A REVISED DIAMETER FOR THE SERPENT MOUND IMPACT CRATER IN SOUTHERN OHIO.
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Introduction: The Serpent Mound crater (centered at 39.0356° N, 83.4039° W) is the only confirmed impact crater in the state of Ohio. It is a complex crater by type with evidence of shock metamorphism [1-4] required for impact crater identification [5]. Like all complex craters, it contains a central peak of structurally-uplifted material [6-9]. This peak of Upper Ordovician to Middle Silurian-aged carbonate rock [7-8] is surrounded by a circular graben of Middle Silurian-Lower Mississippian sedimentary rock [7]. Circumferential normal faults defining the outside edge of this graben approximate the outermost boundary of a 7-8 km diameter circular disturbed area [7].

This estimate [7] however, does not represent the total diameter of the Serpent Mound impact crater. Central peaks and the surrounding crater floors (that have been displaced downward from normal position – i.e. a "ring graben") are only part of the overall morphology of complex craters. While these have been observed at Serpent Mound [7-8], a rim has not previously been identified. The apparent lack of a rim may relate to extensive erosion in southern Ohio, especially near the western part of the crater. In the northwest, glacial activity [7] has removed morphologic traces of a rim and deposited glacial till [7], while in the southwest, drainage along Brush Creek has eroded into the crater interior as far as the ring graben. Along the east side of the crater, between the graben and the Allegheny Escarpment, the landscape consists of rolling farmland, a dearth of bedrock exposures and no topographic indication of a rim. These preclude extensive field investigations in this area; therefore a new approach was needed. This study applies known crater morphometric relationships to the Serpent Mound impact structure and involves the analysis of new data sets to determine if a crater rim can be identified and the true diameter of the crater can be constrained.

A Morphometric Model: [9] demonstrated that terrestrial complex craters, the mean morphometric relationship between the base diameter of the central peak (D_{cp}) and the final rim-to-rim crater diameter (D) is:

$$D_{cp} = (0.23 \pm 0.03)D$$

a relationship comparable to those for complex craters elsewhere in the solar system [10, 11]. This was used to model D of the Serpent Mound crater, but an accurate estimate of D_{cp} was required in order to do this. Previous arbitrary [7] and erroneous [12] estimates have been made resulting in a D_{cp} of 4.8 and 3.7 km respectively. Estimates from this study ranged from 2.6 km using the diameter of the area where shock metamorphism has been documented [7, 9] to 5.0 km measured between prominent slope changes using a digital elevation model (DEM) generated from Shuttle Radar Topography Mission (SRTM) data. These estimates of central peak diameter yielded rim-to-rim diameters ranging from 10-25 km, a range approximately 1.5 to 3x that reported by [7]

Morphologic Traces of a Rim? The same DEM was used to search for morphologic indications of a crater rim. A circular ridge was identified to the east and south of the crater that conformed to the overall shape as delineated by [7]. Eighty-two topographic profiles were made from the center of the crater across the circular ridge and the horizontal distance measured. The center of the crater was defined at a high point in the central peak approximately near the center of the impact crater (39.0356° N, 83.4039° W). Cross sections were produced from this center point along bearings corresponding to places where the circular ridge was present (between N 31.5 E to S 55 E and S 24 E to S 3 E) and ending at points east of the highest point of the ridge. Each radius was measured from the center point to the highest point along the top of the ridge. Radii ranged from 5.07 – 7.06 km, with a mean of 6.01 km and a 1δ standard deviation of 0.455. Values were doubled to model the full rim-to-rim diameter of Serpent Mound based on the assumption that the circular ridge represents vestiges of the rim for the eastern half of the impact crater. Diameters ranged from 10.132 – 14.128 km, with a mean of 12.017 km and a 1δ standard deviation of 0.9044. The highest points of the ridge ranged from 79.93 – 117.19 m above sea level with a mean of 104.14 m and a 1δ standard deviation of 10.85. Variations in radii and high point elevations correspond to local drainage and therefore suggest that erosional modification has affected the morphology of this circular ridge.

