# GRAVITY SURVEY OF THE SERPENT MOUND AREA, SOUTHERN OHIO[1]

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ABSTRACT

Over most of south-central Ohio, the sedimentary Paleozoic rocks exposed at the surface are relatively flat-lying, but in the Serpent Mound area of Highland and Adams Counties they show a circular feature, four miles in diameter, in which the rocks are complexly faulted. This structure has not yet been satisfactorily explained; two of the hypotheses proposed to explain its origin are 1) that it was caused by a "cryptovolcanic" event and 2) that it is an "astrobleme," produced by the impact of a meteoritic body. These two possible mechanisms might be distinguished by the attendant differences in the density variations produced: the cryptovolcanic structure could be associated with large lateral variations in density at the level of the basement rocks, while the meteoritic impact could produce shatter zones and brecciated layers, and small reductions in density in the rock lying closer to the surface. A closely-spaced network of gravity stations extending beyond the limits of the surface expression of the ring structure shows no gravity anomaly pattern that can be related to the surface features. Supporters of the astrobleme hypothesis are more likely to find this evidence useful than are the cryptovolcanists.

## INTRODUCTION

Over most of the area of southern Ohio comprising Highland, Adams, Pike, and Scioto Counties, the sedimentary rocks exposed at the surface are relatively flat-lying, usually dipping less than 1° to the east. In the northeast corner of Adams County, however, is a circular feature, approximately four miles in diameter, in which the normal stratigraphic positions are much disturbed by many intersecting faults (fig. 1). The structure is best described as a central hub surrounded by two concentric annuli. The hub is displaced upwards stratigraphically, and the outer annulus is displaced downwards, while the inner annulus shows little stratigraphic displacement compared with the undisturbed areas surrounding the structure. In these surrounding areas rocks that are mainly

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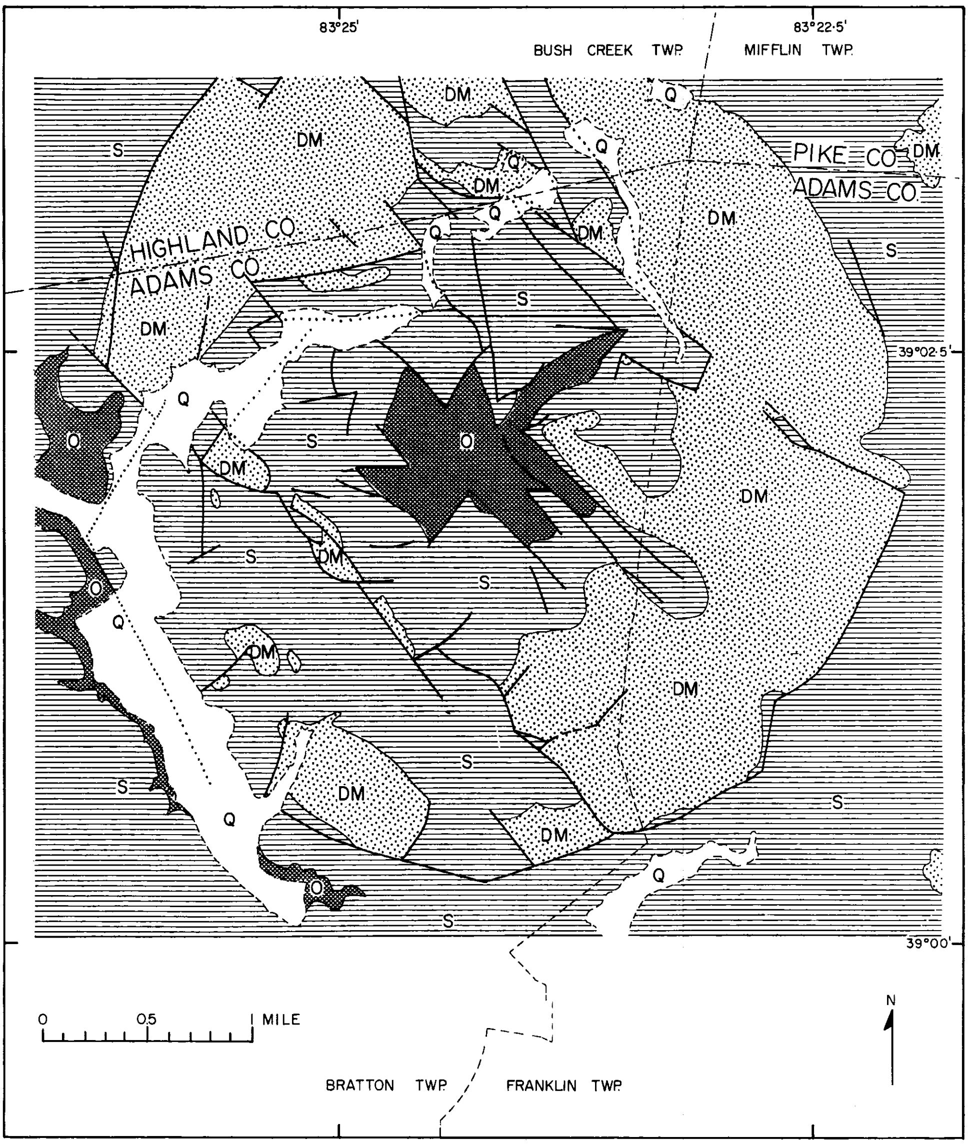
Silurian in age crop out, while within the structure, outcrops of Ordovician, Silurian, Devonian, and Mississippian rocks are present.

Topographically the outer annulus is the highest part of the structure, with the surface rising to a maximum elevation of 1120 feet and being capped by




GEOLOGY AFTER BUCHER (1936)

FIGURE 1

GENERALIZED GEOLOGIC MAP OF SERPENT MOUND AREA, OHIO

Q QUATERNARY SYSTEM — S SILURIAN SYSTEM — CONTACT

DM DEVONIAN AND MISSISSIPPIAN SYSTEMS — O ORDOVICIAN SYSTEM — FAULT

Mississippian sandstone and siltstone. In the inner annulus, surface elevations range from 600 to 800 feet, and the surface rocks are fractured shale, limestone, and dolomite, ranging from Silurian to Devonian in age. The central hub, 700 to 900 feet above sea level, is capped by highly-fractured Ordovician and Silurian limestone and shale (Bucher, 1936). The stratigraphic displacement of these central Ordovician beds, that are at the same elevation as the Mississippian beds of the outer annulus, is approximately 800 feet (Schmidt *et al.*, 1961) and the total thickness of the exposed Paleozoic section is about 950 feet (Bucher, 1936).

