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An eight kilogram chunk and more: evidence for a new class of iron silicide meteorites from the Chiemgau impact strewn field (SE Germany)

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Introduction

The find of a big 8 kg weighting iron silicide chunk (Fig. 1) found about 30 years ago in the Chiemgau meteorite impact strewn field (Fig. 1) [1—3 and references therein] has strongly supported the earlier formulated hypothesis [1—3 and references therein] of an extraterrestrial origin for the abundant occurrences of iron silicides (Fig. 2) in connection with the craters in the elliptically formed strewn field sized about 60 × 30 km [1]. Up to now some thousands of iron silicide particles have been sampled, mostly by metal detectors, roughly amounting to a mass of a few kilograms (apart from the 8 kg chunk). Here we report on new analyses, which establish an obviously common formation and origin.

Fig. 1. Location map for the Chiemgau impact crater strewn field. Middle, right: Iron silicide finds addressed analytically in this paper

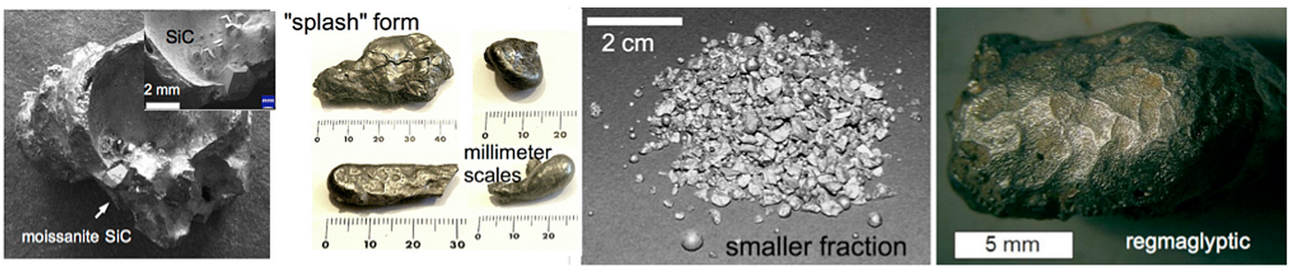

Fig. 2. Various aspects (apart from Fig. 1) of the iron silicide finds from the Chiemgau impact strewn field

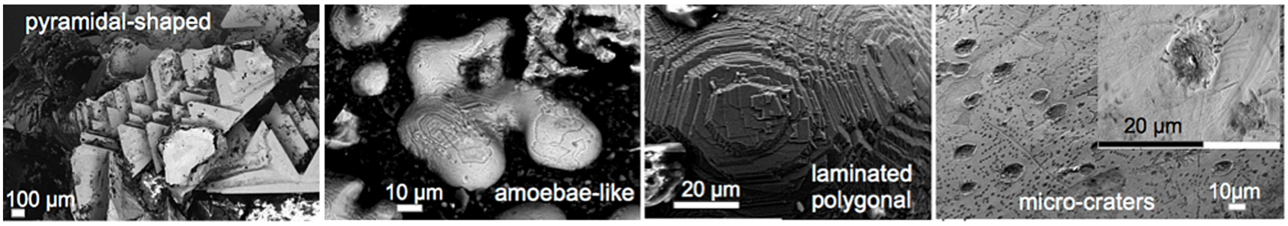

Fig. 3. Internal structure of iron silicides from the Chiemgau strewn field under the SEM

