MELT BEHAVIOR IN TWO IMPACTS CRATERS AT EMMERTING, GERMANY: DEFORMATION, EXPANSION, INJECTIONS, AND THE ROLE OF UNDERPRESSURE AND MUTUAL COLLISIONS OF PEBBLES.

V. Procházka[1], [1] Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Břehová 7, 11519 Praha 1, Czech Republic, vaclav.prochazka@fjfi.cvut.cz.

Introduction: The Crater No. 4 at Emmerting (Bavaria, Germany; the numbering of craters and similar depressions in the area is from [1]) has been already investigated since two decades ago. While no definite evidence for impact has been published, it was shown that there is no viable alternative [2]. Recently a meteorite fragment has been found, as presented along with other evidence at a regional conference [3] and in two papers under review for MAPS.

The target environment, dominated by coarse terrace sediments (pebbles, usually about 1 decimeter in size), is unusual among the impact craters documented so far. Extensive melting of the pebbles has been observed, although fine-grained fraction of the filling mostly represents thermally unaffected material which has been brought after crater formation [3]. While the melting may resemble pre-historic and historic lime burning [4], no charcoal or any archaeological evidence for such an activity has been found. Also, with an 8 m diameter of the depression (and up to 13 m including walls), the crater is too large compared to remnants of limekilns, and it lacks a usual furrow for fuel feeding (cf. [5]).

In the crater No. 5, search for a meteoritic matter has not been performed yet. Its size is almost as that of Crater No. 4 and it is located in a wet environment where building of a limekiln is improbable.

Characterization of melts: The micas, feldspars, or both either melted in the whole pebble, or not at all. No sample which would be heated only from one side has been found. Thin transparent glass frequently covers the pebbles except for their originally bottom side. This glass, however, may have been deposited from the surroundings [6]. Eutectic melting inside the pebbles is very limited, if visible at all. In contrast to stones from limekilns, the pebbles from both craters lack thick glass layers with manifestations of slow viscous flow (e.g., “hanging” droplets).

Below I concentrate on some interesting points of the melt behavior.

Expansion of melts. Significant expansion was documented in several samples (typically impure quartzites), where mainly micas (especially altered biotite) dehydrated, melted and solidified to glass, with abundant skeletal magnetite and locally other minerals crystallized from melt. In both craters, this mica-derived melt also formed extrusions on the surface, in some cases resembling miniature volcanoes. These extrusions are younger than the thin transparent glass coating [6]. In at least two samples of Crater No. 4, silicates not only melted but probably partly evaporated. Abundant bubbles also occur in glass of purely feldspathic composition. In contrast, only limited dissolution of quartz in the melt was locally observed. In carbonate pebbles, effects of probable decarbonization have only been observed on the surface, unlike the slow lime burning.

A question arises how intensive melting, expansion and even partial evaporation of silicate melt could happen inside the pebbles when external heat supply was limited, as evidenced by very thin surface glass layers, and the temperatures did not significantly exceed 1700 °C to melt quartz (also accessory zircon, monazite and rutile have been commonly preserved from the original rocks).

Melt injections and secondary projectiles. Injections of basic, mica-derived or feldspar-derived melt have been observed in the intergranular space and in fractures (formed during the impact, probably by spallation in many cases) in the primary minerals preserved, mainly in quartz and zircon. In extreme cases the melt filled abundant, down to 1 micrometer thin fractures in zircon, where it solidified to glass and tiny Fe-Al oxide crystals (Fig. 1). Either the melt viscosity had to be extremely low (due to very high temperature), or, more likely, there was a pressure gradient. This could be explained by underpressure after rebound of compressed crystals and suction of the surrounding melt. Note that zircon is commonly used in refractory materials for high-temperature industrial processes, and formation of numerous open fractures in zircon only by heating is improbable.

Injections of basic melt into quartzite pebbles are also visible. No reactions of this melt with quartz have been found. The minerals crystallized from the melt (glass) are usually acicular to skeletal and include clinopyroxene, plagioclase, orthopyroxene/olivine and magnetite; a possible primary mineral preserved from the mafic rock is Mg-rich titanomagnetite. Injections of the melt are frequently accompanied by expansion, forming stretched bridges in the quartzite (even from not melted minerals). Another feature of the basic melts is formation of small spheroid cavities where plagioclase and mafic minerals crystallized. These cavities testify for significant gas pressure. Relatively low content of siderophile elements in the basic melt injections precludes their meteoritic origin. Instead, they probably formed by melting of secondary projectiles consisting of mafic rocks like amphibolite. Easy melting and expansion of basic pebbles can be explained by their high content of hydrous minerals, including secondary ones.

Energy source for melting inside the pebbles: I suggest that transformation of shock waves to heat in the soft minerals like micas was significant. No evidence has been found for high pressure in the order of tens of GPa which is usually considered necessary for shock-induced melting [7]. While the peak pressure could be insufficient for instantaneous melting, it could be repeated several times due to collisions of individual pebbles. In addition, underpressure during rebound of the previously compressed minerals and rocks could help to melt expansion and partial evaporation.

Conclusion: The large "void" space among individual pebbles and mutual collisions of pebbles after the impact and explosion of meteorite in coarse unconsolidated targets are important factors which support melting and cause complicated relations between melting and deformation. It can be expected that classical shock effects like PDFs in quartz develop in such targets only at pressure greater than necessary for significant melting, which is another reason why they are rarely found in small craters (see also [8]). Looking for remnants of stone meteorites is both time- and cost consuming. Therefore, unusual deformations are useful indicators of impact in cases where neither definite evidence for impact nor other explanation of the structure was found.

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Fig. 1: Zircon in impure quartzite (crater No. 5), with fine fractures (probably including spallation fractures) filled with glass (dark) and tiny Fe-Al oxide crystals, similar to the glass in the surroundings. Also note the shear movements and pull-apart of individual zircon fragments. Back-scattered electron image.