WHAT CAN BE LEARNED FROM DRILLING INTO IMPACT CRATERS: A REVIEW OF RECENT PROJECTS. Christian Koeberl[1] [1]Department of Lithospheric Research, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria. E-mail: christian.koeberl@univie.ac.at.

Introduction: Currently about 170 impact craters are known on Earth; about one third of those structures is not exposed on the surface and can only be studied by geophysics or drilling. The impact origin of geological structures can only be confirmed by petrographic and geochemical studies; thus, it is of crucial importance to obtain samples of subsurface structures. In addition, structures that have surface exposures often require drilling and drill cores, to obtain information of the subsurface structure, to provide groundtruth for geophysical studies, and to obtain samples of rock types not exposed at the surface.

Motivation to Drill (Status): Of the about 175 individual terrestrial impact structures see http://www.unb.ca/passc/ImpactDatabase/ - although the evidence for a few of those listed is not very strong) and other small crater fields currently identified, about half have been drilled in some way or another, although this does not mean that cores were obtained, that drill cores are preserved anywhere for study, or that that the drilling was documented and published. Of those that were drilled, 90% are not exposed on the surface. The initial motivation to drill these structures was either scientific or economic. Drilling was accomplished in order to: (1) confirm the presence of an impact structure and to learn about the physicochemical processes involved through the study of crater geology; and (2) satisfy economic geological interests, such as exploration for hydrocarbons in structural traps. The economic motivation has largely been potential recovery of commercial quantities of hydrocarbons. Indeed, the potential to discover producible quantities of hydrocarbons at terrestrial impact structures is relatively high in sedimentary basins known to contain hydrocarbons, e.g., in North America, approximately 50 % of the known impact structures in hydrocarbon-bearing basins have commercial oil and/or gas fields.

Successful drilling was performed at a number of craters in the form of local, regional, national, or otherwise collaborative projects. Examples are drilling projects in Canada and the former USSR. In many of those cases cores were not documented to the degree that conforms to present-day standards, and/or core are no longer preserved. Other examples of drilling projects include those at the Ries, Manson, Tswaing, Kalkkop, Puchez-Katunki, Morokweng, and Mjolnir craters.

More recently the International Continental Scientific Drilling Program (ICDP) has supported projects to study impact craters. The first ICDP-supported study of an impact structure was the drilling into the 200-km-diameter, K-T boundary age, subsurface Chicxulub impact crater, Mexico, occurred 2001/2, followed by drillings into the Bosumtwi and Chesapeake Bay craters. Soon the El’gygytgyn crater in Siberia will be drilled. For more program details see [1].

Chicxulub: Chicxulub, centered at N 21° 20' and W 89° 30' on the Yucatán Peninsula, México, is the world’s third largest known impact structure on Earth. Its formation is widely accepted to have been responsible for the dramatic environmental changes at the Cretaceous-Tertiary (KT) boundary.

The ICDP-financed borehole Yaxcopoil-1 was drilled from December 2001 through March 2002 in the southern sector of the crater. This spot is located about 62 km from the approximate crater center, just off the characteristic high-amplitude magnetic anomalies observed across the central uplift as defined by gravity and seismic data. The Yaxcopoil-1 (Yax-1) borehole was planned to core continuously into the lower part of the post-impact carbonate sequence, the impact breccias, and the displaced Cretaceous rocks. The actual drill site was selected for a variety of logistical reasons. Drilling extended to a depth of 1,510 m. Approximately 795 m of post-impact Tertiary carbonate rocks, 100 m of impactites, and 615 m of pre-impact Cretaceous rocks (megablock) were intercepted. The Tertiary rocks are composed of interlayered carbonaceous siltstones, calcarenite, and rare conglomerate and turbidite. The impactites are composed of suevitic and impact melt breccias that have both undergone significant alteration. These impact breccias have been subdivided into 5 units based on macro- and microscopic observations.