The earliest reference to the anomalous nature of the Serpent Mound area is in Dr. John Locke's contribution to the "Second Annual Report on the Geological Survey of the State of Ohio" (1838, p. 266). Under the heading "Observations in the North part of Adams, and the contiguous parts of Highland counties," he wrote, "Although we travelled on that level which should have presented us with the cliff limestone [Silurian], yet we were surprised with its total disappearance as we approached the spring [Sinking Spring, in the southwest corner of Highland County], and in its place was found the sandstone [Mississippian] in large upturned and broken masses. In short, it became evident that a region of no small extent had sunk down several hundred feet, producing faults, dislocations and upturning of the layers of the rocks."

## ORIGIN OF THE STRUCTURE

Two major hypotheses have been presented for the origin of the forces creating the Serpent Mound structure. Bucher (1936) attributed the disturbing forces to "cryptovolcanism," stating that such structures at Serpent Mound and elsewhere " . . . are thought to be the result of a sudden liberation of pent-up volcanic gases, which had accumulated near the surface, the explosion having been too weak to produce a shallow explosion crater . . ." Dietz (1960) described the area of disturbed rocks as an "astrobleme," the origin of the forces being the impact of a meteorite. The forces associated with the propogation of hypervelocity waves produced by the impact are believed to have produced the shatter cones found in the more massive beds near the surface in the disturbed area (Dietz, 1960) and are responsible for the presence of coesite, the high-pressure polymorph of quartz, which has been reported from other areas of meteoritic impact (Chao *et al.*, 1960) and possibly from Serpent Mound (Cohen *et al.*, 1961).

Recently Freeberg (1966) has published an extensive bibliography on structures that are due to impact. She categorized Serpent Mound as one of the "deeply eroded or buried structures possibly of impact origin."

Little can be said of the age of the structure. The youngest beds in the structure which have been disturbed are lower Mississippian, but no more recent limit can be placed on the age of deformation.

## THE GRAVITY SURVEY

The first geophysical work in the area was a magnetic survey by Sappenfield (1950). This survey showed little or no correspondence between magnetic anomaly and surface expression.

To obtain more information on the origin of the structure, a gravity survey was made of the area in 1962 and 1963. If the structure were the result of cryptovolcanism, disturbances could be expected to extend into the basement. These could result in differences in density between the rocks under the feature and those at the same level in the surrounding area. On the other hand, if the structure were an astrobleme, the disturbances could be relatively shallow, perhaps not extending below sea level. Lower density brecciated rocks might be expected under the impact area which might be detected by an areal survey of gravity, but, to do this, a much denser network of gravity stations would be required than that obtained in the only other survey of the area, the general reconnaissance of Ohio (Heiskanen and Uotila, 1956).

Using a new Worden Master Geodetic Gravimeter, the gravity survey was made in the following way. Two complete loops were made between the established gravity station at the 40°N. latitude marker on The Ohio State University campus and a base (base station 7) in Serpent Mound State Park, with intermediate stations at Circleville and Chillicothe. From base station 7, five complete rounds were made to establish nine other base stations at accessible and easily recoverable points throughout the area (fig. 2). For all of this work, the gravity meter was transported by car in a specially designed carrier. Working from the established base stations, local stations were made at 104 other points at approximately ¼-mile spacing within the 4-mile-diameter structure. The usual sets of subsidiary readings at selected points were made over periods of several days at various times during the survey to confirm that the drift rate of the instrument was linear.

Values of station gravity given in table 1 are based on a value of 980.0944(7) gals (1 gal = 1 $cm/sec^2$; 1 milligal, written 1 mgal, = 0.001 $cm/sec^2$) for the station gravity at the 40°N. latitude marker, as determined by Heiskanen and Uotila (1959) by ties to the primary U.S.A. gravity bases. Errors in the value of gravity assumed at this station will not affect the form of the Bouguer anomaly map in the Serpent Mound area. The calibration constant of the instrument, supplied by the manufacturer, was checked in December, 1962, with gravity ties between primary stations in New Zealand and Antarctica. Errors in the manufacturer's calibration were less than 0.2 percent. Tidal corrections were applied to all of the gravity readings used in establishing the base stations. The drift rate remained small and constant throughout the survey and all loops and rounds of readings closed in a most satisfactory manner. Values of gravity at the base stations are not likely to be in error by more than 0.2 mgal, nor at the local stations by more than 0.4 mgal, relative to the 40°N. latitude marker value. A detailed treatment of the errors is given in Zahn's thesis (1965), copies of which are filed in the Main and Orton Libraries of The Ohio State University, and with the Ohio Division of Geological Survey, Columbus.

