CRYPTOEXPLOSIVE STRUCTURE NEAR WETUMPKA, ALABAMA

GEOLOGICAL SURVEY OF ALABAMA

REPRINT SERIES 44

GEOLOGICAL SURVEY OF ALABAMA

Philip E. LaMoreaux
State Geologist

MINERAL RESOURCES DIVISION

Thornton L. Neathery
Chief Geologist

REPRINT SERIES 44

CRYPTOEXPLOSIVE STRUCTURE NEAR WETUMPKA, ALABAMA

By Thornton L. Neathery, Robert D. Bentley, and Gregory C. Lines

Reprinted from
Geological Society of America Bulletin, v. 87, p. 567-573

University, Alabama

1976

Cryptoexplosive structure near Wetumpka, Alabama

THORNTON L. NEATHERY *Geological Survey of Alabama, University, Alabama 35486*
ROBERT D. BENTLEY *Central Washington State College, Ellensburg, Washington 98926*
GREGORY C. LINES *U.S. Geological Survey, Cheyenne, Wyoming 82001*

ABSTRACT

A cryptoexplosive structure that probably resulted from a meteorite impact is located near Wetumpka, Alabama (long 32°31′42″N, lat 86°14′12″W), along the boundary between the Gulf Coastal Plain and the Piedmont physiographic provinces. Its main features are (1) an approximately concentric structural system about 6.5 km in diameter, its rim formed by metamorphic rocks and surrounded by Cretaceous sedimentary rocks; (2) an arcuate ridge of schist extending two-thirds of the way around the structure, which stands 60 to 150 m above the adjacent Piedmont peneplain; (3) the chaotic orientation of Cretaceous and metamorphic units in the center of the structure, perhaps corresponding to the central rebound area; (4) concentric marginal faults with an estimated displacement of 240 to 300 m; and (5) shock effects in feldspar and quartz crystals in rock units that form the rim.

A southward-sloping metamorphic rock surface and a northward-thinning Cretaceous cover afforded a unique geologic setting for the formation and possible preservation of the structure. A shallow marine setting may best explain the shape and distribution of rocks. Nowhere else along the 1,600 km of Coastal Plain–Piedmont boundary is there any faulting of the magnitude described in this report. The age of the Wetumpka cryptoexplosive structure is post-Mooreville (Late Cretaceous) and pre-terrace (Pleistocene?). The name "Wetumpka Astrobleme" is proposed for this structure. *Key words: structural geology; Wetumpka Astrobleme; cryptoexplosive structure; Wetumpka, Alabama.*

INTRODUCTION

A circular area of intensely deformed metamorphic rock mixed with slices of siliceous clastic and carbonate units of Cretaceous age is astride the Coastal Plain–Piedmont boundary at long 32°31′42″N, lat 86°14′12″W, approximately 24 km northeast of Montgomery, Alabama (Fig. 1). The deformation probably resulted from the impact of a meteorite. The structure, herein called the Wetumpka Astrobleme, is the only cryptoexplosive structure known in the Piedmont and is one of the few known that involves crystalline and younger Cretaceous rocks. A possible cryptoexplosive structure in the Coastal Plain province is near Kilmichael, Mississippi (Priddy, 1943, p. 42–46). The Kilmichael structure exposes and involves only Coastal Plain sedimentary rocks. A review of the index to terrestrial impact structures (Freeberg, 1966, 1969) indicated that no cryptoexplosive or impact structure has been described from a geologic setting similar to the Wetumpka Astrobleme. The contrast of chaotically oriented sedimentary units inside the structure and flat-lying, undisturbed sedimentary units outside is similar to the structural relations at Kilmichael, Mississippi (Priddy, 1943); Flynn Creek, Tennessee (Roddy, 1968); and Jeptha Knob, Kentucky (Seegar, 1968). The geometric configuration and structural style is comparable to the cryptoexplosive structures at Wells Creek, Tennessee (Wilson and Stearns, 1968).

The unusual nature of the structure near Wetumpka was referred to in the field notes of E. A. Smith (August 7, 1891), former State Geologist of Alabama. Smith and others (1894), Stephenson (1926, p. 236), Stose (1926), and Monroe (1941) showed irregular distribution of Cretaceous units and faults near Wetumpka on early maps. In the 1950s, L. C. Conant, C. W. Drennen, and H. D. Eargle prepared unpublished geologic maps of the Cretaceous and younger rocks in Elmore County (maps on file at U.S. Geological Survey, Water Resources Division, Tuscaloosa, Alabama). These maps show two fault grabens of Mooreville Chalk, south of Wetumpka, but most of the area was simply marked "structurally disturbed."

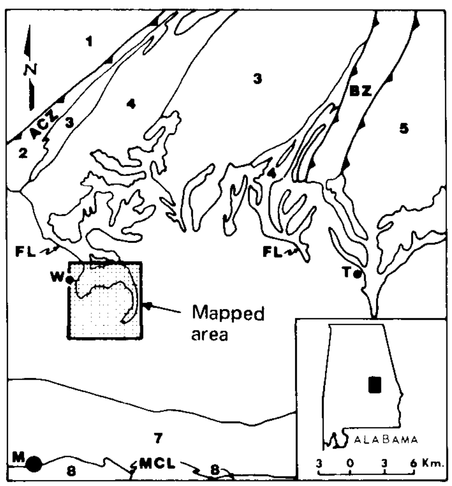


Figure 1. Location of mapped area, east-central Alabama at boundary between Gulf Coastal Plain and Piedmont province. Outcrop limit of Mooreville Chalk is shown near Montgomery (M). 1, Pinckneyville gneiss; 2, Wedowee Formation; 3, augen gneiss; 4, schist and gneiss; 5, gneiss and amphibolite; 6, Tuscaloosa Group; 7, Eutaw Formation; 8, Mooreville Chalk; W, Wetumpka; FL, fall line; T, Tallassee; ACZ, Alexander City zone; BZ, Brevard Zone; MCL, Mooreville Chalk limit.

