IMPACT METAMORPHISM: ON THE WIDTH OF THE GAP BETWEEN OBSERVATION AND MODELING – THE GEOLOGIST'S VIEW VS. THE MODELERS ASSESSMENT II. A. Deutsch[1], K. Wünnemann[2], [1] Institut für Planetologie, WWU Münster, Wilhelm-Klemm-Str. 10, Münster 48149, Germany, deutsca@uni-muenster.de, [2] Museum für Naturkunde, Humboldt-Universität, Invalidenstraße 43, Berlin 10099, Germany, kai.wuennemann@museum.hu-berlin.de.

Introduction: The investigation of impact metamorphism can be split up in observational data resulting from field studies and laboratory analysis of naturally shocked rocks and minerals, and such accumulated in the investigation of experimentally shocked materials and cratering experiments. The latter allow precise definition of the pre-impact properties, and, depending on the experimental set-up an accurate control of the shock pressure. In rare cases, even peak-shock temperatures have been monitored. Results from shock and cratering experiments and nuclear tests yielded, for example, the basic frame for shock barometry in natural craters and for material parameters under extreme pT conditions. The exceedingly varying results form experimental studies on the shock behavior of carbonates, however, drastically show the importance of the experimental design and of the choice of material subjected to shock (see compilation in [1]). Field data, in contrast, provide the basis for a general 3D picture of impact craters. In constant interaction between field geologists, experimentators, and modelers numerical simulations of impact processes can be refined with the ultimate goal to yield predictions of what can be expected in natural crater structures, and how the observations have to be interpreted [2].

Some topics of interest: In recent years, the above addressed interaction has been increasingly acknowledged in the impact community. Yet still, some authors do not consider the importance of specific target properties in the interpretation of observational data. For example, according to the canonical view decorated planar deformations features (PDFs) represent "altered" or "annealed" glass lamellae; however, their presence in the just 1.07 Ma old Lake Bosumtwi crater, where significant thermal overprint has not been documented, clearly indicate that the H_2O bubles in the PDFs are related to target properties – in this case fluid-rich meta-greywackes [3].

Another problem is the amount of impact melt in craters. In general, the estimated melt volume vs. crater size plot on a well defined regression line for impact structures in crystalline targets [4]. In mixed targets, however, estimates of the volumes of shock - impact melts vary for some craters by orders of magnitudes.

Open problems in observation include the fate of carbonates and sulfates in the shock and post-shock regime, as well as the general shock behavior of soft fluid rich sediments or sedimentary rocks. Some of these problems can be and have been successfully tackled by experimental approaches [3, 5, 6, 7]

Impact-induced melting and vaporization: For thermodynamic reasons, vaporization invariably and melting nearly always The investigation of impact metamorphism can be split up in processes that start to occur during and after unloading from shock.

Shear melting. Rare exeptions in the second case include pseudotachylites with stishovite (Vredefort [8]) and black veins in meteorites with a number of high-pressure minerals, including stishovite, hollandites, akimotoite, and ferro-magnesian silicate titanite (e.g., Zagami [9]). These veins most probably form by shear melting and are quenched in the very beginning of unloading. Experimental proof for this idea was provided by [7] although time constraints (i.e, shock duration of 0.7 µs) prohibited the growth of high-P phases.

The matter is more complex in terrestrial impact structures where several generations of "shear melt veins", so-called pseudotachylites, and clastic matrix breccias occur. In the case of the Sudbury impact structure [10], these pseudotachylite zones and bodies reach a thickness at the 100-m-scale. Their origin by friction exclusively [11] is incompatible with the immeadiate reduction of friction, and thus stress, and seems at odds with the mechanical behavior of the crater foor. Zones of extreme shearing occur in the uplift of the Puchez-Katunki too; there they are manifested in up to 200-m-wide diffuse zones characterized by a high-T mineral assemblage that overgrow shock features. These zones are interpreted as boundaries between differentially uplifted blocks.