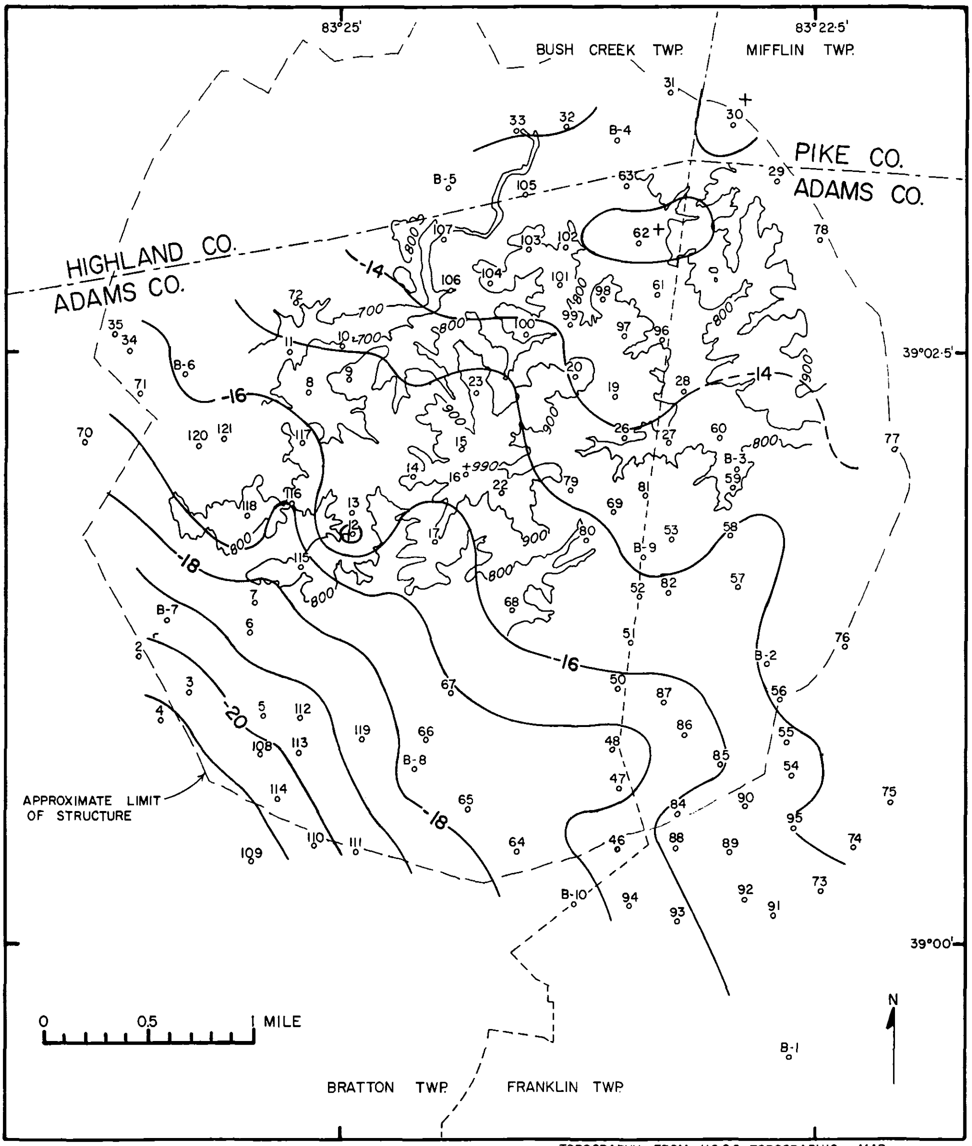
## REDUCTION OF THE DATA

The elevations of the gravity stations were determined by alidade, plane table, and stadia rod, working from the established bench marks in the area. Many points of known elevation were occupied during the survey, giving good checks on the survey accuracy. The estimated maximum elevation error is ±2 feet.

Terrain corrections were estimated at all gravity stations, using Hammer's method (1939). For the outer zones, G through M (2,936 to 71,996 feet from the station), calculations were made at representative points throughout the area, using a standard height for the stations, from which an isogal correction map was constructed. For the gravity stations, the contribution to the terrain correction due to these zones was obtained from this isogal correction map, and corrected for station height. The contribution due to the inner zones, C through F (55 to 2,936 feet), was calculated at each station.

Gravity stations, wherever possible, were situated in relatively flat areas, well away from steep slopes. The terrain corrections ranged from almost zero to 0.50 mgal and are not likely to be in error by more than 0.1 mgal (Zahn, 1965).

The principal source of error in the Bouguer anomaly values is the uncertainty about the density of the section. Using the data of Manger (1963), Batsche (1963), and others, it has been assumed that the vertical column above sea level in southern Ohio contains approximately 45 percent dolomite (2.5 $g/cm^3$), 25 percent limestone (2.6 $g/cm^3$), and 30 percent shale (2.4 $g/cm^3$), giving a mean density of 2.5 $g/cm^3$. Although errors in the assumed density could cause errors of 2 mgal in the Bouguer anomaly, it is unlikely that the differences between the Bouguer anomalies at adjacent stations is in error by more than 0.2 mgal. It seems unlikely that these errors could mask any areal pattern in the anomalies that might be related to either of the hypotheses for the formation of the Serpent Mound structure.




TOPOGRAPHY FROM U.S.G.S. TOPOGRAPHIC MAP

FIGURE 2

BOUGUER ANOMALY MAP OF SERPENT MOUND AREA, OHIO.

CONTOURS AT 100 FOOT INTERVALS SHOWN IN "HUB" AREA OF STRUCTURE.