GENERAL GEOLOGY OF THE AREA

The displaced rocks of the Wetumpka Astrobleme involve both crystalline rocks of the Piedmont province and the Late Cretaceous sedimentary rocks of the Gulf Coastal Plain province (Fig. 1). Crystalline rocks of the Piedmont province consist of several sequences of metasedimentary rocks, a quartz diorite–granite complex, and a large augen gneiss complex. Late Cretaceous sedimentary rocks near Wetumpka consist of the Tuscaloosa Group overlapped by the Eutaw Formation. Within the Wetumpka Astrobleme, isolated outcrops of post-Eutaw Mooreville Chalk are present more than 16 km north of the normal regional outcrop limits of this formation (Fig. 1) near Montgomery, Alabama. High terrace deposits of Pleistocene(?) age overlie the Coastal Plain sedimentary rocks and locally overlie the crystalline rocks.

Immediately north of the Wetumpka Astrobleme, there is a sequence of metasedimentary rocks composed predominantly of biotite-garnet-feldspathic schist and gneiss with minor beds of amphibolite and quartzite (Fig. 1). Intruding them are masses of elongate orthogneiss that are concordant to the regional foliation.

The regional structure of the crystalline terrane has been described by Bentley and Neathery (1970). Peripheral to the Wetumpka Astrobleme, the compositional layering and major foliation strike northeastward and dip regularly to the southeast at moderate angles. Two major cataclastic zones cross the area; the Alexander City

Geological Society of America Bulletin, v. 87, p. 567–573, 6 figs., April 1976, Doc. no. 60409.