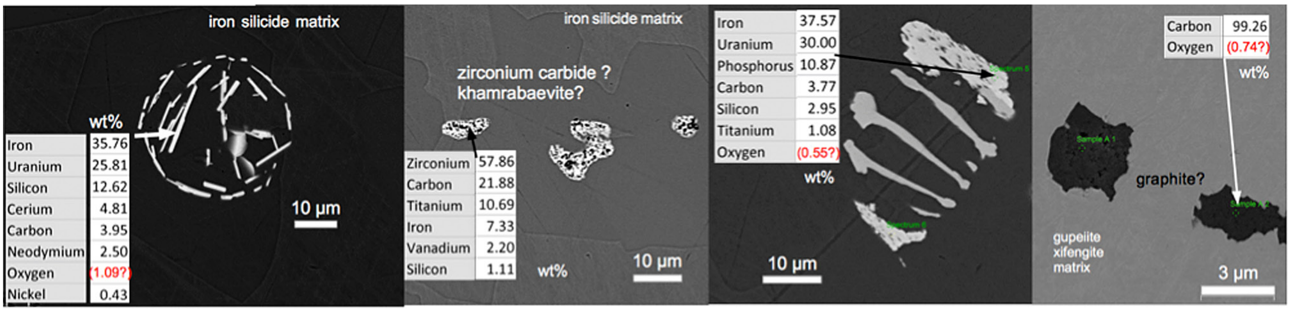

Fig. 4. SEM-EDS micrographs and analyses; samples from Fig. 1, right. Quite comparable analyses have been made in the 8 kg iron silicide chunk (Fig. 1) [3] and in earlier analyses of various finds

Methods and results

Optical microscopy, SEM, TEM and EBSD analyses, Raman spectroscopy.

Elements: Apart from the main constituents Fe, Si more than 30 other chemical elements have been evidenced so far like uranium, the REE cerium, yttrium und ytterbium, or gallium. No decay products of uranium like thorium or lead have been measured.

Iron silicide minerals of the matrix: gupeiite, xifengite, hapkeite, naquite and linzhite; hapkeite Fe_2Si in its cubic polymorph and in its trigonal polymorph (the most stable iron silicide up to 255 GPa).

Identified minerals: Carbides — silicon carbide moissanite SiC (cubic and hexagonal polymorphs), titanium carbide TiC, khamrabaevite (Ti,V,Fe)C, probably zirconium carbide ZrC (Fig. 4) — Graphite C, zircon $ZrSiO_4$; Carbon and TiC/(Ti,V,Fe)C in a matrix of cubic hapkeite and cubic gupeiite; SiC and TiC/(Ti,V,Fe)C as superpure crystals in the iron silicide matrix (Fig. 2). — Calcium-aluminum inclusion (CAI) minerals $CaAl_2O_4$, calcium monoaluminate, krotite, and $Ca_2Al_2O_5$, dicalcium dialuminate.

Shock metamorphism and micro-impacts: planar deformation features (PDF) in moissanite; open, tensile spallation fractures in titanium carbide crystals; cosmic particle impacts (Fig. 3).

Conclusion

Enigmatic internal structures and exotic composition for all sizes of iron silicide samples from the Chiemgau impact crater strewn field establish a common formation process and a common source.

Artificial production, geogenic formation (and e.g. fulgurite formation) can be excluded, which is basically also supported by the find situations in the field [1, 2]. The iron silicides are of extraterrestrial origin.

The iron silicides in their entity belong to the Chiemgau meteorite impact strewn field.

They should constitute a new class of meteorites. For reasons of definiteness we suggest to name the trigonal Fe_2Si polymorph hapkeite — 2T possibly rating a new mineral name [2].

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Evidence of meteorite impact-induced thermal shock in quartz

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Introduction

Thermal shock is a mechanical load caused by a rapid change of temperature (heating or cooling) in a material that may fracture if the stress exceeds its tensile strength. While thermal shock plays an important role in material sciences and in industrial production, it has rarely been considered in impact cratering. *A priori*, this is easily understood, because hypervelocity impact shock producing the well-known rock and mineral deformations (shock metamorphism) precedes a thermal shock on pressure release. However, if the shock pressures are enough to melt or vaporize target rocks (beginning at a few tens of GPa), then on rapid contact of melt or vapor with less or no shocked rocks in the immediately following excavation stage, extreme thermal shock can be expected to exert mechanical load and a kind of secondary shock fracturing. Here, I report on observations in quartz of shocked impactites with evidence of strong thermal shock fracturing and of ballen quartz formation by thermal shock, the latter originally suggested in a recent paper [1].

