THE FATE OF CARBONATES DURING THE FORMATION OF THE RIES IMPACT STRUCTURE, GERMANY.

G. R. Osinski. Centre for Planetary Science and Exploration/Depts. Earth Sciences/Physics and Astronomy, University of Western Ontario, London, ON N6A 5B7, Canada (gosinski@uwo.ca).

Introduction: Meteorite impact events are a fundamental geological process through the Solar System and, in recent years, it has been recognized that they have shaped the geological and biological evolution of Earth. One of the major advancements in the past few decades was the realization that large impact events have caused significant environmental change that has contributed to at least one mass extinction event – the Cretaceous-Paleogene event 65 Myr. ago [1]. Following the discovery of the Chicxulub impact structure in present-day Mexico [2], much research has been conducted into the cause(s) of the mass extinction [3]. The exact killing mechanism(s) remain debated; however, what is clear is the fact that the Chicxulub impact occurred into a target comprising ~3 km of interbedded carbonates and evaporites and that this 'target effect' played a major role in the ensuing mass extinction.

Unlike impacts into dense, non-porous crystalline rocks, the response of porous and volatile-rich sedimentary rocks to impact remains debated. Historically, it was thought that carbonates (e.g., $CaCO_3$ [calcite] and $CaMg(CO_3)_2$ [dolomite]) and evaporites (e.g., $CaSO_4.2H_2O$ [gypsum]) decompose during impact to produce large amounts of climatically active CO_2 and various S species, respectively [4]. More recently, it has become apparent that melting of these lithologies is also an important process (see review in [5]). In this contribution, the fate of limestones at the Ries impact structure, Germany, is revisited.

Ries impact structure: The ~24 km diameter Ries impact structure, Germany, is one of the best preserved complex impact structures on Earth [6]. The impact occurred ~14.5 Myr. ago in a flat-lying sequence of predominantly Mesozoic sedimentary rocks that unconformably overlay Hercynian crystalline basement [7]. The thickness of the sedimentary sequence is estimated at ~470–820 m at the time of impact and comprises, from the base upwards, sandstones and shales and the thick Malm limestone that outcropped at the surface, in places, at the time of impact.

A series of impactites (impact-produced rocks) are present within and around the Ries structure. Impact melt-bearing crater-fill breccias ("crater suevites") occur within a central cavity ~12 km in diameter, overlain by a ~400 m thick series of post-impact lacustrine sedimentary rocks [6]. The crater suevites have been sampled by three drill holes (Deiningen, Nördlingen 1973, and Hole 1001). The central basin is bounded by the so-called "inner ring", which is composed of weakly shocked rocks from the uppermost part of the crystalline basement, together with sedimentary lithologies. This inner basin is surrounded by the megablock zone, which comprises a chaotic mixture of large (m to 100 m scale) blocks of both crystalline and sedimentary rocks. Various different types of proximal impactites occur within this megablock zone and outside the crater rim: (1) Bunte Breccia and megablocks; (2) polymict crystalline breccias; (3) 'surficial' or 'outer' suevites; (4) coherent impact melt rocks.

Previous studies of carbonates at the Ries impact structure: Several previous studies have studied carbonates at the Ries impact structure [8–12]. Interpretation of their origin is not straightforward as they may be *pre-impact* (i.e., fragments of the pre-impact Malm limestones), *syn-impact* (i.e., impact melt products or the products of decomposition), *immediately post-impact* (i.e., produced during the impact-generated hydrothermal system) or *significantly post-impact* (i.e., diagenetic or modern day weathering products). The most recent studies have generally favoured a combined impact melt and hydrothermal origin for the majority of the obviously syn- or post-impact carbonates [8, 10–12]. However, in a recent review, Stöffler et al. [13] dismiss this large body of previous peer-reviewed literature and, based on no provided data, suggest that the volume of carbonate melt "is subordinate and cannot be derived from shock-molten Malmian limestone".

Methods: Polished thin sections of ~60 impact melt-bearing breccia samples from both the crater and surficial or outer suevites were investigated using a combination of optical microscopy and back-scattered electron imagery and wavelength dispersive spectrometry on a JEOL 8530 hyperprobe at the University of Western Ontario.

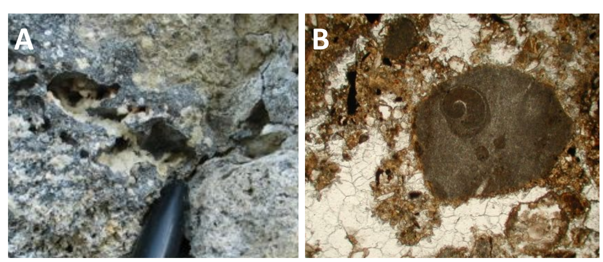

Fig. 1. A. Field image showing vuggy calcite of hydrothermal origin from the Seelbronn quarry. Image is 5 cm across. **B.** Plane polarized light photomicrograph showing a clast of pre-impact Malm limestone with an intact gastropod fossil. Calcite also occurs in the groundmass (white, bottom right).

Results – Hydrothermal and Pre-Impact Carbonates. It is clear from this study that carbonates of hydrothermal origin and clasts of pre-impact Malm limestones do occur within the impact melt-bearing breccias of the Ries structure as shown in Figure 1A and 1B, respectively. However, it is possible with consideration of textures and chemistry to distinguish these carbonates from those that are clearly of an impact melt origin, as shown in the next section.