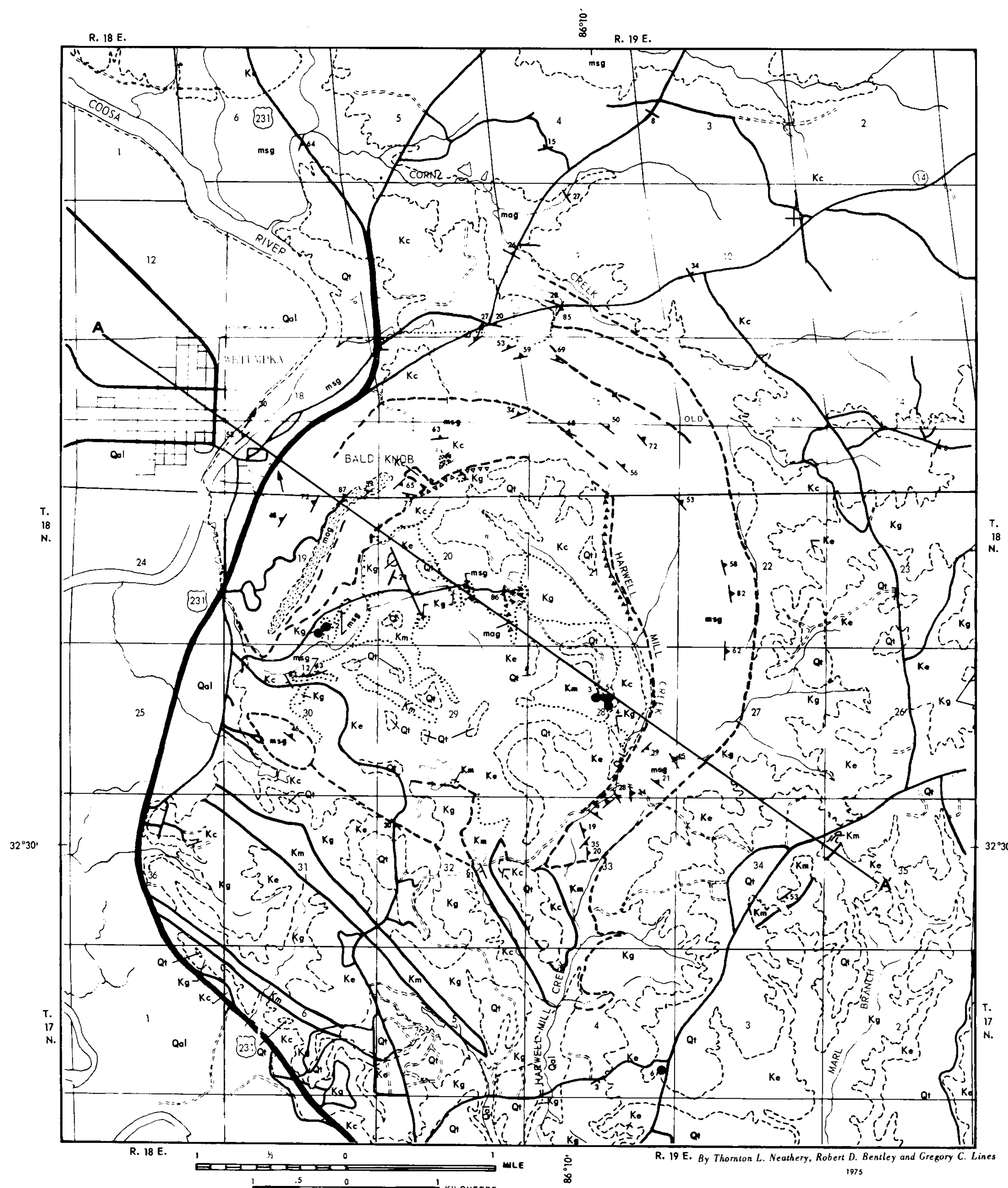
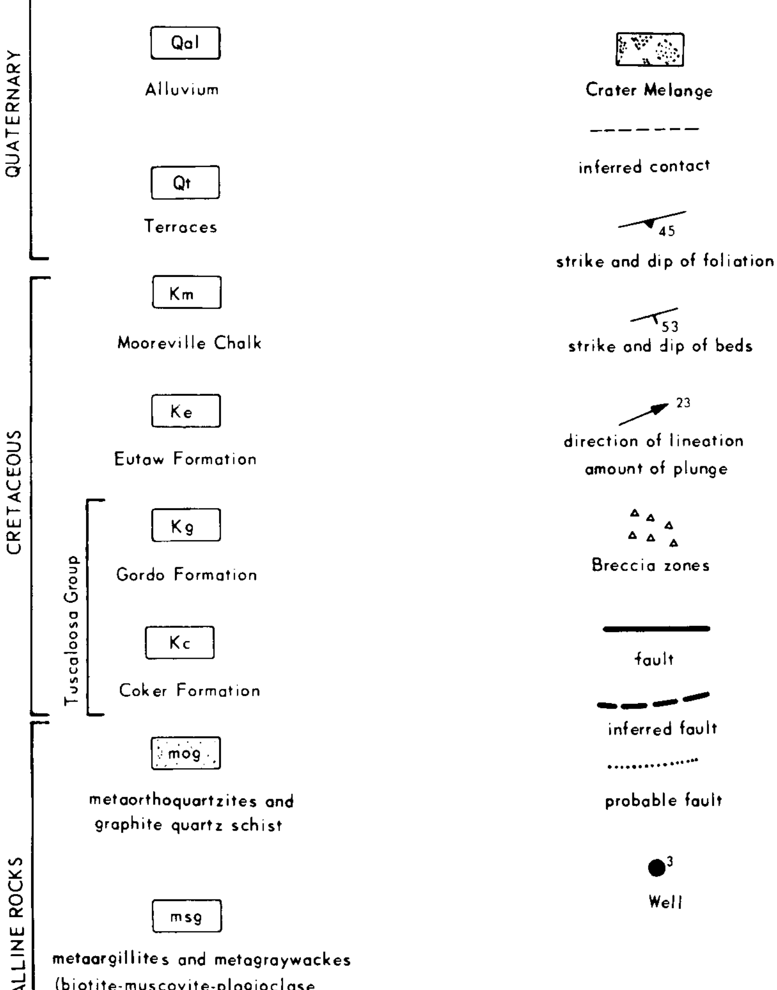
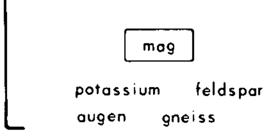


Figure 2A. Geologic map of Wetumpka Astrobleme.

EXPLANATION FOR FIGURES 2A AND 2B





fault, 12 km north of the Wetumpka structure, and the Brevard fault, 15 km east (Fig. 1). No major faults are known in the immediate vicinity of the Wetumpka Astrobleme other than those associated with the structure. High-altitude imagery from the LANDSAT satellite and conventional aircraft do not indicate any lineaments that suggest major faulting or jointing in the vicinity of the structure, although the Wetumpka Astrobleme is clearly defined.

The Cretaceous sedimentary rocks are, in ascending order, the Coker and Gordo Formations of the Tuscaloosa Group; the Eutaw Formation; and the Mooreville Chalk of the Selma Group, all of which unconformably overlie the crystalline rocks. Each of these units thins northward in surface sections, reflecting the regional feathering out of the sedimentary rocks onto the crystalline basement. The Cretaceous sedimentary rocks dip southward 9 to 15 m/km.

High terrace deposits of Pleistocene(?) age and low terrace deposits and alluvium of Pleistocene and Holocene age overlie much of the Cretaceous rocks, and in a few areas, they overlie pre-Cretaceous metamorphic rocks. The base of the high terrace deposits is at an altitude between 90 and 180 m above mean sea level. The low terrace deposits and alluvium are most extensive in and adjacent to existing flood plains of the Alabama, Coosa, and Tallapoosa Rivers to the west and south of the Wetumpka Astrobleme. The base of the low terrace deposits ranges from 60 to 73 m above mean sea level and as much as 30 m above the base of the alluvium in river flood plains. These terrace deposits overlie parts of the disturbed crystalline rock and Cretaceous sedimentary rocks in the central part of the structure and establish a minimum age for the structure (Fig. 2).