Drill results together with geophysical and borehole database, including new offshore marine seismic data, led to a revised crustal model for the multi-ring Chicxulub structure. The main results were published in two special issues of the journal *Meteoritics and Planetary Science* in June and July 2004. However, given the size of Chicxulub, many questions remain open and additional questions came up as a result of the Yax-1 core results, making Chicxulub an ideal candidate for further drilling studies

Bosumtwi: The 1.07 Ma, 11 km diameter Bosumtwi impact crater in Ghana is one of only four known impact craters associated with a tektite strewn field. It is a well-preserved complex young impact structure, displays a pronounced rim, and is almost completely filled by Lake Bosumtwi, a hydrologically closed basin. Basement rocks are 2.1-2.2 Ga metasediments and metavolcanics of the Birimian Supergroup. Seismic reflection and refraction data defined the position of a 1.9-km-diameter central uplift. An international and multidisciplinary ICDP-led drilling project combined two major scientific interests in this crater: to obtain a complete paleoenvironmental record from the time of crater formation about one million years ago, at a near-equatorial location in Africa, for which very few data are available so far, and to obtain a complete record of impactites at the central uplift and in the crater moat, for ground truthing and comparison with other structures.

The project resulted in retrieval of 16 drillcores within the 8.5-km-diameter Lake Bosumtwi, using the GLAD-800 lake drilling system, from June to October 2004. The 14 sediment cores are being investigated for paleoenvironmental indicators. The two impactite cores, LB-07A and LB-08A were drilled into the deepest section of the annular moat (540 m) and the flank of the central uplift (450 m), respectively. They were the main subject of a special issue of "Meteoritics and Planetary Science" (April/May 2007). Drilling progressed in both cases through the melt rock/impact breccia layer into fractured bedrock. LB-07A comprises lithic (in the uppermost part) and suevitic impact breccias with appreciable amounts of impact melt fragments. Core LB-08A comprises suevitic breccia in the uppermost part, followed with depth by a thick sequence of greywacke dominated metasediment with suevite and a few granitoid dike intercalations. It is assumed that the metasediment package represents bedrock intersected in the flank of the central uplift. I

The results from the Bosumtwi impact crater scientific drilling project are important for comparative studies and re-evaluation of existing data from other terrestrial impact craters, and to understand essential aspects of the impact process.

Chesapeake Bay: This impact structure, 35 Myr old and 85 km in diameter, is one of the largest and best preserved impact structures on Earth. The structure was drilled in the central part at Eyreville in 2005-2006 during an ICDP-USGS drilling project. Three drill cores (Eyreville A, B, and C), intersecting the impact structure to a total depth of 1766 m, were recovered within the central zone of the structure in the deep crater moat. The crater fill comprises post-impact sediments, sediment clast breccias and sedimentary megablocks (the so-called Exmore breccia beds, interpreted as resurge breccias), a large granitic and a small amphibolitic megablock, gravelly sand, suevites and lithic impact breccias (1397-1551 m), and granites/pegmatites and mica schists. In the upper part (above ~1474 m) of the section the suevite is mostly melt rich and contains two intervals (5.5 and 1 m thick) of impact melt rock. In the deeper parts of the section (below 1474 m) mostly suevitic polymict impact breccia alternates with large blocks of cataclastic gneiss. Results of this project are currently being prepared for publication.

Outlook: In 2009 the 18-km-diameter, 3.6 Ma El'gygytgyn impact structure will be drilled in yet another ICDP project, providing again an opportuneity to marry paleoclimate and impact research. This structure is unusual in that the impact occurred into acid volcanic rocks.

However, it is necessary to discuss suggestions towards future drilling projects that are relevant for impact research: what is the importance of studying impact craters and processes, why is it important to drill impact craters or impact crater lakes, which important questions can be answered by drilling, which craters would be good targets and why; is there anything about the impact process, or of impact relevance, that can be learned by drilling outside any craters; what goals should be set for the future; how important is collaboration between different scientific fields collaborating between different science fields? Ipmact cratering studies have much to gain from experience from past drilling projects (ICDP and others), and future scientific drilling of impact structures will provide crucial importance to help us understand the formation of such structures and their geological and biological importance.

References: [1] Koeberl, C., and Milkereit, B. (2007) Continental drilling and the study of impact craters and processes – an ICDP perspective. In: *Continental Scientific Drilling* (eds. Harms, U., Koeberl, C., and Zoback, M.D.), Springer, Heidelberg, p. 95-161.

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