Results – Carbonates of Impact Melt Origin. Notwithstanding previous studies at the Ries that have proposed an impact melt origin for carbonates, further new evidence is presented below:

Liquid immiscible textures. Because of the different physical properties of carbonate and silicate melts, a mixture of impact melts derived from carbonate and silicate rocks will likely not mix and homogenize. Accordingly, textural evidence immiscible textures between calcite and silicate phases (e.g., ocellar or emulsion textures of globules of carbonate in silicate glass, sharp menisci and budding between silicate and carbonate glasses, and deformable and coalescing carbonate spheres within silicate glass) are widespread at the Ries. Such textures provide unequivocal evidence for carbonates and silicate glasses being in the liquid state at the same time.

Carbonate spherules and globules. Individual calcite spherules and more irregularly-shaped globules are common at the Ries structure. In the Wörnitzostheim core, certain horizons are dominated by globular calcite textures (Fig. 2A) to the extent that these sections may be termed carbonate impact melt rocks equivalent to carbonatite igneous rocks.

Vesicular carbonates. Because of the ionic nature of carbonate melts they do not form glasses no matter how fast the cooling rate. However, in the Ries impact melt-bearing breccias, there are unique angular fragments of calcite that contain vesicles. To the knowledge of the author such textures have not been documented to date at any other terrestrial impact crater. The simplest explanation for these textures is that they represent rapidly quenched particles of carbonate melt which, if the melt was silicate, would be a vesicular glass.

Carbonate chemistry. Analyses of the above carbonates possessing textural evidence of a melt origin show a distinctly different composition to the vuggy calcite shown in Figure 1A. In general, the hydrothermal vuggy calcite is more-or-less pure $CaCO_3$ with only trace (<1 wt%) MgO; whereas the calcite with textural evidence for a melt origin typically contains >1 wt% MnO and FeO. This distinction in composition is consistent with, and supportive of, the melting of carbonates at the Ries.

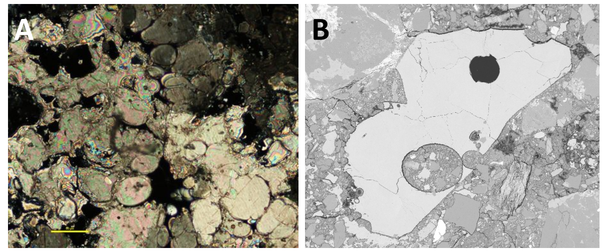

Fig. 2. A. Plane polarized light photomicrograph showing globular calcite in the groundmass of impact melt-bearing breccias in the Wörnitzostheim drill core. Image is 4 mm across. **B.** Backscattered electron image of a vesicular calcite clast (white, encompassing most of the field of view) within impact melt-bearing breccias from the Zipplingen locality.

Discussion and Conclusions: Since the first proposal for carbonate melts at the Ries structure in 1999 by Graup [8], evidence for the melting of carbonates during impact has now been documented at the Chicxulub, Haughton, Meteor Crater, Steinheim, and Tenoumer impact structures [14–18]. In this contribution, new evidence for carbonate melts derived from shock melting of the Malmian limestone at the Ries impact structure is presented, strongly supporting previous suggestions for the melting of carbonates at the Ries [8, 10, 11]. The recent suggestion by Stöffler et al. [13] that carbonate melts are lacking that they "cannot be derived from shock-molten Malmian limestone" is, therefore, surprising and needs to be revisited.

References: [1] Alvarez, L.W. et al. (1980) *Science*, *208*, 4448, 1095–1108. [2] Hildebrand, A.R. et al. (1991) *Geology*, *19*, 867–871. [3] Pierazzo, E. and Artemieva, N. (2012) *ELEMENTS*, *8*, 1, 55–60. [4] Agrinier, P. et al. (2001) *GCA*, *65*, 15, 2615–2632. [5] Osinski, G.R. et al. (2008) *GSA Sp. Pub. 437*. K.R. Evans et al., eds. 1–18. [6] Pohl, J. et al. (1977) *Impact and explosion cratering*. R.B. Merrill et al., eds. Pergamon Press. 343–404. [7] Schmidt-Kaler, H. (1978) *In* E.C.T. Chao et al., eds. Verlag Bayerisches Geologisches Landesamt. 8–11. [8] Graup, G. (1999) *MAPS*, *34*, 425–438. [9] Baranyi, I. (1980) *Beiträge zur naturkundlichen Forschung Südwest-Deutschlands*, *39*, 37–56. [10] Osinski, G.R. (2003) *MAPS*, *38*, 11, 1641–1668. [11] Osinski, G.R. et al. (2004) *MAPS 39*, 10, 1655–1684. [12] Osinski, G.R. (2005) *Geofluids*, *5*, 202–220. [13] Stöffler, D. et al. (2013) *MAPS*. [14] Jones, A.P. et al. (2000) *Impacts and the Early Earth, Lecture Notes in Earth Sciences 91*. I. Gilmour and C. Koeberl, eds. Springer-Verlag. 343–361. [15] Osinski, G.R. and Spray, J.G. (2001) *EPSL*, *194*, 1-2, 17–29. [16] Pratesi, G. et al. (2005) *MAPS*, *40*, 1653–1672. [17] Osinski, G.R. et al. (2003) *66th MetSoc*, 5070 pdf. [18] Anders, D. et al. (2011) *Geophysical Research Abstracts*, *13*.

Acknowledgements: GRO acknowledges funding from NSERC, CSA and MDA through his Industrial Research Chair in Planetary Geology.