DESCRIPTION OF THE WETUMPKA ASTROBLEME

Crystalline rocks form an arcuate ridge 6.5 km in diameter extending two-thirds of the way around the north side of the structure (U.S. Geol. Survey Wetumpka and Mount Meigs 15-minute quadrangles). On the south side of the structure, one isolated ridge of crystalline rock stands above the

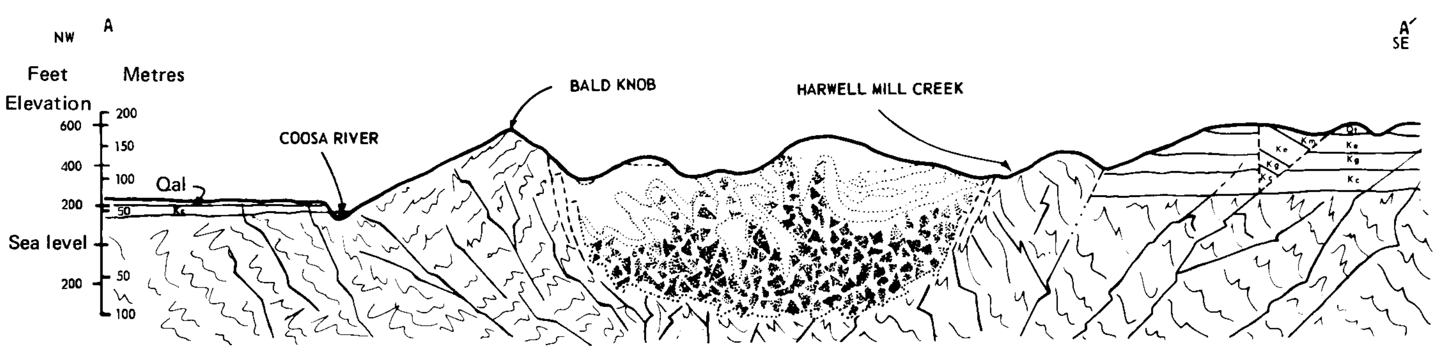


Figure 2B. Cross section A-A'.

surrounding partial blanket of Cretaceous Coastal Plain sedimentary rocks. The central area of disturbed Coastal Plain sedimentary rocks has broad rolling hills and valleys 100 to 150 m below the ridge. Locally, on the inside and outside edges of the ridge, there are steep escarpments with 50 to 75 m relief. The relief in these scarps exceeds any local relief away from the structure.

The crystalline rocks that form the rim of the structure are uniform in composition, consisting principally of fine- to medium-grained, biotite-garnet-feldspathic schist and gneiss and, locally, of quartzite and graphite-muscovite schist (Fig. 2). A thin amphibolite unit occurs on the east ridge of the structure. These units, with the exception of quartzite and graphite-muscovite schist, occur in the adjacent crystalline rocks.

The center of the structure consists mainly of Cretaceous rocks, locally covered by terrace deposits (Fig. 2). Faulting, slumping, and folding have disrupted the strike and dip of the Cretaceous units, and many appear to be in reverse stratigraphic order. At several localities, rock units that correspond to the Gordo Formation lie between the Mooreville Chalk and the Eutaw Formation. Near the center of the Wetumpka Astrobleme, in an area that would correspond to the central rebound core of a meteor crater, the clastic Cretaceous sedimentary rocks are chaotically mixed with angular blocks of crystalline rocks. The scarcity of good exposures inside the structure, together with the chaotic orientation of units, limits the mapping of geologic contacts (Fig. 2).

The structural relief of the crystalline rocks in the vicinity of the Wetumpka Astrobleme is illustrated in Figure 3. The regional uniform surface of the crystalline rocks slopes southward 10 to 20 m/km. The Wetumpka Astrobleme stands 60 to 150 m above the otherwise flat surface. This structure forms circular or arcuate ridges of crystalline rocks that pierce the blanket of Cretaceous sedimentary rocks.

Foliation in the exposed crystalline rocks in the ridges that form the Wetumpka Astrobleme defines two-thirds of a circular, dome-like structure (Fig. 2), approximately 6.5 km in diameter, that is inconsistent with the regional structural grain. Foliations along the arcuate ridge dip outward from the center of the structure except along the southern tip of the rim where foliation reflects a complex fold system that is possibly of pre-impact origin.

The astrobleme is believed to contain many faults, but few surface expressions of faults were observed. Faults are inferred from observed zones of brecciation, from the close spacing of stratigraphic units, and from the presence of steep scarps where faults are deemed to occur. Concentric faults were mapped along the inside of the main arcuate ridge and at the contacts between the crystalline and Cretaceous rocks, where steep scarps and breccia occur; and on the outside of the ridge, where similar scarps occur, especially along the northeast and east sides of the structure. The abnormal attitude of the crystalline and Cretaceous rocks is best explained by the presence of faults along the outer limits of the structure. The south part of the structure lacks an enclosing ridge but is bounded by the west-northwest–trending sets of paired faults that may bound narrow grabens (Fig. 2).

Breccia zonès occur along the inside escarpment of the arcuate ridge on the north side of the structure and near the center of the structure (Fig. 2). The breccia consists of irregular blocks of bedded Cretaceous sandstone mixed with angular fragments of schist and milky-white vein quartz in a matrix of sandstone and finely crushed metamorphic rock (Fig. 4). The fragments of breccia range in diameter from a few millimetres to several metres. Most of the crystalline rock fragments are badly weathered; only skeletal minerals, mica, quartz, and opaque minerals are identifiable. Feldspar is generally altered to clay.