Quartz microfracturing

Very unusual microfracture patterns in quartz have been observed to occur in meteorite impact rocks in a manner so far not described in the literature to our knowledge (Fig. 1). The polymictic impact breccia in Fig. 1A comes from the recently proposed impact event in the Czech Republic [2, 3]. Individual small quartz grains are distributed throughout the matrix in most cases not contacting each other (Fig. 1, B) but revealing extreme mosaic-like microfracturing Fig. 1, C—F). In many of the grains this microfracturing is more or less sharply limited to a concentric rim zone encasing a largely untouched core with a few sub-planar fractures in some cases. Multiple sets of true planar features (PFs) known as an impact shock effect also occur (Fig. 1, C). Similarly unusual quartz fracturing has been reported also from the Nalbach-Saarland impact event [4] where abundant isolated quartz grains in an impact melt glass are observed, as is the case for the recently described granitic impact melt rock sheet in SE Bavaria [5]. In all three cases a tec-

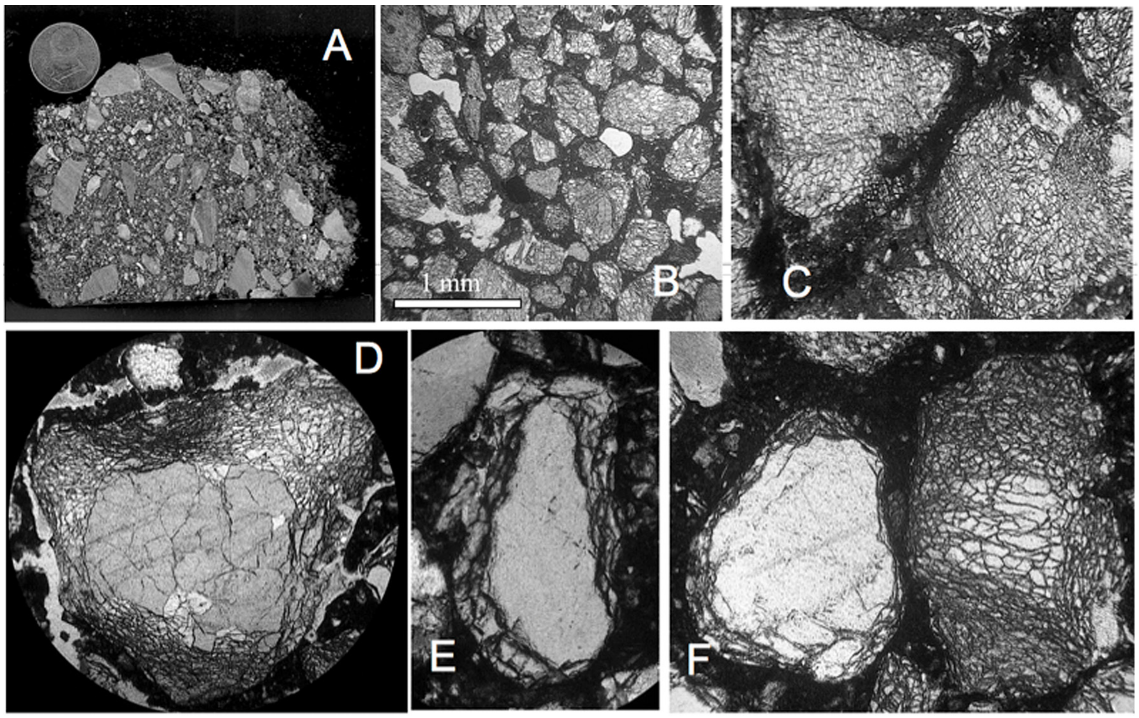

Fig. 1. A: Polymictic impact breccia from the Czech impact site [2, 3]. B: Close-up of the breccia showing intensely fractured quartz grains that are floating in the breccia matrix without contacts. C: Selected quartz grains from the breccia matrix with multiple sets of planar fractures (PFs, densely developed cleavage). D-F: Quartz grains from the breccia matrix exhibiting the spectacularly fractured rim regions around a widely untouched core with some planar and subplanar fractures. B-F: Thin section photomicrographs, crossed polarizers

