**EXPLORING THE ORIGIN OF CARBONATES FROM WELL M0077A, CHICXULUB CRATER, MEXICO.** 

N. D. Garroni[1], G. R. Osinski[1] and S. L. Simpson[1]. [1]Centre for Planetary Science and Exploration/Dept. Earth Sciences, University of Western Ontario, London, ON N6A 5B7, Canada (ngarroni@uwo.ca).

**Introduction:** There are ~190 confirmed impact craters on Earth [1] with ~40% formed in carbonate-bearing sedimentary target rocks [2]. Despite this, it is uncertain how carbonates react to hypervelocity impact. Some authors suggest melting occurs [e.g., 2, 3], whereas others suggest they decompose [e.g., 4, 5] producing the residual oxides CaO and MgO from calcite and dolomite respectively, and releasing $CO_2$ into the atmosphere. With pressure reaching well into the hundreds GPa and temperature in the thousands K [6], conditions for both carbonate melting and decomposition are easily attained [7]. Studying how carbonates react to hypervelocity impacts has implications towards planetary exploration as carbonates have been found elsewhere in the solar system, in addition to understanding impact related climate disruptions. In this study, we explore the origins of carbonates in the M0077A drill core within the Chicxulub impact structure, Mexico.

**Chicxulub impact structure:** The Chicxulub crater formed ~66 Ma off the north shore of Yucatan, Mexico. It is estimated to be 190 ± 10 km in diameter [8, 9], and is the only crater on Earth with an unequivocal peak ring [8, 10, 11]. The impact occurred into a seaward thickening, 2 to 3.8 km thick [12] shallow marine sequence [13] composed of near equal amounts of dolomite, limestone and anhydrite, and minor amounts of sandstone and shale [14]. It has been suggested that vaporization of these sedimentary rocks from impact may have caused a large scale climate disruption through the release of climatically active gases, leading to the K-Pg mass extinction event [15].

**Previous discoveries of carbonate melt at Chicxulub impact structure:** Several studies have investigated impactites (impact-produced rocks) and, more specifically, the effect of impact melting on carbonate rocks from several wells in the area and have discovered evidence for primary carbonate melt [16–20]: feathery-textured carbonates, theorized to represent rapidly quenched carbonate melt under stress; irregular shaped "blebs" of carbonate, which may represent immiscibility textures; carbonate melt groundmass; and exsolution of carbonate melt as droplet-like inclusions.

**Rocks from well M0077A :** Underlying the post-impact Paleogene deposits is 104 m of impact melt-bearing breccia (unit 2) followed by 25 m of impact melt rock (unit 3) [21]. Unit 2 is divided into three sub-units (2A, 2B and 2C) based on clast size and melt content, both increasing with depth. Unit 3 is divided into two sub-units (3A and 3B) based on the occurrence of schlieren texture, as seen in unit 3A.

**Methods:** Samples obtained from core M0077A, drilled during Expedition 364 of the International Ocean Discovery Program and International Continental Scientific Drilling Program, were used for this study. Polished thin sections from ~20 depths throughout the impact melt-bearing breccia (unit 2) and impact melt rocks (unit 3) were investigated using a combination of (1) optical microscopy, and (2) back-scattered electron imagery with wavelength dispersive X-ray spectroscopy (WDS): the former using a Nikon Eclipse LV100 POL microscope with a Nikon DS-Ri1 mounted camera; and latter using a JEOL JXA-8530F field-emission electron microprobe, both at the University of Western Ontario.

**Results—Post-impact hydrothermal and pre-impact carbonates:** It is clear that carbonates of pre-impact limestones and hydrothermal origin do occur in the impact melt-bearing breccias (unit 2). Sedimentary features such as laminations have been observed in some limestone clasts and others have preserved foraminifera (Fig. 1A), both indicative of pre-impact origin. Post-impact hydrothermal activity is prevalent throughout units 2 and 3 as coarse crystalline calcite, some of which has been shown to contain elevated concentrations of manganese. Additionally, at some localities, a zeolite phase predates the calcite (Fig. 1B).
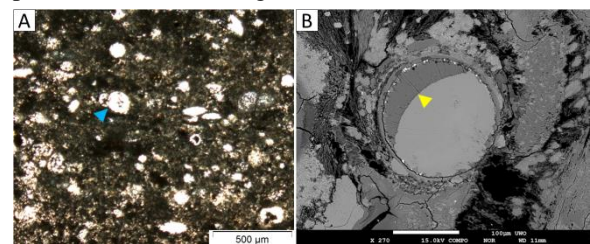


**Figure 1: A** – Plane polarized light microphotograph showing clast of pre-impact limestone. Pelagic foraminifera highlighted by blue arrow. Image is ~1.7 mm across. Section is from 65R-1, 11.5-13.5 cm (688.025 mbsf). **B** – Backscatter electron image of carbonate-silicate melt immiscibility replaced by secondary zeolite and calcite (alternatively could be a vesicle that was later filled). Zeolite phase (yellow arrow) pre-dates the calcite phase (light grey fill). Image is ~0.4 mm across. Section is from 53R-2, 17.5-19.5 cm (657.115 mbsf).