In the center of the structure, chaotically oriented blocks of Cretaceous sedimentary rocks are mixed with blocks of crystalline rocks (Fig. 2). In some exposures, large areas of Cretaceous sedimentary rock appear to be flat-lying; in adjacent areas, however, vertical to steeply dipping or overturned beds indicate intense localized folding and faulting. Near the center of the structure, angular blocks of foliated schist randomly oriented in a sandstone matrix are exposed in several road cuts, especially in the NW¼SE¼ and NE¼SE¼ sec. 20, T. 18 N., R. 19 E. (Fig. 2). Highly contorted and faulted beds of Cretaceous rocks are exposed in a nearby road cut (Fig. 5).

Aeromagnetic Survey

An unpublished regional aeromagnetic survey made of the crystalline rocks of Alabama in 1973 included the area underlain by the Wetumpka Astrobleme (Alabama Geol. Survey). A deep northeast-trending magnetic low coincides with the western part of the structure. The general

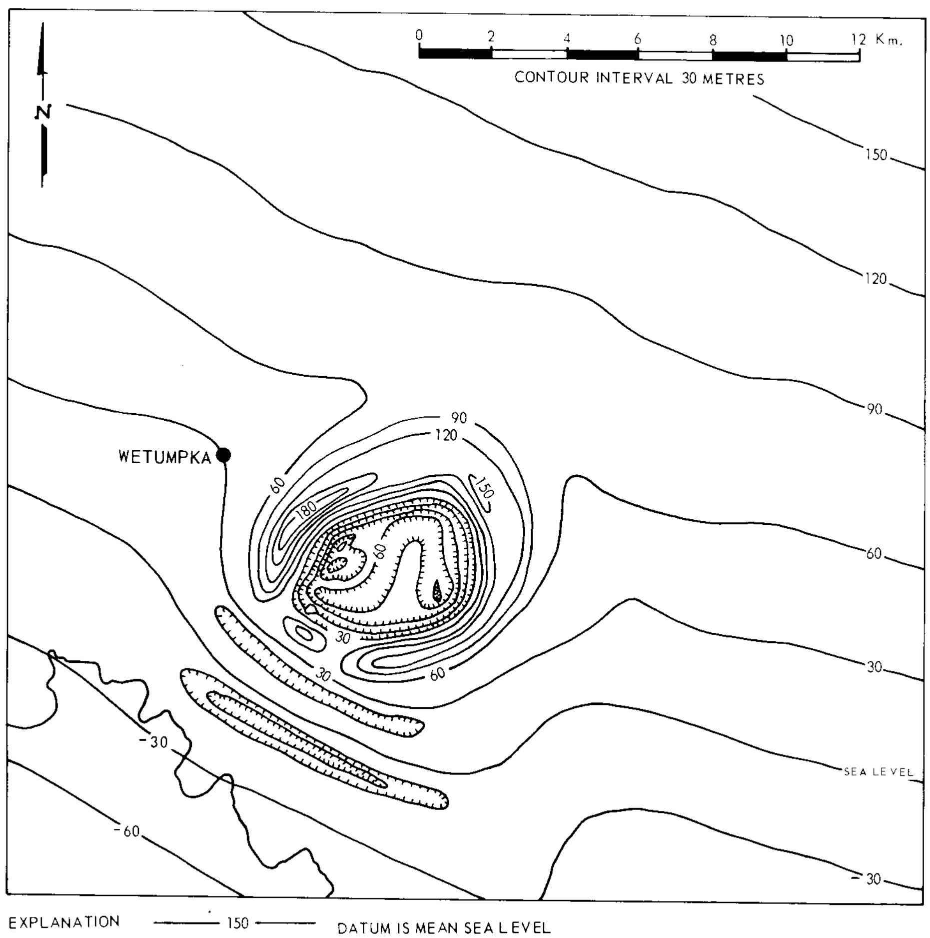


Figure 3. Structural contour map showing configuration of top of crystalline rocks near Wetumpka Astrobleme.

configuration of the magnetic anomaly, however, coincides more with the general regional surface and subsurface structures than with any features of the Wetumpka Astrobleme. These magnetic data do not preclude the existence of a central uplift, however, because any anomalies associated with the uplift area would be smaller than the flight-line spacing of the regional study.

Subsurface Data

Five water wells have been drilled in the central area of the structure (Fig. 2). Wells 1 and 2, 70 m apart, penetrated approximately 100 m of dissimilar Cretaceous sedimentary strata, a phenomenon not possible based upon regional thicknesses (J. C. Scott, 1970, written commun.). Well 1 penetrated more than 70 m of clay and sand that appear to be from the Coker Formation. Well 2 was collared in sandy residuum, but in a short distance, it penetrated varicolored clay, gravelly sand, and sandy clay. Well 2 bottomed at a depth of 50 m in the Gordo Formation. Neither well penetrated metamorphic rocks or more than one Cretaceous formation. Therefore, the Cretaceous formations must dip steeply in wells 1 and 2.

Wells 3, 4, and 5 are approximately 3 km east-southeast of wells 1 and 2 (Fig. 2). Well 3 penetrated 21 m of Mooreville Chalk and bottomed at 27 m in the upper beds of the Eutaw Formation. Well 4, about 100 m southwest of well 3 and at approximately the same collar elevation, bottomed in the Mooreville at a depth of 40 m. Well 5, about 50 m east of well 3 and approximately 6 m higher at the collar, penetrated Mooreville Chalk for about 30 m and bottomed in upper Eutaw sand beds at 32 m. A cross section through wells 3, 4, and 5 indicates a sharp irregular relief suggestive of steep folding (Fig. 2).