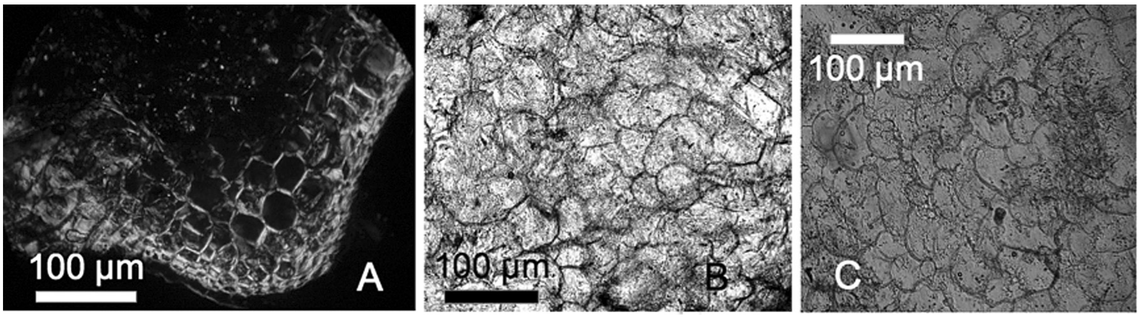

Fig. 2. Silica ballen structures as a shock indicator. A: Czech impact; ballen as diaplectic silica glass [3]. B: Shocked granitic melt rock sheet near Bach/Regensburg (Bavaria, Germany) [5]. C: Saarland impact (Germany) [4]. Photomicrographs, A crossed polarizers, B, C plane light

tonic origin and a direct shock-wave microfracturing can reasonably be excluded.

Ballen structures

Ballen structures in silica form a characteristic texture in quartz that in general is considered a result from various stages of phase transformation and recrystallization of amorphous silica like e. g., diaplectic glass and hence are regarded as shock indicator (e. g., [6]). A different model has recently been suggested [1] that proposes a formation of ballen in quartz in an extreme thermal shock event. This idea has been taken up and is here shown to be a probable indicator of impact thermal shock in other impact events (Fig. 2).

Discussion and conclusion

The presented here results of thin section analyses of quartz shocked in three young impact events in the Czech Republic and in Germany reveal observations strongly supporting processes of thermal shock that in the past have in general been disregarded in impact cratering research. Noticeably, in all three impact events both effects the extremely strange microfracturing and the ballen quartz formation occur together with impact melt glass and diaplectic silica and, hence, point to affinity. In particular the micro-fractured quartz grains «floating» isolated in the matrix imply high confining pressure for maintaining coherence, and the microfracturing limited to a rim all around the grains can best, and probably only, be explained by a sudden complete immersion in rock melt and/or vapor shortly after shock wave passage, experiencing extreme thermal shock heating and rapid cooling. The ballen quartz formation fits well into this process and emphatically supports the model presented in [1]. Hence, thermal shock should become a more considered feature in future impact cratering research.

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Chiemite — a high PT carbon impactite from shock coalification/carbonization of impact target vegetation

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Introduction

Unusual carbonaceous matter in the form of mostly centimeter-sized lumps and cobbles has been sampled in the southeast Bavarian Alpine Foreland, in the Czech Republic near Pardubice and in the Saarland region near the French border (Fig. 1). It is a highly porous blackish material with a glassy luster on freshly crushed surfaces (Fig. 2). The material is unknown from any industrial or other anthropogenic processes and thus appears to have a natural origin. Here we report on results of a detailed analysis of this strange matter pointing to a process of formation in proposed meteorite impact events. From its first discovery in the Bavarian Chiemgau impact crater strewn field [1] the name *chiemite* gained currency, and in particular these finds have already been addressed earlier (references in [1]) before a more general occurrence in impact sites became obvious [2, 3].

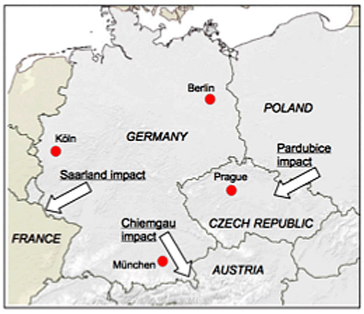

Fig. 1. Location map for the three chiemite sources in the Chiemgau, Saarland and Czech impact strewn fields

Fig. 2. Freshly broken chiemite sample. Photo width 6 cm

Material

Typical chiemite samples from the field are shown in Fig. 3 as pure chiemite matter, where the pseudomorphosis after wood sticks out, and in compound with rock and organic matter. Under the SEM the typical strongly porous texture is evident. Physical properties are a low density mostly <1 g/cm^3, a significant electrical conductivity and in some cases a moderate magnetic susceptibility and remnant magnetization.

Methods (with a focus on the Chiemgau impact chiemite):

Optical and atomic force microscopy, X-ray fluorescence spectroscopy, scanning and transmission electron microscopy (SEM, TEM), high-resolution Raman spectroscopy, X-ray diffraction and differential thermal analysis, as well as δ^{13}C and ^{14}C radiocarbon isotopic data analysis.

