PETROGRAPHY AND GEOCHEMISTRY OF DRILL CORE SAMPLES FROM THE SERPENT MOUND STRUCTURE, OHIO: CONFIRMATION OF IMPACT ORIGIN. Christian Koeberl[1], Paul C. Buchanan[1], and Richard W. Carlton[2]. [1]*Institute of Geochemistry, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria (christian.koeberl@univie.ac.at);* [2]*Ohio Division of Geological Survey, 4383 Fountain Square Dr., Columbus, OH 43224, U.S.A.*

Summary: Rocks from two recently drilled cores into the Serpent Mound structure, south-central Ohio, were studied for their petrographical and geochemical characteristics. The cores were drilled near the central uplift and in the annular outer zone, and reached depths of 903 and 629 m, respectively. Samples of the core from various depth in the central uplift showed abundant evidence for shock metamorphism in the form of multiple sets of planar deformation features (PDFs) in quartz, confirming the impact origin for the Serpent Mound structure. Crystallographic orientations of the PDFs indicate a fairly high shock level. Three samples were analyzed for major and trace element compositions: two breccia samples and one breccia host rock sample (carbonate-rich). Minor enrichments in siderophile elements (Cr, Co, Ni, Ir) indicate the possible presence of about 0.2 % of a meteoritic component in the breccia samples.

Introduction and Geology: The Serpent Mound structure has a diameter of about 8 km and is located in northern Adams County, Ohio. The structure, which is situated in a generally undisturbed region at the western edge of the Appalachian escarpment, is marked by a central uplift consisting of a circular region of intensely deformed, faulted, and brecciated Ordovician to Mississippian rocks that have been uplifted at least 300-400 m above their normal stratigraphic position. The central uplift, which is characterized by seven radially oriented anticlines, forms a topographic high and is surrounded by a transition zone. This zone consists mainly of Silurian dolomites and limestones and is surrounded by a ring graben that is defined by concentric faults (e.g., [1, 2]). The rocks of the ring graben are mainly of Devonian and Mississippian age and are at stratigraphically lower positions than normal. The structure is also evident in seismic profiles of the area [2]. Abundant sphalerite mineralization is found in fault breccias and fractures over most of the structure, mainly hosted within Silurian carbonate rocks. The name Serpent Mound refers to a large Native American monument on the western flank of the structure (a 450 m long mound in the form of an uncoiling serpent), which was probably constructed between 800 B.C. and 100 A.D.

The structure was suspected by Dietz [3] to be of impact origin because of the occurrence of abundant shatter cones, which are found mainly in Ordovician limestone from the central uplift. Furthermore, the high-pressure quartz modification coesite has been found in samples from the Middle Silurian dolomite at the central uplift (Cohen et al., [4, 5]), although this identification was later doubted [1, 2]. While the impact origin of Serpent Mound found some acceptance (cf. [6]), no confirming evidence in the form of shock-characteristic planar deformation features (PDFs) in rock-forming minerals from the structure was available so far. This led Hansen [2] to embrace the non-descriptive "cryptoexplosion" origin for the feature. The situation changed in 1993, when two drill cores that were obtained in 1979 by the J.L. Carroll Exploration Company were donated to the Ohio Division of Geological Survey. The first core (DGS 3274) was drilled in the central uplift to a depth of 903 m, and the second core (DGS 3275) was drilled in the disturbed transition zone to a depth of 629 m. The core in the central uplift penetrates Silurian and Ordovician carbonates, shales, and minor sandstones, chert, and K-bentonites. A variety of breccia types are abundant in the core. Shatter cone fragments are found within these drill cores as well [2]. Breccia dikes with widths of mm to cm are common. More details on the cores are reported elsewhere [7, 8].

Samples and Methods: More than 20 samples from core #3274 were taken for petrographical studies. Petrographic thin sections of these samples were studied by optical microscopy to classify the rock type and to study any evidence of shock metamorphism, if present. Crystallographic orientations of the PDFs were measured on the optical microscope using a universal stage with 4 axes. In addition, major and trace element analyses were done on three breccia samples by standard X-ray fluorescence (XRF) and instrumental neutron activation analysis (INAA) procedures.

Results: Breccias in core #3274 (from the central uplift) were found to be composed predominantly of carbonate sedimentary rocks in a carbonate matrix. Some samples represent semi-mature, moderately sorted quartz sandstone with small amounts of quartz cement. Individual grains display undulatory extinction. Some mylonitic veins are present as well. Lithic clasts within the carbonate-rich breccias contain abundant shell fragments and other fossils. Grain mounts were made from a breccia (depth about 438 m) by dissolution of the carbonate matrix and mounting the remaining quartz, feldspar, epidote, and opaque minerals in epoxy. Quartz grains in these samples are shock metamorphosed to variable degrees. Moderate (single sets of PDFs in a few quartz grains) to high degrees of shock metamorphism are common. Grains containing two to three sets of PDFs are most abundant (Fig. 1a,b). A maximum of six sets of PDFs per grain was observed. For the measurement of the crystallographic orientations of the PDFs, only quartz grains displaying two or more sets of PDFs were analyzed to allow some confidence in assignment of crystallographic planes relative to the a_1, a_2, and a_3 axes. Ninety-six grains were analyzed and orientations for 232 sets of PDFs were determined in these grains. Of these, 170 sets of PDFs (73 %) could be assigned with confidence to a rational crystallographic plane. The results show a clear maximum at the shock-characteristic orientations of {1013} and {1012}. Less pronounced maxima occur at the {1011}, {2131}, and {5161} orientations. Basal (0001) orientations are rare. The distribution of orientations of PDFs in samples from the Serpent Mound structure suggests that the shock levels experienced by these rocks were relatively high ($>$ 10 GPa) and confirm that the structure formed by hypervelocity impact.