Shock Features

The crystalline rock in the south rim of the structure shows many internal features that indicate shock origin. Feldspar crystals with deformed twinning lamellae (Figs. 6A and 6B) were found in specimens of gneiss. Feldspars with kink bands similar to these deformed lamellae can occur only under conditions of high stress not generally found in regional tectonites (Bunch, 1968). Most of the quartz grains show undulatory extinction, and many exhibit two sets of planar fractures with discontinuous undulatory extinction (Fig. 6C).

Most biotite crystals are bent and

Figure 4. Brecciated blocks of muscovite-quartz schist in a matrix of unconsolidated Cretaceous sedimentary rocks along the inside of escarpment (S½ sec. 17, T. 18 N., R. 19 E.). Hammer for scale.

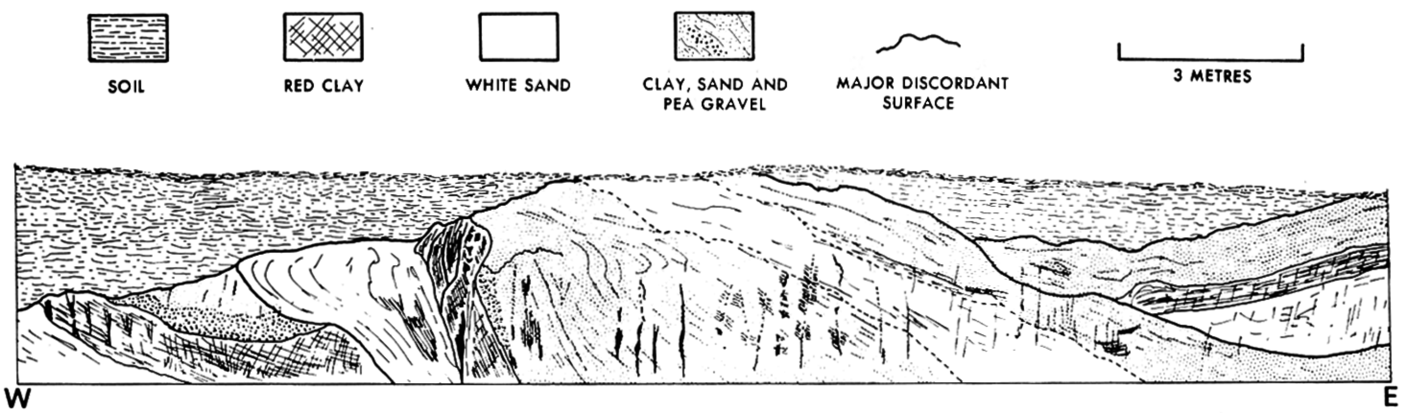


Figure 5. Sketch of contorted and faulted Cretaceous sedimentary rocks near center of Wetumpka Astrobleme (NW¼SE¼ sec. 20, T. 18 N., R. 19 E.).

strained. Thin sections exhibit an irregular textural banding composed of coarse- and fine-grained crystallite. In the schist and gneiss, narrow bands of fine-grained material appear to have formed locally by granulation of coarser material along late cleavages (Fig. 6D). None of these internal features were present in crystalline rocks away from the structure.

No shock features such as coesite, shatter cones, or impactite have been found within the Wetumpka Astrobleme.

DISCUSSION

The Wetumpka Astrobleme is unique in the Piedmont geology. Nowhere along 1,600 km of Coastal Plain–Piedmont boundary is there reported a combination of geologic conditions and effects that so clearly defines an impact structure.

The faulting, folding, and breccia zones associated with much of the structure seem to have formed by instantaneous deformation. The folds in Cretaceous units are irregularly oriented relative to bordering faults, indicating inhomogeneous stress fields near structural discontinuities. The angular blocks of unconsolidated sediments, mixed with crystalline rock fragments in a matrix of Cretaceous sand and finely broken metamorphic material, can be interpreted only as products of intense and catastrophic structural dislocation. The chaotic nature of these breccia zones suggests that they were formed in open fractures rather than having been progressively emplaced by usual fault mechanisms. The shock features found in the crystalline rocks indicate high-stress deformations not usual to crystalline rocks of the region. The contorted nature of the folds in the Cretaceous units indicates a high degree of ductility of the sediments when they were deformed. The highly contorted folds in the sedimentary rocks mixed with the breccias and large fragments of crystalline rocks near the center of the astrobleme suggest a dual origin for the materials, with the angular fragments forming during instantaneous compressional deformation at impact and the ductile sediments flowing into present position during rebound. Within the crater, large blocks of Cretaceous units are relatively undeformed, which suggests that some of the material may have slid into the crater area after the rebound.

The irregularly oriented blocks of schist near the center of the crater are interpreted as the central uplift of crystalline substratum. The high relief of the rim suggests an upward structural movement of the crystalline rock during compression. Chaotically disturbed Cretaceous units that form most of the crater floor probably represent fall-back ejecta. If the setting for the Wetumpka Astrobleme was submarine, the effects of the catastrophic turbidity current on the reorientation of the strata are unknown.