Results

The most significant observations described in [4] are tabulated in short as follows.

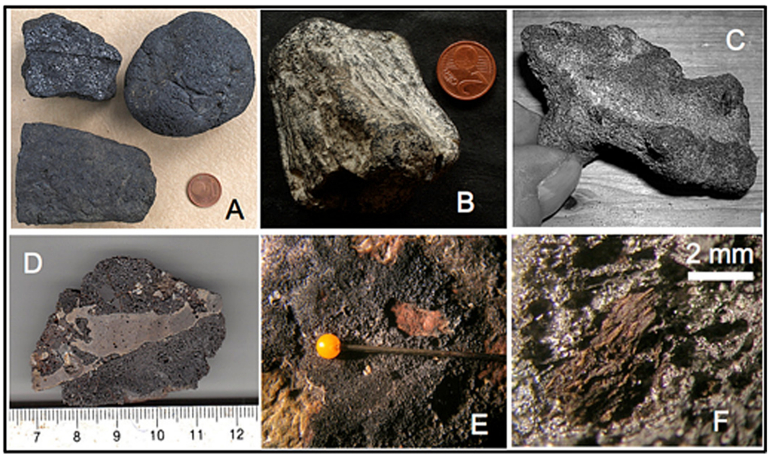

Fig. 3. Chiemite samples from the field. A: various shapes. B, C: chiemite fragments pseudomorphic after pieces of branches. D: chiemite breccia-like intermeshed with a limestone cobble. E: chiemite crust on a sandstone cobble. F: relatively fresh wood particle embedded in chiemite [4]

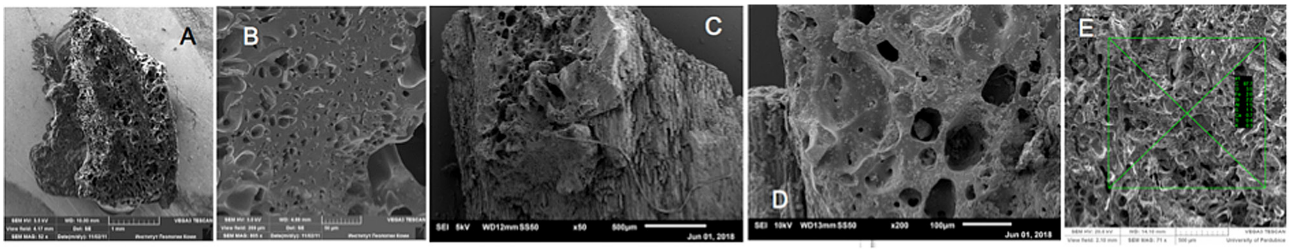

Fig. 4. Chiemite under the SEM. Chiemgau impact (A, B) [3], Saarland impact (C, D), Czech impact (E). Fossilized wooden structure in C

XRF: about 90 % carbon, remaining Si, Al and Fe, subordinately S; traces of other elements.

SEM, microprobe: almost pure glass-like carbon matrix contains finely dispersed micrometer- and submicrometer-sized inclusions with a complex composition not known mineralogically.

XRD, XR synchrotron diffraction: Evidence of nanocrystalline diamond and graphite.

TEM: Glass-like carbon structural features. Crystalline carbyne and diamond matter with different order level.

TEM and Raman: Polycrystalline fine grained aggregates to polynanocrystalline diamond aggregates and amorphous diamond-like carbon exists. — α-carbyne and β-carbyne but not any graphite were observed.

Raman spectroscopy: Submicrometer-sized optically transparent substances are carbyne-like carbon or diamond-like carbon.

Carbon isotopes: Carbon $\delta^{13}C_{PDB}$ data show values between –22.6 and –24.6 ‰ near to data of C3 plants.

Radiocarbon data for two chiemite samples are void of ^{14}C corresponding to an age of > 48,000 years BP not compatible with the chiemite find situation.