The major element abundances confirm that these samples are carbonate-dominated sediments. All samples are rich in CaO (15 - 61 wt%) and have high loss on ignition values (26 - 42 wt%). The SiO_2 contents range from about 1.5 to 32 wt%. The trace element compositions are typical of sedimentary rocks with a major dolomite or limestone component. The host-rock for the breccia in SM1-16b is limestone with minor silica and high Sr contents, while the breccia dike has a composition with a slightly lower content of volatiles. The chondrite-normalized rare earth element patterns are also typical for upper crustal rocks, with La_N/Yb_N ratios of about 5-8 and minor to moderate negative Eu anomalies (Fig. 2). The limestone-dominated rock has much lower REE abundances and a slight increase towards the heavy REEs in a chondrite-normalized diagram, indicating admixture of a minor amount a heavy-REE rich trace mineral. Particular attention was paid to siderophile element contents to determine the possible presence of an extraterrestrial component. Because of the carbonate-dominated composition of the breccias, detection limits for Ir were quite favorable by INAA. Compared to the limestone-dominated host rock (SM1-16b), the two breccia samples show enrichments in Cr, Co, Ni, and Ir. This is especially obvious in the case of the breccia-host rock pair (SM1-16a/b), with Cr, Co, and Ni values being about 10 times higher in the breccia than in the host rock, and Ir being significantly enriched as well (to about 0.2 ppb). Taken at face value, this would be indicative of the presence of about 0.2 % of an extraterrestrial component with chondritic composition.

Acknowledgments: This work was supported by the Austrian Science Foundation FWF (project Start Y-58) (to C.K.). We acknowledge the John L. Carroll Mineral Exploration Company for the donation of the cores, which are stored at the Ohio Division of Geological Survey (DGS). B. Abate (Univ. Vienna) helped with some of the analyses.

References: [1] Reidel, S. P., et al., Am. J. Science, 282, 1343-1377, 1982; [2] Hansen, M. C., Ohio Geology, 1994 - Winter, p. 1-7, 1994; [3] Dietz, R. S., Science, 131, 1781-1784, 1960; [4] Cohen, A. J., et al., Science, 134, 1624-1625, 1961; [5] Cohen, A. J., et al., J. Geophys. Res. 67, 1632-1633, 1962; [6] Koeberl, C., and Anderson, R.A., in GSA Special Paper 302, p. 1-29, 1996; [7] Baranoski, M., et al., Ohio Div. Geol. Survey Report of Investigations, 1998, in review; [8] Carlton, R. W., et al., Geology, 1998, submitted.

Fig. 1a. Photomicrograph of fine-grained sandstone in sample SM1-27 (870 m depth), showing abundant fracturing - but no PDFs - in the somewhat rounded quartz grains. Photo taken with parallel polars, 2 mm wide.

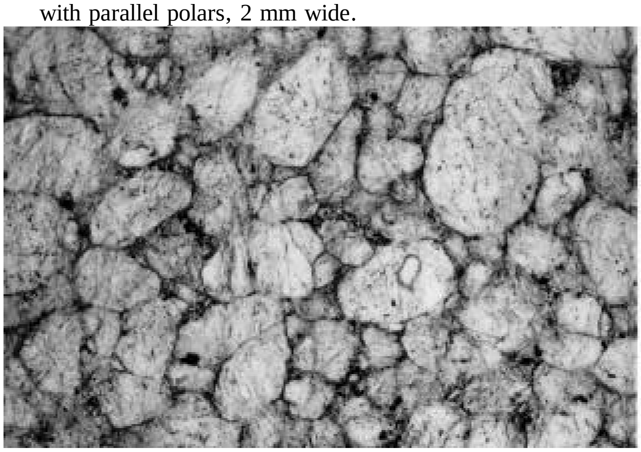

Fig. 1b. Photomicrograph of a quartz grain in sample SM1-36a (438 m depth) displaying at least two sets of PDFs (arrows). Crossed polars, 0.3 mm wide..

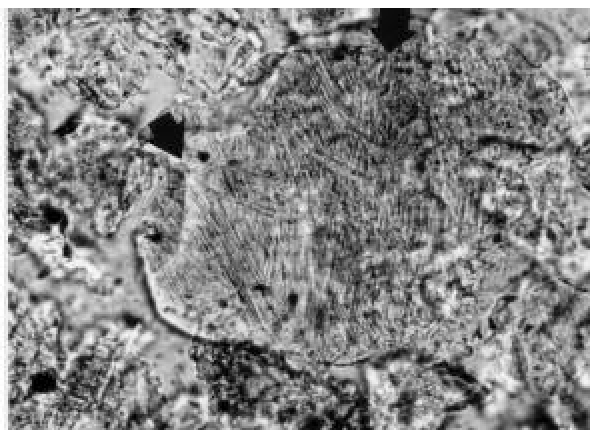

Fig. 2. Chondrite-normalized rare earth element abundances in a breccia-host rock pair (SM1-16a/b) and a different breccia from the Serpent Mound drill core DGS 3274.