Impact melt lithologies – the "normal" case. Melt lithologies, ranging from pure glass, over glass with schlieren (Fig. 1), vacuoles and bubbles, to partially or totally crystallized and/or altered occur in quite different settings in and around impact structures. The size/volume of the melt lithologies range from µm-sized spherules to an estimated volume of 2.5 x 10^4 km^3 for the differentiated impact melt sheet (SIC) at the Sudbury impact structure [12]. The understanding of their respective formation processes on the level of geological observations (i.e., small scale) is in part still limited and unsatisfactory.

Based on a geochemical analysis of melt lithologies and their precursor rocks from the Popigai impact structure, it was possible for the first time to relate glassy and crystallized distal ejecta to specific source regions in a crater [13]. Using this approach, a current project on different melt lithologies from the Bosumtwi [14] and the Chesapeake impact strucutres [15] is devoted to the issue of the generation of different types of melt, namely tektites, microtektites, fall-back spherules, and melt lithologies in breccias that occur inside and around the crater. Constraining structural properties of impact glasses [16], their precursor lithologies, mixing, and physical conditions during melting and cooling will allow to provide a set of solid input parameters to refine numerical models of impact melt formation which so far consider only the peak shock pressure as criteria for melting (e.g., [17, 18]).

Impact melt sheets – open issues. A new idea in the area of impact melting is the proposed occurrence of carbonatic or carbonate-rich melt lithologies (e.g. [19]). Large scale melting of carbonates at >10 GPa and > 2000K [19] is not supported by the phase diagram for calcite [20]; such pT conditions can only be reached if the sedimentary target material has a large porosity. Melting of carbonate clasts in suevites and impact melt rocks, however, during the post-shock regime seems to occur much more widespread than hitherto assumed [21]. Melting and vaporization of sulfates is of prime interest in the context of the mass extinction at the K-T (Paleogen) boundary [22]. Again, a newly constructed phase diagram [23] indicates that solid (i.e., non-poros $CaSO_4$) hardly will melt in the impact regime as extreme pressures are required for melt. We expect significant progress in the understanding of impact-induced melting of sedimentary rocks by applying numerical models that include porosity into the code [24]. We note in addition that the melt volume resulting in numerical simulations of impact events always exceeds the volume observed in nature.

Another challenging problem in modeling is related to differentiation and cooling of the SIC [12, 25] and large impact melt pools at other terrestrial planets [26]: These melt bodies are topped by thick bodies of breccias (in the case of the SIC > 1700 m of Onaping breccias [10]), acting as insolation which in turn, causes slow cooling of the melt, probably accompanied by differentiation.

Conclusion: The gap between observation in nature and experiments, and modeling becomes increasingly smaller although in some fields, the gap is insurmountable: In nature we see the end product, not the thermodynamic path material takes to reach this stage. In models, we construct simplified cases that can not take into account specific details.

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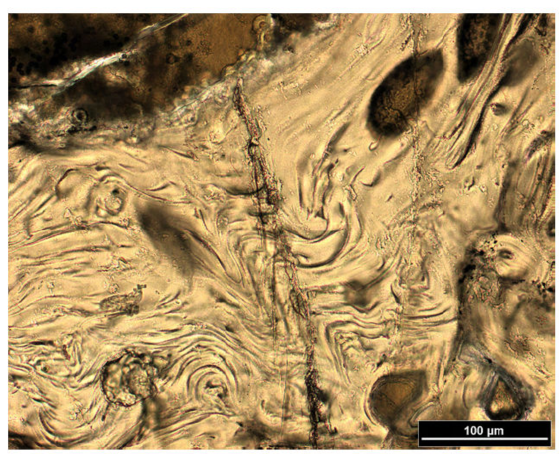

Figure 1. Micrograph of schlieren-rich glass from a suevite of the ICDP-USGS drillcore Eyreville; Chesapeake impact structure; //nicols.