Discussion and conclusions

The fully amorphous chiemite matrix contains diamond, amorphous diamond-like carbon and monocrystalline carbyne inclusions. The strongly porous texture requires an intense gas phase during formation. — Carbyne formation needed very high *PT* conditions of about 4—6 GPa and 2,500—4,000 K. Probable carbon glass was formed at temperatures as high as 3,800—4,000 K. — Organic matter was involved in the formation process. — The lack of ^{14}C requires an age > 48,000 years (less probable) or isotope separation. — Chiemite does not correspond to any known natural earth material. An industrial formation and an occurrence from e.g. wildfires can reasonably be excluded. — The chiemite components show similarities to after-coal meteorite impacts [5]. — We propose the chiemite was formed by meteorite impact shock having affected vegetation like wood and peat in the impact target area, hence establishing a new kind of impactite that originated from immediate shock transformation of organic matter to high-rank carbon. — The impactite nature is underlined by the occurrence of chiemite samples in three established or proposed young impact strewn fields (Fig. 1). The finds closely resembling each other up to the enigmatic absence of ^{14}C despite their evident young ages, and a so far unknown isotope separation in the impact process has to be assumed. — In all three impact cases there is much evidence of big airbursts, which initiated extreme-temperature gas jets impinging on the ground. — The surviving of fresh organic matter in the impactite under these extreme conditions is important for astrobiological aspects. — The prediction [5, 6] of more impact diamonds from organic matter than hitherto assumed is likewise underlined.

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Artifact-in-impactite: a new kind of impact rock. Evidence from the Chiemgau meteorite impact in southeast Germany

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Introduction

The Chiemgau impact (Fig. 1) as a meanwhile established Holocene impact event has featured quite a few exceptional observations in the last 15 years, which are summarized in [1, and references therein]. From the beginning of research it was clear that a huge catastrophe in the Bronze Age or Celtic era must have already affected densely populated regions, and in a routine archeological excavation at Lake Chiemsee the worldwide unique constellation was encountered that an impact catastrophe layer was excavated sandwiched between settlement layers of the Stone Age/Bronze Age and the Roman Period (Fig. 1, 2) [2]. Among the finds of ceramics, stone tools, bones and metal artefacts also featured externally rather unsightly lumps, which were found by use of metal detectors and were addressed as «slag» by the excavator. Here we report on specifically conducted mineralogical-geochemical investigations on 16 «slag» samples which have led to very remarkable results.

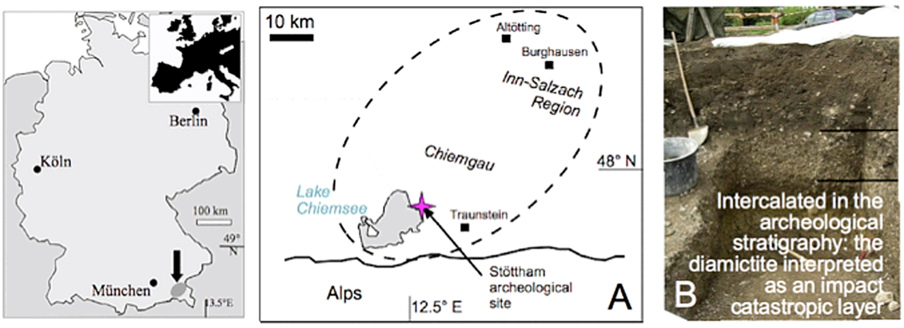

Fig. 1. Location map for the Stöttham archeological excavation (B) in the Chiemgau impact crater strewn field

Fig. 2. Inventory of the Stöttham archeological site (from left to right): diamictite of the catastrophic layer; archeological finds; carbon, metallic and glass spherules; strongly corroded and fractured cobbles, metal-rich «slag»

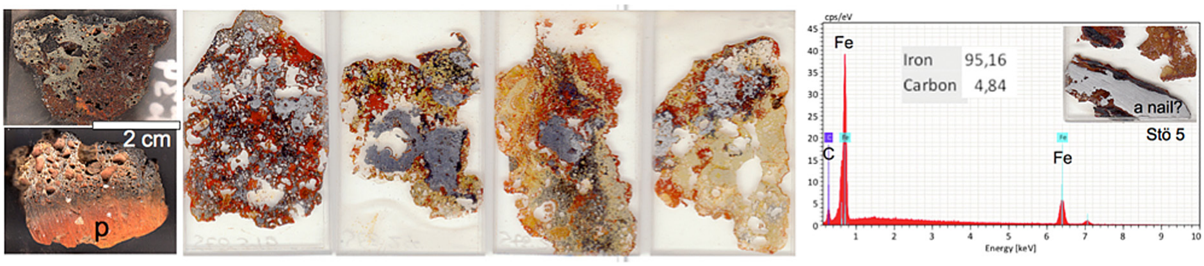

Fig. 3. Cut faces (to the left) and scanned images of corresponding thin sections accenting the shredded iron metallic particles as parts of the polymictic impact breccia. p = pottery shard merging into vesicular fusion. Rightmost: EDS spectrum of an iron particle (a nail fragment?). Apart from a little carbon Fe is the only element

