Meteorite impact on a micrometer scale: iron silicide, carbide and CAI minerals from the Chiemgau impact event (Germany)

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Introduction: The Holocene Chiemgau impact event is considered to have produced a large meteorite crater strewn field in southeast Germany in the Bronze Age/Celtic era ([1], and ref. therein). The impact is documented by impact melt rocks and various glasses, strong shock metamorphism, geophysical anomalies and ejecta deposits, and substantiated by the abundant occurrence of metallic, glass and carbon spherules. Enigmatic carbon matter containing carbynes and diamond-like/carbyne-like carbon allotropes also testify extreme temperatures and pressures [2, 3]. From the beginning of the discovery and investigation of the strewn field, extended finds of iron silicide particles in the subsoil mainly composed of xifengite and gupeiite and obviously associated with the craters played a significant role as possible meteoritic matter. New analytical SEM, TEM and EBSD have shown that the iron silicides when going down to micrometer scales are hosting a real «zoo» of more than 30 chemical elements, extremely rare minerals and peculiar textural features.

Observations: *Iron silicides (Fig. 1, A)*. — So far the minerals xifengite, gupeiite, fersilicite, ferdisilicite and hapkeite have been established to occur as a matrix of intimate intergrowth. Different from the cubic hapkeite found for the first time in the Dhofar 280 lunar meteorite [4], the Chiemgau hapkeite could be shown to be the trigonal polymorph. *Carbides (Fig. 1, A)*. — The iron silicide matrix contains abundant extremely pure crystals of SiC, cubic moissanite, TiC, and (Ti, V, Fe) C, khamrabaevite. *Calcium-aluminum inclusions, CAIs (Fig. 1, B)*. — The Chiemgau iron silicides contain 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 with the brownmillerite-type structure. *Zirconium and uranium (Fig. 1, C, D)*. — Zirconium (zircon or/and baddeleyite) shows as possible exsolution lamellae in iron silicide. Clusters of tiny (< 10 μm) zircon crystals coated by uranium are interspersing the iron silicide matrix. EDX spectra show the uranium to be free of any decay products

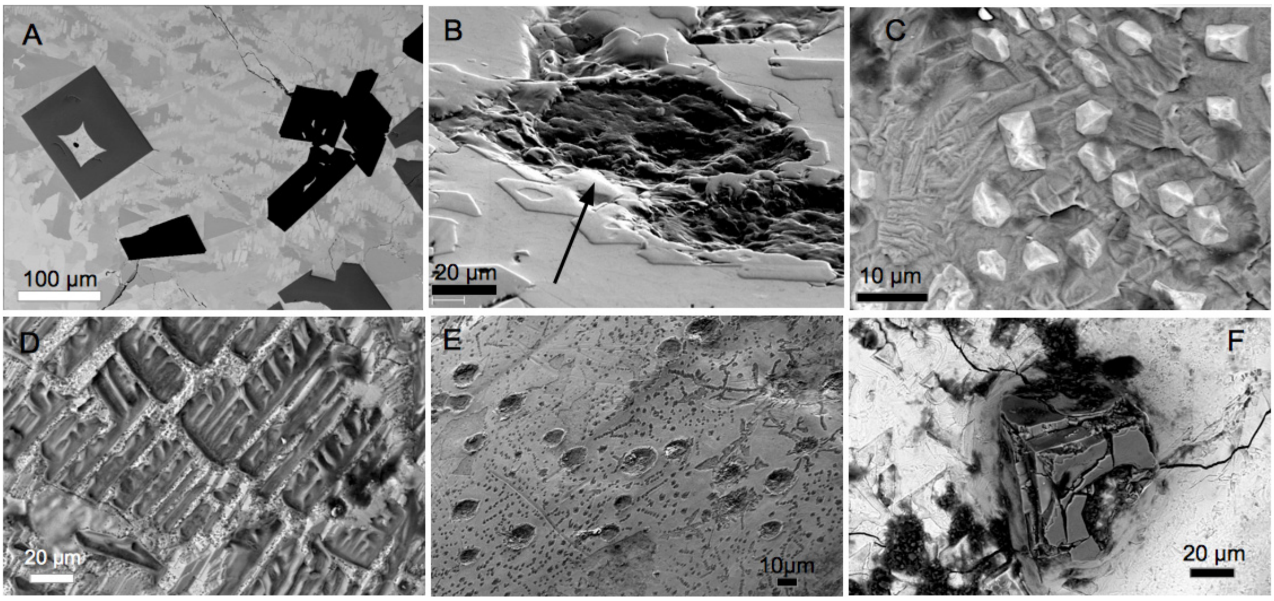

Fig. 1. A: Titanium carbide (dark gray) and silicon carbide (moissanite, black) crystals in a matrix of intergrowth of various iron silicides. B: Light edging CAIs (arrow) around black C (graphite, diamond?) film in iron silicide matrix. C: Zircon crystals in iron silicide matrix. The white tips on the crystals have been shown to be uranium. D: Zirconium (zircon or/and baddeleyite) possible exsolution lamellae in iron silicide. E: Rimmed micro-craters on the surface of an iron silicide particle. F: Strongly fractured titanium carbide crystal in iron silicide matrix. Note the open, tensile fractures pointing to dynamic (shock?) spallation