Lateral Extent of Structural Deformation: Morphology alone provides only circumstantial evidence of a crater rim. More importantly, examination of structural deformation beyond the crater interior can serve to delineate the location of the modified rim by the identification of concentric normal faults along the periphery. The paucity of exposures beyond the ring graben precludes a thorough examination of the structural geology at the surface.

Subsurface data however, has provided a means of assessing the true lateral extent of structural deformation associated with Serpent Mound. Hundreds of well logs for oil, gas, and water wells for the study area (provided courtesy of the Division of Geological Survey, Ohio Department of Natural Resources) were examined in search of the most evident geologic boundary in the Serpent Mound area – the contact (unconformity) between Middle Silurian carbonates and the fissile brown and black shales of the Upper Devonian Olentangy and Ohio Shales. Well logs for 18 townships in 4 counties were examined in the Division of Geological Survey databases covering the impact structure and the area centered immediately to the east and west of the Allegheny Escarpment where this contact was mostly likely to still be preserved. Devonian shales have been removed by glacial activity to the west and generally dip below most well holes further to the east. Only those drilling logs where the contact between the black shales of the Upper Devonian and the gray or white carbonates of the Middle Silurian was clearly identified and geographic coordinates or street addresses were included in the well log were used for used for subsurface contouring. In the 17 instances where street addresses were the only location information available, lat/long coordinates were collected from the DEM from the center of the property. Contact elevations were determined by subtracting the depth to the contact from the well top elevations provided in each log. In instances where geographic locations had to be approximated, well top elevations were collected from the DEM of the study area. In addition, this study used 7 stations from the [7] geologic map that were suitable for constraining the contact within the crater and 5 stations collected by a Global Positioning System (GPS) receiver (horizontal error of $\leq \pm 3.7$ m) in the Brush Creek township of Highland County where the contact is well exposed (this study).

These data points were imported into a contour surface modeling program (3DField) to produce a contour map of the base of the Devonian in and surrounding the Serpent Mound impact crater. Contouring clearly shows a circular anomaly centered at approximately 39.04° N, -83.39° W. Here the base of the Devonian is up to 58 m lower than the surrounding region and deviates from the eastward regional dip angle and direction (0.08 – 0.09° E). When data from within approximately 7 km of the crater center are removed, the regional dip is restored across the study area, highlighting the influence of the impact crater on this important contact in the area. The maximum displacement exceeds the maximum amount of relief (21.4 m) noted along the unconformity between the Middle Silurian and Upper Devonian strata [13]. Therefore, the extent of downward displacement of the base of the Devonian is spatially associated with the Serpent Mound impact crater and is confined to an area < 14 km in diameter. The low density of well locations per unit area did not allow for discrimination of this downward displacement by faults or folds. Based on knowledge of typical structural deformation in better preserved complex craters, it is assumed that concentric normal faults accommodated this displacement.

Discussion and Conclusion: The 3 methods utilized in this study have provided independent means of constraining the actual diameter of the Serpent Mound impact crater. Morphometric analysis that involved a number of D_{cp} estimates were used to constrain the initial rim-to-rim diameter of Serpent Mound to within 10 – 25 km, a value much larger than the disturbed area mapped by [7]. Reexamination of the landscape surrounding Serpent Mound crater unveiled a circular ridge approximately 5 – 7 km from the center of impact. The circularity of this ridge and its conformity to the shape of that portion of the crater defined by [7] strongly support the hypothesis that this ridge is the eroded remnant of the crater rim in the east. Therefore, the morphology alone suggests that the Serpent Mound impact crater ranges from approximately 10 – 14 km in diameter, a value well within the constraints modeled using the known morphometric relationship: $D_{cp} = (0.23 \pm 0.03)D$ from [9]. The 10-14 km diameter also coincides with the lateral extent of structural deformation (<14 km diameter) as indicated by subsurface contouring. The consistency of modeled crater diameter ranges using multiple techniques, the circularity of the eastern ridge and its conformity to the interior portions of the crater, and the lateral extent and circularity of structural deformation all suggest that the maximum diameter of the Serpent Mound impact crater is approximately 14 km and that the circular ridge east of the disturbed area as defined by [7] represents the eroded remnant of the crater rim.

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