GRAVITY ANOMALY CONTOUR INTERVAL 1 MILLIGAL

B-7 GRAVITY BASE STATION

23 GRAVITY STATION

TABLE 1

*Data for gravity survey of Serpent Mound area*

| Station | Latitude (N) | | Longitude (W) | | Elevation feet | Observed gravity mgal | Theoretical gravity mgal | Free air corr. mgal | Free air anomaly mgal | Terrain corr. mgal | Bouguer corr. mgal | Bouguer anomaly mgal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees | Minutes | Degrees | Minutes | | | | | | | | |
| B1 | 38 | 59.5 | 83 | 22.6 | 753 | 9800 28.44 | 9800 91.22 | 70.83 | + 8.05 | 0.11 | 24.02 | −15.86 |
| B2 | 39 | 01.2 | | 22.7 | 779 | 30.33 | 93.72 | 73.27 | + 9.88 | 0.05 | 24.85 | −14.92 |
| B3 | | 02.0 | | 22.9 | 786 | 31.68 | 94.90 | 73.93 | +10.71 | 0.04 | 25.07 | −14.32 |
| B4 | | 03.4 | | 23.5 | 720 | 38.72 | 96.96 | 67.72 | + 9.48 | 0.26 | 22.97 | −13.23 |
| B5 | | 03.2 | | 24.4 | 767 | 35.62 | 96.66 | 72.14 | +11.10 | 0.20 | 24.47 | −13.17 |
| B6 | | 02.4 | | 25.8 | 693 | 36.35 | 95.49 | 65.18 | + 6.04 | 0.15 | 22.11 | −15.92 |
| B7 | | 01.4 | | 25.9 | 756 | 27.39 | 94.01 | 71.11 | + 4.49 | 0.18 | 24.12 | −19.45 |
| B8 | | 00.7 | | 24.6 | 775 | 26.85 | 92.98 | 72.90 | + 6.77 | 0.11 | 24.72 | −17.84 |
| B9 | | 01.6 | | 23.4 | 817 | 28.67 | 94.31 | 76.85 | +11.21 | 0.05 | 26.06 | −14.80 |
| B10 | | 00.2 | | 23.8 | 729 | 29.60 | 92.25 | 68.57 | + 5.92 | 0.13 | 23.26 | −17.21 |
| 2 | | 01.2 | | 26.1 | 680 | 30.88 | 93.72 | 63.96 | + 1.12 | 0.10 | 21.69 | −20.47 |
| 3 | | 01.1 | | 25.8 | 677 | 30.73 | 93.57 | 63.68 | + 0.84 | 0.18 | 21.60 | −20.58 |
| 4 | | 01.0 | | 26.0 | 670 | 30.42 | 93.43 | 63.02 | + 0.01 | 0.15 | 21.37 | −21.21 |
| 5 | | 01.0 | | 25.4 | 728 | 28.38 | 93.43 | 68.48 | + 3.43 | 0.05 | 23.22 | −19.74 |
| 6 | | 01.3 | | 25.5 | 768 | 27.38 | 93.87 | 72.24 | + 5.75 | 0.05 | 24.50 | −18.70 |
| 7 | | 01.4 | | 25.5 | 782 | 27.07 | 94.01 | 73.55 | + 6.61 | 0.04 | 24.95 | −18.30 |
| 8 | | 02.3 | | 25.2 | 815 | 28.63 | 95.34 | 76.66 | + 9.95 | 0.33 | 26.00 | −15.72 |
| 9 | | 02.4 | | 24.9 | 868 | 25.58 | 95.49 | 81.64 | +11.73 | 0.33 | 27.69 | −15.63 |
| 10 | | 02.5 | | 25.0 | 713 | 36.18 | 95.63 | 67.06 | + 7.61 | 0.23 | 22.74 | −14.90 |
| 11 | | 02.5 | | 25.2 | 687 | 37.55 | 95.63 | 64.62 | + 6.54 | 0.22 | 21.92 | −15.16 |
| 12 | | 01.7 | | 24.9 | 861 | 25.43 | 94.46 | 80.99 | +11.96 | 0.26 | 27.47 | −14.85 |
| 13 | | 01.8 | | 24.9 | 853 | 26.10 | 94.60 | 80.23 | +11.73 | 0.18 | 27.21 | −15.30 |
| 14 | | 02.0 | | 24.6 | 909 | 22.33 | 94.90 | 85.50 | +12.93 | 0.25 | 29.00 | −15.82 |
| 15 | | 02.1 | | 24.3 | 974 | 18.40 | 95.04 | 91.61 | +14.97 | 0.37 | 31.07 | −15.73 |
| 16 | | 02.0 | | 24.3 | 981 | 17.70 | 94.90 | 92.27 | +15.07 | 0.40 | 31.29 | −15.82 |
| 17 | | 01.7 | | 24.5 | 889 | 22.61 | 94.46 | 83.62 | +11.77 | 0.33 | 28.36 | −16.26 |
| 19 | | 02.3 | | 23.6 | 867 | 27.47 | 95.34 | 81.55 | +13.68 | 0.13 | 27.66 | −13.85 |
| 20 | | 02.4 | | 23.8 | 946 | 22.23 | 95.49 | 88.98 | +15.72 | 0.50 | 30.18 | −13.96 |
| 22 | | 01.9 | | 24.2 | 963 | 18.96 | 94.75 | 90.58 | +14.79 | 0.39 | 30.72 | −15.54 |
| 23 | | 02.3 | | 24.3 | 948 | 20.59 | 95.34 | 89.17 | +14.42 | 0.50 | 30.24 | −15.32 |
| 26 | | 02.1 | | 23.5 | 807 | 30.75 | 95.04 | 75.91 | +11.62 | 0.10 | 25.74 | −14.02 |
| 27 | | 02.1 | | 23.3 | 769 | 32.92 | 95.04 | 72.33 | +10.21 | 0.11 | 24.53 | −14.21 |
| 28 | | 02.3 | | 23.2 | 758 | 34.16 | 95.34 | 71.30 | +10.12 | 0.12 | 24.18 | −13.94 |
| 29 | | 03.2 | | 22.7 | 876 | 28.69 | 96.66 | 82.40 | +14.43 | 0.18 | 27.94 | −13.33 |
| 30 | | 03.5 | | 22.9 | 773 | 36.05 | 97.10 | 72.71 | +11.66 | 0.23 | 24.66 | −12.77 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 03.6 | 23.3 | 729 | 38.51 | 97.25 | 68.57 | + 9.83 | 0.19 | 23.26 | −13.24 |