Evidence for disturbance in the Cretaceous sequence outside the structure is obscure. The Cretaceous clastic units are similar in appearance to each other and vary slightly in lithology from place to place,

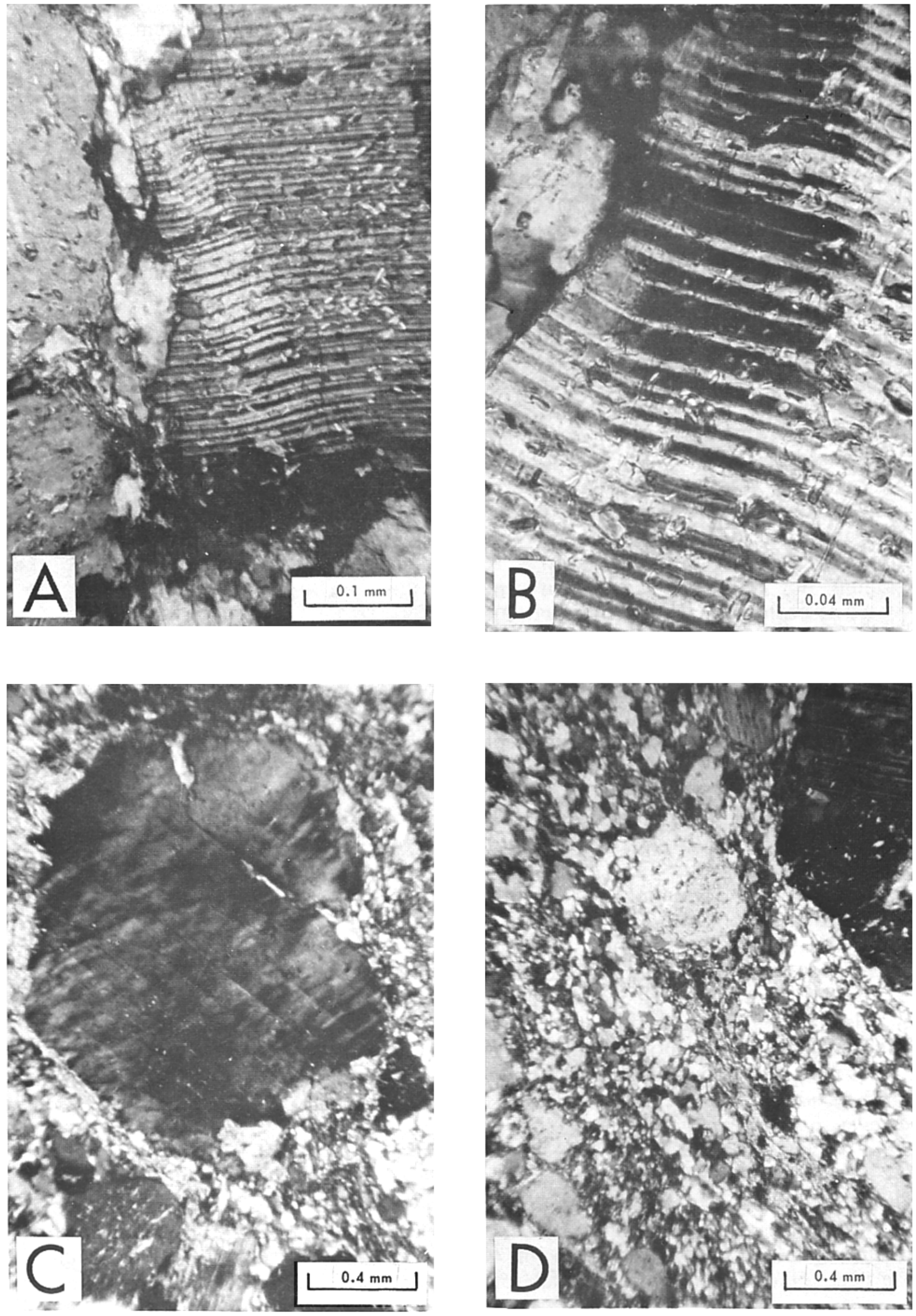


Figure 6. Photomicrograph of fine-grained, biotite-muscovite-feldspathic gneiss from southern rim area of Wetumpka Astrobleme, showing shock features. A. Plagioclase feldspar crystal exhibiting kink banding of twinning lamellae (crossed nicols). B. Close-up of deformed lamellae. Note change in isotropism along lamellae in zone of distortion (gray to black), indicating change in refraction index and extinction angle (crossed nicols). C. Highly shocked quartz crystals exhibiting two sets of planar fracture. Discontinuous undulatory extinction along set 1 (NE-SW) crossing set 2 (NW-SE) with minor offsetting (crossed nicols). D. Mortar texture of crystallite along late cleavage suggestive of shock shear.

thus hindering resolution of any structural disturbance. However, on a tributary of the Marl Branch (N½SE¼ sec. 34, T. 18 N., R. 19 E.), a slice of Mooreville Chalk is preserved and may indicate a depressed outer zone filled with material that has slid off the rim. Also, the grabens on the southwest side of the Wetumpka Astrobleme structure could be extensional features related to impact. Elsewhere, erosion has removed the Cretaceous strata.

The Upper Cretaceous Mooreville Chalk, the youngest sedimentary unit deformed, is preserved in large blocks within the structure and in the grabens along the southwest side. These rocks are more than 16 km north of the undisturbed outcrop limits of the Mooreville and verify that the rocks extended at least that far north at the time of deformation. No younger strata are deformed. If younger strata were present at the time of deformation, they would be mixed with the Mooreville and older units, but they are not. Thus, younger beds had already been eroded from the Mooreville before deformation or the Mooreville was being deposited at the time of deformation. A shallow marine setting may be reasonable, considering the strata involved and the general lack of shock features associated with the Wetumpka Astrobleme.

