed after shock front propagation at the excavation stage and during ejection in unresolved processes. They must have already existed at the impact and must have experienced the shock deformations logically at earlier shock collisions in the cosmos, as it is basically known from meteorites. The impact velocity of the mostly small FESI particles at the impact itself must have been too small as that still significant shock effects could have formed. The same reasoning applies to the impact microcraters that partially litter the surfaces of the iron silicides (Figure 13), that they were created by a high-energy bombardment on existing iron silicides in the cosmos before the Chiemgau impact. It is difficult to imagine a formation on the surface of new iron silicide particles created during the impact. We are aware of e.g., the microcraters on presumably terrestrially formed Australasian microtektites [49] but see no relation in their formation to the microcraters on the iron silicides. Also, the "frozen" impact of the zircon crystals into a presumably molten FESI matrix is most likely explained by shock compression, but also requires pre-existence of the FESI particle before the Chiemgau impact.

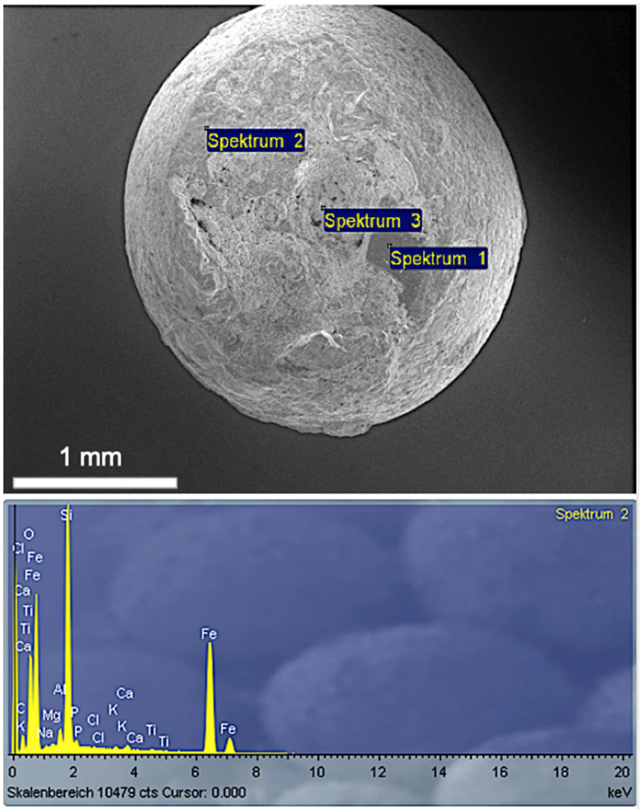


Figure 33. *SEM image and EDS spectrum of a FESI spherule from the Chiemgau impact strewn field exhibiting typical soil elements.*

Despite the assumption that at least a considerable part of the iron silicides originates from the cosmos and was an essential part of the whole Chiemgau impact event, we do not want to exclude a new formation of iron silicides in the violent impact of extreme temperatures and pressures, without understanding so far how such a process could have taken place. We bring here in Figure 33 the SEM image of a Chiemgau FESI spherule and an EDS spectrum taken from its surface. Remarkable and different from the larger part of FESI EDS spectra the chemical elements except for the FESI component are those typically found in soils like Mg, Al, Na, K, Ca, Cl, P. Although thoroughly cleaned, it cannot be ruled out that these are indeed original soil constituents that entered (and were measured) in microcracks during impact or spherule recovery. We leave it at that and refer to further investigations, which will pursue the question of the new formation of iron silicides during an impact.

5. Conclusions

About 20 years after the discovery of the crater strewn field of the Chiemgau impact with the simultaneous abundant detection of the iron silicides gupeiite and xifengite, which practically do not occur naturally on earth, we see ourselves today on the one hand confronted with the probably largest Holocene impact event, on the other hand we have an enormous extension of the knowledge to the iron silicides, concerning distribution, abundance of the findings as well as meaning of the newly additionally found iron silicide mineral varieties, among them the hapkeite, and their characteristics. We emphasize the peculiarity of the in many cases quite unusual accompanying minerals of the titanium/khamrabaevite, silicon, zirconium and uranium carbides and the calcium aluminum inclusions (CAIs), not to forget the postulated shock effects in the TiC and SiC crystals, which have virtually identical shapes to the planar deformation structures of the PDFs, PFs, kink bands and feather structures so well-known from silicate rocks, especially quartz. In the overall view of all these findings, it is now possible to conclude exactly what the original discoverers had suspected relatively quickly 20 years ago that both the large crater strewn field and the iron silicides were a common phenomenon of a cosmic event in recent prehistoric times. For the found and extremely deeply analyzed iron silicides, among them an excavated FESI find of 8 kg mass, the conclusion must arise that we are dealing here with the Chiemgau impact together with worldwide increasing single proofs of extraterrestrial iron silicides, with a new class of meteorites. The rejection of the impact, which is still articulated by a few isolated sides until today, without a single presented and published counter-argument, does not go beyond the pure rejection.

Acknowledgements

The first appreciation with deep gratitude goes to the group of discoverers of the Chiemgau impact of the local researchers and amateur archeologists (W. Mayer, R. Beer, G. Benske, C. Siegl, R. Sporn, T. Bliemetsrieder), who in the first years of exploration, despite some hostility, quite meticulously carried out the field work to the craters and the iron silicides with the most careful documentation at considerable personal financial commitment. Of this group, W. Mayer must be singled out because he was without doubt the discoverer of the Chiemgau Impact phenomenon and the early enthusiastic promoter of the research. The team received essential support by the first scientific analyses of the iron silicides by Dr. B. Raeymaekers (InfraServGendorf), who produced the first evidence for the main components gupeiite and xifengite with the superpure titanium carbides as accompanying minerals. Together with him the hypothesis of a cosmic event with meteoritic iron silicides and impact craters in a large strewn field was established for the first time.

We express a big thankyou to the CIRT (Chiemgau Impact Research Team) which in the following years until today showed so much commitment to all the research work with some emphasis on Dr. Michael A. Rappenglück M. A., astronomer and archeoastronomer, and his wife Barbara Rappenglück M. A., historian, to Hans-Peter Matheisl and Alfred Dufter for manifold scientific, technical, and organizational contributions and help for 15 years and longer.

A big thank you also goes to all the landowners, too many to mention by name, who made the search for the iron silicides possible and in many cases were actively involved in the recovery. Of the local authorities, special mention must be made of the municipality of Grabenstätt with its now retired mayor Georg Schützinger, for whose support great thanks are expressed. Finally, we would like to thank the non-profit association *"Forschungsförderverein Chiemgau Impakt e.V."*, whose chairman and deputy district administrator Josef Konhäuser helped to overcome many difficulties.

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