| 32 | 03.5 | 23.8 | 747 | 37.51 | 97.10 | 70.26 | +10.67 | 0.18 | 23.83 | −12.98 |
| 33 | 03.4 | 24.1 | 711 | 39.66 | 96.96 | 66.88 | + 9.58 | 0.15 | 22.68 | −12.95 |
| 34 | 02.5 | 26.1 | 814 | 28.11 | 95.63 | 76.56 | + 9.04 | 0.19 | 25.97 | −16.74 |
| 35 | 02.6 | 26.2 | 785 | 30.61 | 95.78 | 73.84 | + 8.67 | 0.07 | 25.04 | −16.30 |
| 46 | 00.4 | 23.5 | 788 | 26.86 | 92.54 | 74.12 | + 8.44 | 0.15 | 25.14 | −16.55 |
| 47 | 00.7 | 23.5 | 778 | 27.47 | 92.98 | 73.18 | + 7.67 | 0.05 | 24.82 | −17.10 |
| 48 | 00.8 | 23.6 | 785 | 27.08 | 93.13 | 73.84 | + 7.78 | 0.05 | 25.04 | −17.21 |
| 50 | 01.1 | 23.5 | 820 | 26.10 | 93.57 | 77.13 | + 9.66 | 0.18 | 26.16 | −16.32 |
| 51 | 01.3 | 23.5 | 846 | 25.58 | 93.87 | 79.57 | +11.28 | 0.14 | 26.99 | −15.57 |
| 52 | 01.5 | 23.4 | 833 | 27.00 | 94.16 | 78.35 | +11.19 | 0.07 | 26.57 | −15.31 |
| 53 | 01.7 | 23.3 | 834 | 28.59 | 94.46 | 78.45 | +12.58 | 0.03 | 26.60 | −13.99 |
| 54 | 00.7 | 22.6 | 737 | 31.85 | 92.98 | 69.32 | + 8.19 | 0.16 | 23.51 | −15.16 |
| 55 | 00.9 | 22.6 | 734 | 32.39 | 93.28 | 69.04 | + 8.15 | 0.20 | 23.41 | −15.06 |
| 56 | 01.1 | 22.7 | 759 | 31.33 | 93.57 | 71.39 | + 9.15 | 0.11 | 24.21 | −14.95 |
| 57 | 01.5 | 22.9 | 792 | 29.61 | 94.16 | 74.50 | + 9.95 | 0.06 | 25.26 | −15.25 |
| 58 | 01.7 | 22.9 | 805 | 29.38 | 94.46 | 75.72 | +10.64 | 0.02 | 25.68 | −15.02 |
| 59 | 01.9 | 22.9 | 792 | 31.12 | 94.75 | 74.50 | +10.87 | 0.05 | 25.26 | −14.34 |
| 60 | 02.2 | 23.0 | 780 | 31.98 | 95.19 | 73.37 | +10.16 | 0.05 | 24.88 | −14.67 |
| 61 | 02.8 | 23.3 | 746 | 35.77 | 96.07 | 70.17 | + 9.87 | 0.13 | 23.80 | −13.80 |
| 62 | 03.0 | 23.4 | 743 | 37.66 | 96.37 | 69.89 | +11.18 | 0.13 | 23.70 | −12.39 |
| 63 | 03.2 | 23.5 | 724 | 37.82 | 96.66 | 68.10 | + 9.26 | 0.24 | 23.10 | −13.60 |
| 64 | 00.4 | 24.1 | 761 | 27.53 | 92.54 | 71.58 | + 6.57 | 0.04 | 24.28 | −17.67 |
| 65 | 00.6 | 24.3 | 705 | 31.10 | 92.84 | 66.31 | + 4.57 | 0.10 | 22.49 | −17.82 |
| 66 | 00.9 | 24.5 | 810 | 25.14 | 93.28 | 76.19 | + 8.05 | 0.09 | 25.84 | −17.70 |
| 67 | 01.1 | 24.4 | 810 | 26.07 | 93.57 | 76.19 | + 8.69 | 0.08 | 25.84 | −17.07 |
| 68 | 01.4 | 24.1 | 780 | 29.69 | 94.01 | 73.37 | + 9.05 | 0.05 | 24.88 | −15.78 |
| 69 | 01.8 | 23.6 | 833 | 27.92 | 94.60 | 78.35 | +11.67 | 0.04 | 26.57 | −14.86 |
| 70 | 02.1 | 26.3 | 686 | 34.92 | 95.04 | 64.53 | + 4.41 | 0.10 | 21.88 | −17.37 |
| 71 | 02.3 | 26.0 | 698 | 35.10 | 95.34 | 65.65 | + 5.41 | 0.18 | 22.27 | −16.68 |
| 72 | 02.7 | 25.2 | 704 | 37.45 | 95.93 | 66.22 | + 7.74 | 0.16 | 22.46 | −14.56 |
| 73 | 00.2 | 22.5 | 747 | 30.43 | 92.25 | 70.26 | + 8.44 | 0.15 | 23.83 | −15.24 |
| 74 | 00.4 | 22.3 | 815 | 26.95 | 92.54 | 76.66 | +11.07 | 0.05 | 26.00 | −14.88 |
| 75 | 00.6 | 22.1 | 755 | 31.01 | 92.84 | 71.02 | + 9.19 | 0.08 | 24.08 | −14.81 |
| 76 | 01.3 | 22.3 | 871 | 25.08 | 93.87 | 81.93 | +13.14 | 0.08 | 27.78 | −14.56 |
| 77 | 02.1 | 22.1 | 832 | 29.42 | 95.04 | 78.26 | +12.64 | 0.03 | 26.54 | −13.87 |
| 78 | 03.0 | 22.5 | 842 | 30.40 | 96.37 | 79.20 | +13.23 | 0.08 | 26.86 | −13.55 |
| 79 | 01.9 | 23.8 | 869 | 25.83 | 94.75 | 81.74 | +12.82 | 0.09 | 27.72 | −14.81 |
| 80 | 01.7 | 23.7 | 840 | 26.81 | 94.46 | 79.01 | +11.36 | 0.07 | 26.80 | −15.37 |
| 81 | 01.9 | 23.4 | 843 | 27.70 | 94.75 | 79.29 | +12.24 | 0.03 | 26.89 | −14.62 |
| 82 | 01.5 | 23.3 | 841 | 26.68 | 94.16 | 79.10 | +11.62 | 0.05 | 26.83 | −15.16 |
| 84 | 00.6 | 23.2 | 809 | 26.54 | 92.84 | 76.09 | + 9.79 | 0.14 | 25.81 | −15.88 |
| 85 | 00.8 | 23.0 | 924 | 19.16 | 93.13 | 86.91 | +12.94 | 0.48 | 29.48 | −16.06 |
| 86 | 00.9 | 23.2 | 931 | 18.41 | 93.28 | 87.57 | +12.70 | 0.34 | 29.70 | −16.66 |
| 87 | 01.0 | 23.3 | 927 | 18.79 | 93.43 | 87.19 | +12.55 | 0.36 | 29.57 | −16.66 |