DEVELOPMENT OF THE WETUMPKA ASTROBLEME

Several geologic factors seem to have contributed to the development of the Wetumpka Astrobleme. The differences in thickness of the Cretaceous blanket, as well as any overlying body of water, may have differentially dissipated the impact force. The unconsolidated Cretaceous sediments are as much as 300 m thick to the south, but the thickness may have been only 100 to 150 m on the north edge of the structure. Under a thinner Cretaceous cover, the crystalline rocks in the northern part of the astrobleme may have been more compressed than the crystalline rocks under the thicker Cretaceous cover in the southern part of the astrobleme area. Also, the crystalline rocks at the south side of the astrobleme would be less affected by compression, because the unconsolidated sediments could be more tightly compressed in a given unit volume and thus might not transmit the total compressional force to the crystalline rock. The orientation of the original foliation of the crystalline rocks in the Wetumpka area may have been such that the impact force was partially deflected and reoriented along common northeast-oriented joints and faults in the crystalline basement. The break in the rim of the southwest quadrant was developed by faulting during refraction and uplift, probably as a result of lithologic control and foliation. Recent studies of impact structures suggest that lithologic differences do not have a primary effect during the compression stage of the shock wave; however, they do have a strong effect subsequent to refraction. Excavation stage concomitant with the refraction thereby does affect crater shape (B. M. French, 1971, written commun.).

The graben faults appear to be a part of a system of faults outside the structure. They could have originated by gravity sliding off the flanks of the impact structure during rebound or by concentric grabens that resulted from extensional adjustment. The graben faults may extend and cut underlying crystalline rocks, or they may transect only the Cretaceous strata.

The possible evolution of the Wetumpka Astrobleme can be summarized as follows: (1) A meteorite, having a trajectory possibly inclined to the south, plunged either into a shelf of exposed Cretaceous Coastal Plain sediments with Mooreville Chalk at the surface or into a shallow-water carbonate bank of Mooreville Chalk. (2) During impact, the underlying rocks were thrust downward, and on rebound the crystalline rim rocks were pushed upward. During rebound, concentric grabens formed around the structure, locally preserving the youngest strata. (3) If exposed, erosion of the crater through the rimless zone on the southwest side may have excavated the crater interior and connected the crater area to the regional drainage. If submerged, water rushing into the crater may have eroded the soft parts of the rim. (4) Subsequently, a river flowed into the crater and covered much of the area with alluvial deposits. (5) The course of the river changed and the interior of the crater was dissected by subsequent erosion.

ACKNOWLEDGMENTS

We thank John C. Scott for many discussions and information about Cretaceous sedimentary rocks in the area and for giving us unpublished well information. We thank Charles E. Weaver for his efforts to find coesite. We are indebted to B. M. French, J. M. Kellberg, E. A. King, T. W. Offield, and R. G. Stearns for constructive reviews of the manuscript and for their many helpful suggestions.

REFERENCES CITED

Bentley, R. D., and Neathery, T. L., 1970, Geology of the Brevard fault zone and related rocks of the inner Piedmont of Alabama: Alabama Geol. Soc. Guidebook, 8th Ann. Field Trip, 119 p.

Bunch, T. L., 1968, Some characteristics of selected minerals from craters, *in* French, B. M., and Short, N. M., eds., Shock metamorphism of natural materials: Baltimore, Mono Book Corp., p. 413–432.

Freeberg, J. H., 1966, Terrestrial impact structure — A bibliography: U.S. Geol. Survey Bull. 1220, 91 p.

——1969, Terrestrial impact structure — A bibliography, 1965–1968: U.S. Geol. Survey Bull. 1320, 39 p.

Monroe, W. H., 1941, Notes on deposits of Selma and Ripley age in Alabama: Alabama Geol. Survey Bull. 48, 150 p.

Priddy, R. R., 1943, Montgomery County mineral resources: Mississippi Geol. Survey Bull. 51, 115 p.

Roddy, D. J., 1968, The Flynn Creek crater, Tennessee, *in* French, B. M., and Short, N. M., eds., Shock metamorphism of natural materials: Baltimore, Mono Book Corp., p. 291–322.

Seegar, C. R., 1968, Origin of the Jeptha Knob structure, Kentucky: Am. Jour. Sci., v. 266, p. 630–660.

Smith, E. A., Johnson, L. C., and Langdon, D. W., 1894, Geology of the Coastal Plain of Alabama: Alabama Geol. Survey Spec. Rept. 6, p. 549–555.

Stephenson, L. W., 1926, The Mesozoic rocks, *in* Adams, G. I., and others, Geology of Alabama: Alabama Geol. Survey Spec. Rept. 14, p. 231–250.

Stose, G. W., ed., 1926, Geologic map of Alabama: Alabama Geol. Survey Spec. Map 7.

Wilson, C. W., Jr., and Stearns, R. G., 1968, Geology of the Wells Creek structure: Tennessee Div. Geology Bull. 68, 236 p.

Manuscript Received by the Society March 12, 1973
Revised Manuscript Received June 18, 1975
Manuscript Accepted June 24, 1975
Publication Authorized by the State Geologist, Geological Survey of Alabama