like thorium or lead. *Textural features, probable shock effects.* — Apart from the matrix intergrowth the iron silicides occur as microscopic amoebae-like and pyramidal-shaped aggregates. The surface of iron silicide particles may exhibit clusters of rimmed 10–20 µm-diameter craters pointing to a bombardment by micron-sized projectiles (Fig. 1, E). Moissanite crystals show multiple sets of closely spaced planar features reminding of shock-produced planar deformation features (PDFs). Ubiquitous open fractures (Fig. 1, F) are implying tensile character of the deformations and may easily be explained by impact shock spallation. The peculiar occurrence of uranium without its decay products may be interpreted as the result of a shock event that could have led to complete resetting of the U-Pb isotopic system.

Discussion and conclusions. – Since some time iron silicides have begun to play an increasing role in meteoritics and planetary science to name but the xifengite and gupeiite minerals in ureilites or the Fe-silicides (e. g., the hapkeite) in lunar rocks [4, 5]. As from 2014 on Earth roughly a dozen of Fe-silicide occurrences are suggested to be related with an extraterrestrial origin, the Chiemgau finds being exceptional because of the relation with a proposed meteorite impact and crater strewn field. This relation is substantiated by the many peculiar properties (xifengite, gupeiite, hapkeite, fersilicite, ferdisilicite intergrowth, extremely pure, in part larger crystals of cubic moissanite and titanium carbide/khamrabaevite, various indications of probable shock effects) and in particular by the verification of CAIs. For the iron silicide particles the intimate CAI coexistence of the high-temperature/low-pressure $CaAl_2O_4$ krotite and the high-pressure $Ca_2Al_2O_5$ phase imply a complex formation history pointing at the same time to a possibly strange impactor to have produced the Chiemgau strewn field. In this context, we remind of the Stardust findings suggesting comets with regard to formation and composition are much more complex than thought. Moreover, only recently, from the visit of the Hayabusa spacecraft to the Near-Earth asteroid (25143) Itokawa it is concluded that it was probably formed from the merger of two separate bodies of quite different composition [6]. Hence, we should get rid off the simple idea that impacts on earth are related with either stony or iron meteorites.

References

1. *Ernstson, K., Mayer, W., Neumair, A., Rappenglück, B., Rappenglück, M. A., Sudhaus, D., Zeller, K.W.* The Chiemgau Crater Strewn Field: Evidence of a Holocene large impact event in Southeast Bavaria, German // Journal of Siberian Federal University, Engineering & Technologies V. 1, 2010. P. 72103.

2. *Shumilova, T. G., Isaenko, S. I, Makeev, B. A., Ernstson, K., Neumair, A., Rappenglück, M. A.* Enigmatic poorly structured carbon substances from the Alpine Foreland, southeast Germany: evidence of a cosmic relation // 43rd Lunar and Planetary Science Conference, 2012, 1430.pdf.

3. Ernstson, K., Shumilova, T.G., Isaenko, S.I, Neumair, A., Rappenglück, M. A. From biomass to glassy carbon and carbynes: evidence of possible meteorite impact shock coalification and carbonization // Modern Problems of Theoretical, Experimental and Applied Mineralogy,Yushkin Memorial Seminar, 2013, Proceedings Volume, P. 369–371.

4. *Anand, M., Taylor, L. A., Nazaraov, M. A., Shu, J., Mao, H.-K., Hemley, R. J.* New Lunar Mineral HAPKEITE: Product of Impact-Induced Vapor-Phase Deposition in the Regolith? // 34th Lunar and Planetary Science Conference, 2012, 1430.pdf.

5. *Nazarov, M. A., Demidova, S .I., Ntaflos, Th., Brandstaetter, F.* Origin of native silicon and Fe-silicides in lunar rocks // 45th Lunar and Planetary Science Conference, 2014, 1090.pdf.

6. *Lowry, S. C., Weissman, P. R., Duddy, S. R., Rozitis, B., Fitzsimmons, A., Green, S. F., Hicks, M. D., Snodgrass, C., Wolters, S. D., Chesley, S. R., Pittichová, J., van Oers, P.* The Internal Structure of Asteroid (25143) Itokawa as Revealed by Detection of YORP Spin-up // Astronomy & Astrophysics, V. 562, A48, 9 p., published online 05 February 2014.