TABLE 1. *Continued*

| Station | Latitude (N) | | Longitude (W) | | Elevation feet | Observed gravity mgal | Theoretical gravity mgal | Free air corr. mgal | Free air anomaly mgal | Terrain corr. mgal | Bouguer corr. mgal | Bouguer anomaly mgal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees | Minutes | Degrees | Minutes | | | | | | | | |
| 88 | | 00.4 | | 23.2 | 712 | 32.10 | 92.54 | 66.97 | + 6.53 | 0.22 | 22.71 | −15.96 |
| 89 | | 00.4 | | 22.9 | 712 | 32.42 | 92.54 | 66.97 | + 6.85 | 0.28 | 22.71 | −15.58 |
| 90 | | 00.6 | | 22.9 | 725 | 32.09 | 92.84 | 68.19 | + 7.44 | 0.21 | 23.13 | −15.48 |
| 91 | | 00.1 | | 22.7 | 853 | 23.60 | 92.10 | 80.23 | +11.73 | 0.09 | 27.21 | −15.39 |
| 92 | | 00.2 | | 22.9 | 866 | 22.60 | 92.25 | 81.46 | +11.81 | 0.25 | 27.63 | −15.57 |
| 93 | | 00.1 | | 23.2 | 809 | 25.54 | 92.10 | 76.09 | + 9.53 | 0.10 | 25.81 | −16.18 |
| 94 | | 00.2 | | 23.5 | 708 | 31.29 | 92.25 | 66.59 | + 5.63 | 0.11 | 22.59 | −16.85 |
| 95 | | 00.5 | | 22.6 | 810 | 27.24 | 92.69 | 76.19 | +10.74 | 0.10 | 25.84 | −15.00 |
| 96 | | 02.6 | | 23.3 | 792 | 32.73 | 95.78 | 74.50 | +11.45 | 0.09 | 25.26 | −13.72 |
| 97 | | 02.6 | | 23.5 | 815 | 31.27 | 95.78 | 76.66 | +12.15 | 0.03 | 26.00 | −13.82 |
| 98 | | 02.7 | | 23.6 | 836 | 30.30 | 95.93 | 78.63 | +13.00 | 0.19 | 26.67 | −13.48 |
| 99 | | 02.6 | | 23.8 | 841 | 29.43 | 95.78 | 79.10 | +12.75 | 0.12 | 26.83 | −13.96 |
| 100 | | 02.6 | | 24.0 | 844 | 29.08 | 95.78 | 79.39 | +12.69 | 0.12 | 26.92 | −14.11 |
| 101 | | 02.8 | | 23.8 | 834 | 30.44 | 96.07 | 78.45 | +12.82 | 0.07 | 26.60 | −13.71 |
| 102 | | 02.9 | | 23.8 | 830 | 31.18 | 96.22 | 78.07 | +13.03 | 0.21 | 26.48 | −13.24 |
| 103 | | 02.9 | | 24.0 | 831 | 30.93 | 96.22 | 78.16 | +12.87 | 0.18 | 26.51 | −13.46 |
| 104 | | 02.8 | | 24.2 | 846 | 29.57 | 96.07 | 79.57 | +13.07 | 0.42 | 26.99 | −13.50 |
| 105 | | 03.2 | | 24.0 | 705 | 39.31 | 96.66 | 66.31 | + 8.96 | 0.12 | 22.49 | −13.41 |
| 106 | | 02.8 | | 24.4 | 705 | 37.87 | 96.07 | 66.31 | + 8.11 | 0.17 | 22.49 | −13.81 |
| 107 | | 03.0 | | 24.5 | 704 | 38.72 | 96.37 | 66.22 | + 8.57 | 0.20 | 22.46 | −13.69 |
| 108 | | 00.8 | | 25.4 | 724 | 27.71 | 93.13 | 68.10 | + 2.68 | 0.06 | 23.10 | −20.36 |
| 109 | | 00.4 | | 25.5 | 693 | 27.36 | 92.54 | 65.18 | 0.00 | 0.14 | 22.11 | −21.97 |
| 110 | | 00.4 | | 25.1 | 763 | 24.69 | 92.54 | 71.77 | + 3.92 | 0.06 | 24.34 | −20.36 |
| 111 | | 00.4 | | 24.9 | 740 | 26.63 | 92.54 | 69.60 | + 3.69 | 0.09 | 23.61 | −19.83 |
| 112 | | 01.0 | | 25.2 | 683 | 31.49 | 93.43 | 64.24 | + 2.30 | 0.14 | 21.79 | −19.35 |
| 113 | | 00.8 | | 25.2 | 676 | 31.10 | 93.13 | 63.58 | + 1.55 | 0.14 | 21.56 | −19.87 |
| 114 | | 00.6 | | 25.3 | 673 | 30.15 | 92.84 | 63.30 | + 0.61 | 0.25 | 21.47 | −20.61 |
| 115 | | 01.6 | | 25.2 | 801 | 26.85 | 94.31 | 75.34 | + 7.88 | 0.08 | 25.55 | −17.59 |
| 116 | | 01.9 | | 25.2 | 807 | 27.48 | 94.75 | 75.91 | + 8.64 | 0.09 | 25.74 | −17.01 |
| 117 | | 02.1 | | 25.2 | 839 | 26.51 | 95.04 | 78.92 | +10.39 | 0.26 | 26.76 | −16.11 |
| 118 | | 01.8 | | 25.5 | 854 | 25.20 | 94.60 | 80.33 | +10.93 | 0.27 | 27.24 | −16.04 |
| 119 | | 00.9 | | 24.9 | 762 | 27.16 | 93.28 | 71.67 | + 5.55 | 0.07 | 24.31 | −18.69 |
| 120 | | 02.1 | | 25.7 | 778 | 29.77 | 95.04 | 73.18 | + 7.91 | 0.21 | 24.82 | −16.70 |
| 121 | | 02.1 | | 25.6 | 719 | 33.95 | 95.04 | 67.63 | + 6.54 | 0.12 | 22.94 | −16.28 |