**Results—Textures from impact melt carbonates:** Below we describe new evidence of carbonate melts at Chicxulub from the Expedition 364 well M0077A.

*Irregular carbonate spherules:* Large, sub-rounded carbonate bodies occur in unit 2A (Fig. 2A). They are between 1 and 5 mm large and are commonly witnessed in core and thin section. These features are relatively durable as hydrothermal alteration has not destroyed all of the original fabric; some even show what appear to be budded melt droplets, which are accentuated by one or two rims of clay of unknown origin (Fig. 2A).

*Liquid immiscible textures:* Liquid immiscibility between carbonate and silicate melt occurs due to their differing physical properties, which causes a strong non-ideality of mixing [3, and references therein]. Textural evidence for this can be found throughout unit 2 commonly as circular or irregular "blebs" of calcite (now secondary) within a palagonitized silicate melt (Fig. 2B). Vesicles in the silicate melt can of course be used to explain this phenomenon, and for some, that may be the case. However, certain features are best explained by melt immiscibility, such as curved menisci of what is now palagonite between two "blebs" of calcite, which also exhibit directional flowage of melt as seen in Fig. 2B. This was first described by Graup [3] at the Ries impact crater, Germany.

In the melt-rich breccia of unit 2C are a second variety of irregular carbonate blebs. These carbonates have an envelope of clay and occur within a pyroxene, plagioclase and glass dominated matrix (Fig. 2C). The majority are aligned in the direction of flow with some being nearly stretched apart and others taking on a "teardrop" shape (Fig. 2D). As with the majority of the carbonates found in M0077A, these are likely to have been replaced by secondary calcite.

**Discussion and conclusions:** Hydrothermal activity has altered much of the impact melt-bearing breccia at Chicxulub. Despite this, carbonate melt features have been found in three other wells across the crater, in addition to ejecta deposits (e.g., [16–20]). In this contribution, we provide new evidence from the offshore well, M0077A providing additional support to these previous claims. The aforementioned liquid immiscibility textures and irregular carbonate spherules are compelling to the argument; however, they also have their shortcomings that cannot be ignored, i.e. gas vesicles to explain immiscible carbonates, and altered limestone clasts to explain spherules. As such, unravelling the fate of carbonates at the Chicxulub structure is an ongoing and difficult task.
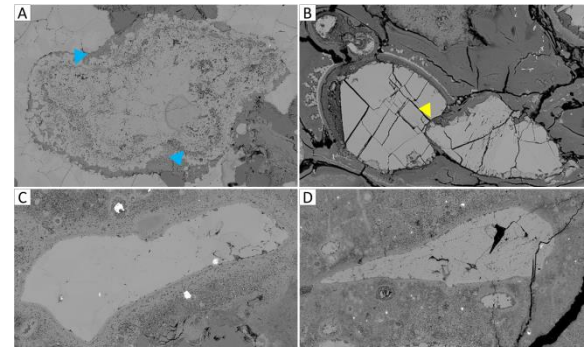


**Figure 2: A** – Irregular carbonate spherule enveloped by secondary calcite and zeolite. Hemispherical protuberances, interpreted as budded melt droplets, highlighted by blue arrows. Image is ~2.25 mm across. Section is from 53R-3, 50-51 cm (658.490 mbsf). **B** – Two melt "blebs" converging with a meniscus of silicate glass (now altered to palagonite) highlighted by yellow arrow. Image is ~0.5 mm across. Section is from 61R-2, 42-43 cm (679.510 mbsf). **C** – Irregular carbonate bleb with thin clay envelope. Image is ~1.1 mm across. Section is from 83R-1, 54.5-56.5 cm (712.625 mbsf). **D** – "Teardrop" shaped carbonate bleb aligned with direction of flow. Image is ~3.0 mm across. Section is from 83R-1, 54.5-56.5 cm (712.625 mbsf).

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