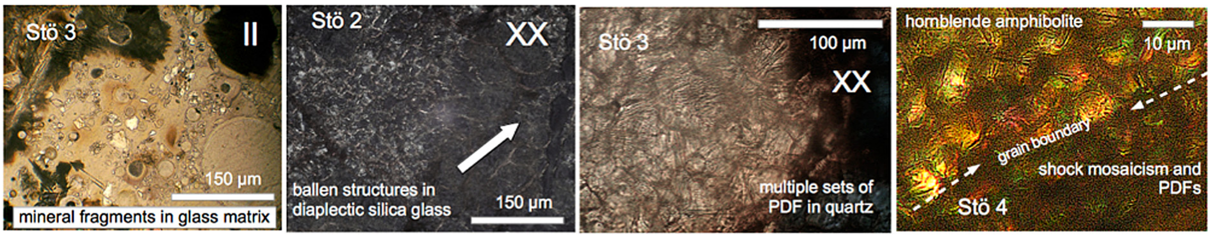

Fig. 4. Shock metamorphism in polymictic «slag» breccias. Photomicrographs

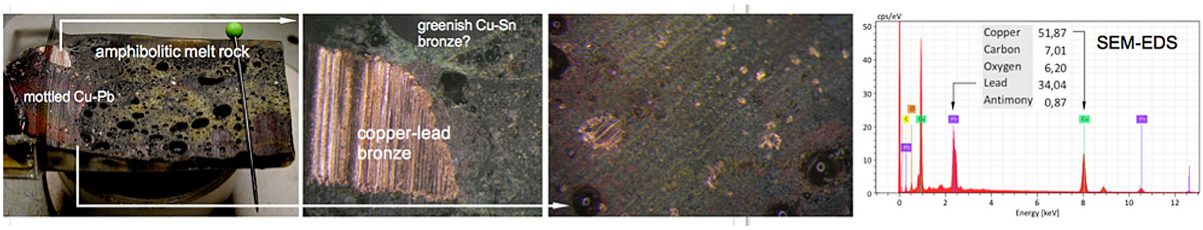

Fig. 5. «Slag» containing high leaded bronze fragments and mottled matter, and possibly Sn bronze

Material and analyses

On preparation of the «slags» by cutting and thin-section analyses with the polarizing microscope (Fig. 2), the «slags» turned out to be polymictic breccias with all signs of an impact melt rock with vesicular remnants of alpine Quaternary cobbles of the region mixed with multicolored rock fragments and abundant glass (Fig. 3). As a noticeable portion, partially shredded metal particles interpenetrate the breccia, which the metal detector had obviously classified as slag (Fig. 3). As already demonstrated earlier in the diamictite of the catastrophe layer [2], the «slag» breccias contain abundant shock effects, here with greater density and intensity (Fig. 4).

The most remarkable observation in the «slag» proved to be bronze fragments, which according to SEM-EDS analyses are an unusual high leaded bronze (Fig. 5), which according to EDS penetrates the breccia also in fine and finest particles (Fig. 5). In addition to probable normal tin bronze (Fig. 5), iron particles (Fig. 3) are particularly noticeable, which according to EDS consist only of iron without any other element apart from very little carbon (Fig. 3), a composition indicating iron in some processed condition.

Conclusions

The new investigations demonstrate once more impressively that the Stöttham archeological site had been involved in a meteorite impact invent, the Chiemgau impact. The original finding of a meteorite impact layer between two archeological horizons was to be classified as unique worldwide. From the point of view of both archeology and impact research, the new analyses have put the crown on it by revealing human objects and impact shock intimately intertwined in the same samples — a worldwide novelty defining an artifact-in-impactite as a new kind of impact rock. A more exact dating of the Chiemgau impact, based on the metallic components, is a significant side effect of these unusual samples and their investigation, scheduling the impact event between 900 and 600 BC [3].

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