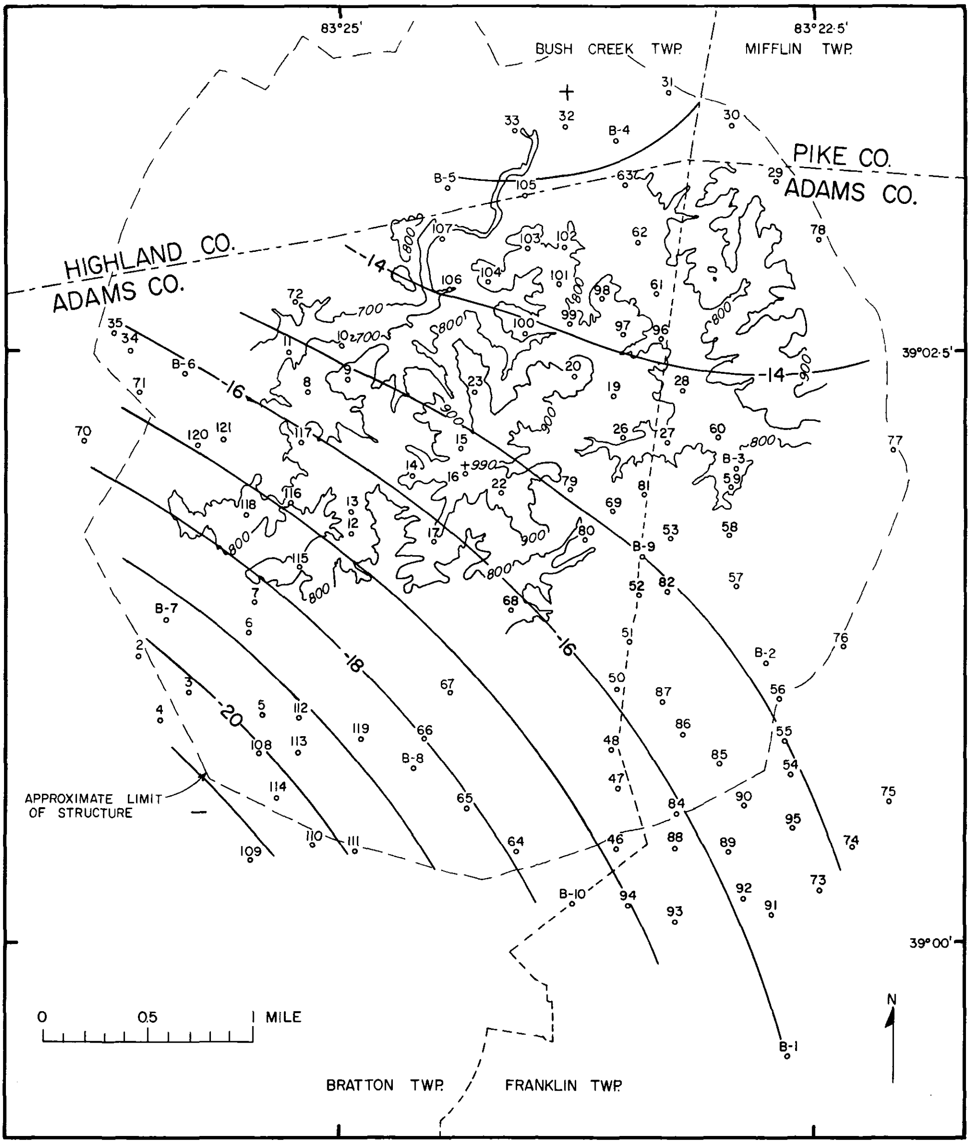



FIGURE 3

TOPOGRAPHY FROM U.S.G.S. TOPOGRAPHIC MAP

SECOND DEGREE TREND SURFACE MAP OF SERPENT MOUND AREA, OHIO

CONTOURS AT 100 FOOT INTERVALS SHOWN IN "HUB" AREA OF STRUCTURE.

GRAVITY ANOMALY CONTOUR INTERVAL 1 MILLIGAL

B-7 GRAVITY BASE STATION

23 GRAVITY STATION

## ANOMALY MAPS

The isogals on the Bouguer anomaly map of the Serpent Mound area (fig. 2), trend northwest-southeast, as they do on the regional map of this part of Ohio (Heiskanen and Uotila, 1956). Values decrease regularly from $-12$ mgal in the southwest corner of Pike County to $-22$ mgal at the limit of the present survey, and to $-40$ mgal 7 miles farther to the southwest. The cause of the regional gradient (28 mgal in 15 miles) is not known, but is most unlikely to be associated with changes in density or total thickness of the Paleozoic sedimentary rocks, which here increase in thickness to the east by approximately 1000 feet in 20 miles (Owens, 1967). Almost certainly it is related to horizontal variations in density of the underlying basement, the surface of which probably lies at 2700 feet below sea level in this area, but not enough is known about the configuration or composition of the basement here to permit intelligent speculation. The regional gradient can be accounted for in terms of a horizontal cylinder, of density contrast 0.5 g/cm$^3$ and radius about 8 miles, buried 5.7 miles below the surface (Zahn, 1965), but until more is known about the basement it is not possible to assess Zahn's model. In any case, it seems unlikely that a disturbance at this depth could produce a small surface expression like that in the Serpent Mound area.

There are no closed isogals on the map that are in any way related to the surface topography in the disturbed area.

Another approach that can be attempted is to isolate regional trends from local anomalies by means of least-squares fitting of polynomial surfaces to the data (Krumbein, 1959). This has been done with the Bouguer anomalies from Serpent Mound for surfaces of first degree (a plane with 3 polynomial terms) to sixth degree (28 polynomial terms). The second degree surface (fig. 3) approximates the regional trend quite well. The residual anomalies obtained by subtracting this surface from the Bouguer anomalies are shown on figure 4. The maximum residual is $+1.8$ mgal and the root-mean-square value for all residuals is 0.4 mgal. The residuals appear to be quite "noisy," with no systematic pattern associated with the hub area of Serpent Mound. Much of this variation is due to the random errors in the observations of gravity and in the elevation and terrain corrections.

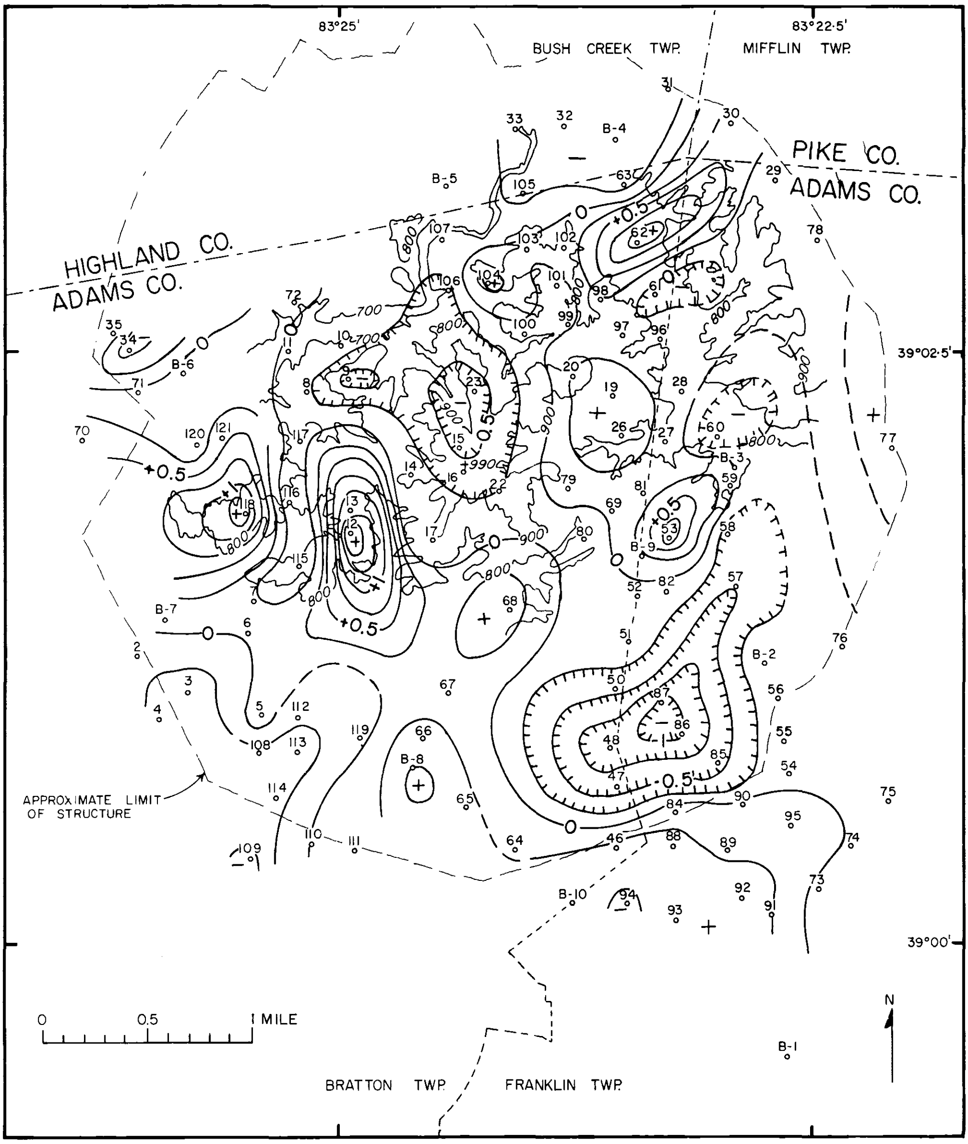
Any attempt to relate the negative anomaly just north of the hub to the structural feature of Serpent Mound requires that one also explain similar anomalies nearby—an impossible task, at present, in view of the lack of detailed geologic knowledge of the area.

Smoothing of this residual map to remove the noise can be accomplished in many ways; the method which has been used here is to remove from the second-degree residuals the residuals of the sixth degree surface, as these are fairly good measures of the amount of noise present. Figure 5, which presents the results of this operation, shows that there is still no strong correlation with the structural features.

## DISCUSSION

If the structure were due to meteoritic impact, a gravity anomaly reflecting the lower density of the brecciated material might have been expected, as in similar areas elsewhere (Innes, 1961; Halliday and Griffin, 1963). If the cause were cryptovolcanism, a gravity anomaly reflecting the change in attitude of the basement might be found.

Proponents of the astrobleme hypothesis could account for the absence of a relationship between the anomaly maps and the surface expression by postulating either that most of the broken rock had been removed by erosion or that there is very little density contrast between the broken and the less-disturbed strata. The cryptovolcanists may contend that there is little density contrast between




TOPOGRAPHY FROM U.S.G.S. TOPOGRAPHIC MAP

FIGURE 4

SECOND DEGREE RESIDUAL MAP OF SERPENT MOUND AREA, OHIO

CONTOURS AT 100 FOOT INTERVALS SHOWN IN "HUB" AREA OF STRUCTURE

GRAVITY ANOMALY CONTOUR INTERVAL 0.25 MILLIGAL

B-7 GRAVITY BASE STATION

23 GRAVITY STATION

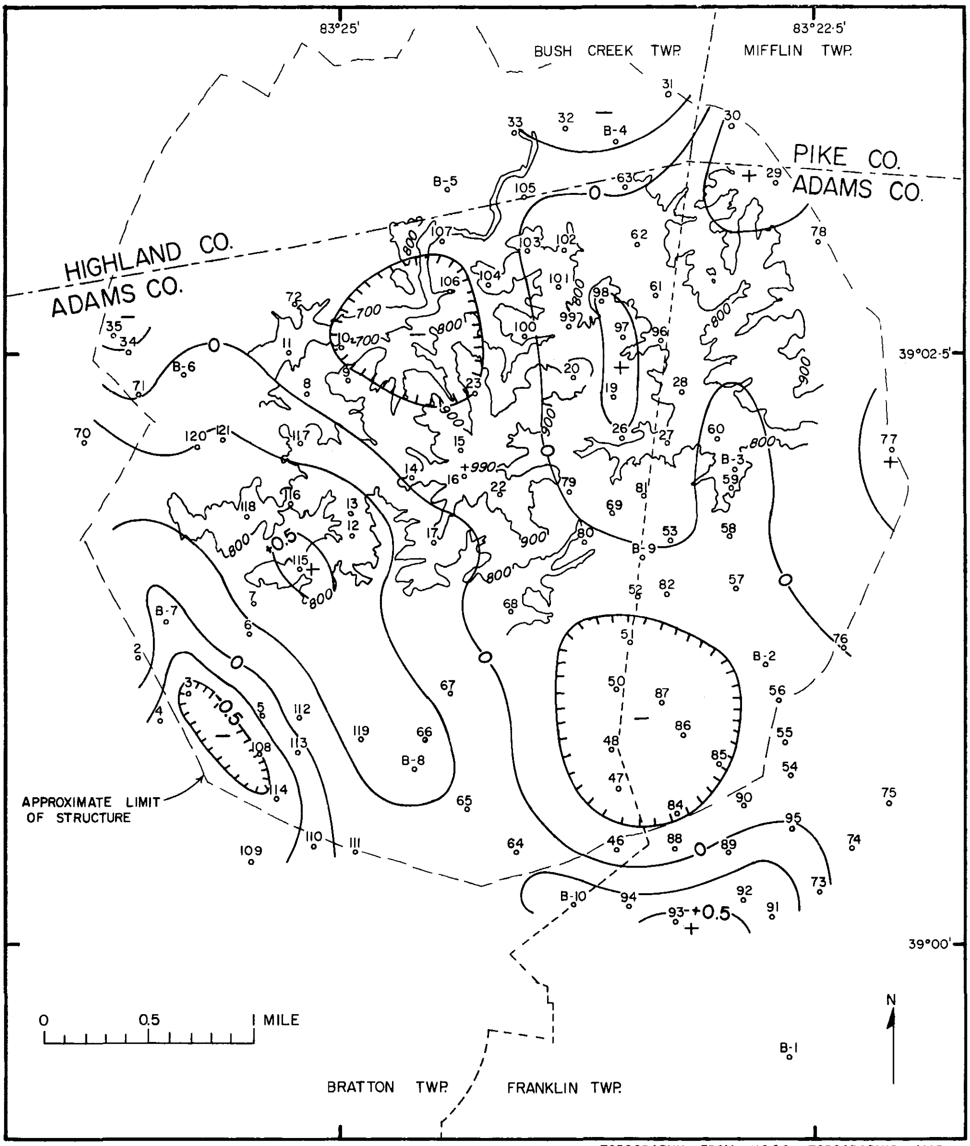



FIGURE 5

(SECOND DEGREE RESIDUAL) - (SIXTH DEGREE RESIDUAL) MAP OF SERPENT MOUND AREA, OHIO

CONTOURS AT 100 FOOT INTERVALS SHOWN IN "HUB" AREA OF STRUCTURE

GRAVITY ANOMALY CONTOUR INTERVAL 0.25 MILLIGAL

B-7 GRAVITY BASE STATION

23 GRAVITY STATION

the upper basement rock and the lower part of the sedimentary section. Of these, the erosion hypothesis seems the most valid. The presence of rock fragments considered to be shatter cones in the surface rocks now, however, would indicate that erosion has not proceeded below the depth affected by the propagation of the hypervelocity waves.

Obviously the best way to determine the geologic character of the Serpent Mound structure would be to core the rocks to depths well below the surface of the basement, at points on a line through the disturbed area and into the undisturbed areas beyond. Further valuable information could also be obtained relatively cheaply from a detailed reflection seismic survey in the area.

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Details of the positions of all gravity stations and all surveying and gravity data have been deposited with the Ohio Division of Geological Survey.

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