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Postimpact deformation associated with the late Eocene Chesapeake Bay impact structure in southeastern Virginia

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ABSTRACT

Upper Cenozoic strata covering the Chesapeake Bay impact structure in southeastern Virginia record intermittent differential movement around its buried rim. Miocene strata in a graben detected by seismic surveys on the York River exhibit variable thickness and are deformed above the crater rim. Fan-like interformational and intraformational angular unconformities within Pliocene–Pleistocene strata, which strike parallel to the crater rim and dip 2°–3° away from the crater center, indicate that deformation and deposition were synchronous. Concentric, large-scale crossbedded, bioclastic sand bodies of Pliocene age within ~20 km of the buried crater rim formed on offshore shoals, presumably as subsiding listric slump blocks rotated near the crater rim.

INTRODUCTION

At large buried impact structures on the Yucatan Peninsula of Mexico and in the lower Chesapeake Bay region, crater topography and postimpact deformation significantly influenced late Cenozoic sedimentation and structure. Despite burial by 300–1000 m of Cenozoic carbonate sediments, the circumferential ring structure of the Cretaceous–Tertiary Chicxulub crater is reflected in the present landscape, including a ring of sinkholes overlying the outer rim (e.g., Perry et al., 1995; Pope et al., 1996; Morgan et al., 1997).

At the late Eocene Chesapeake Bay impact site (Fig. 1A), the submarine crater bathymetry was muted by near instantaneous partial filling with impact debris and wash-back or resurge deposits (Poag, 1997). Postimpact strata over the crater generally dip gently inward and are offset by numerous normal faults, presumably in response to differential compaction of the thick crater fill (Poag, 1996, 1997). In southeastern Virginia, long-recognized but previously unexplained anomalous stratigraphic and structural features are present within Miocene and Pliocene strata. In this paper we review near-surface structures and facies changes in later Tertiary formations close to the outer rim faults of Poag et al. (1994) that strike parallel to the crater rim. We attribute these features to postimpact deformation caused by slump-block motion near the outer rim of the impact structure. Evidence for ongoing

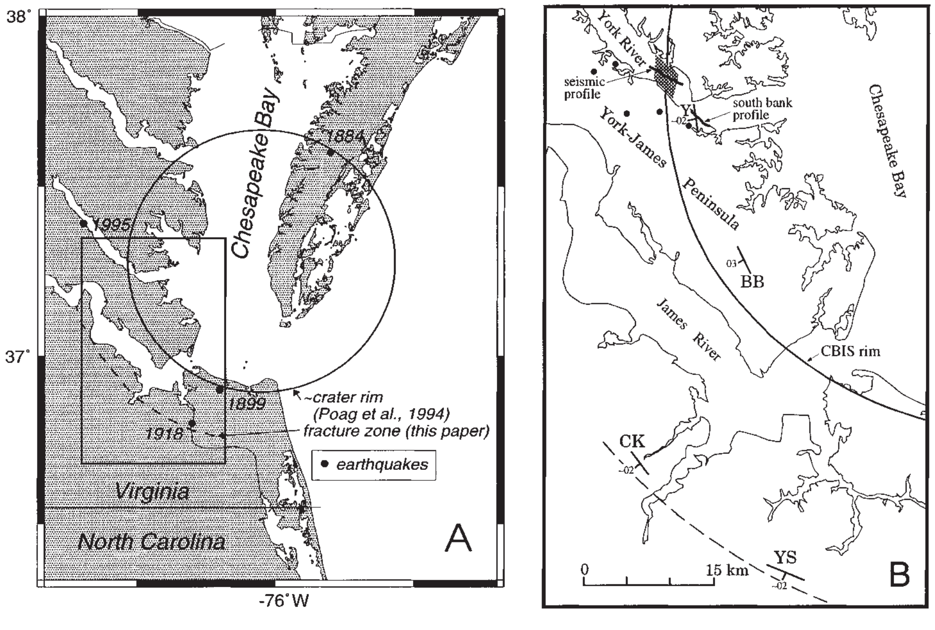

Figure 1. A: Approximate location of outer rim of Chesapeake Bay impact structure and epicenters of earthquakes from A.D. 1775 to present. Numbers indicate year earthquake occurred. 1995 earthquake (magnitude 2.6) occurred within 2 km (68% probability) of location shown (Sibol et al., 1996); older earthquakes (unknown magnitude) within 10 to 20 km of locations shown (Martin Chapman, 1998, personal commun.). Magnitudes for the latter are unknown. Solid line is crater rim from Poag et al. (1994). Dashed line marks postulated location of secondary fault zone. B: Solid line is crater rim from Poag (1997). Thick line on south bank of York River shows location of cross section in Figure 3. Irregular line in York River marks location of seismic line in Figure 6. Solid circles mark locations of wells used in identification of reflectors in seismic line in Figure 6. Shaded region in York River shows graben imaged in seismic surveys. Dashed line marks postulated location of secondary fault zone. Strike and dip symbols show attitude of Pliocene-Pleistocene contact. Numbers indicate dip angle in degrees. Y = Yorktown; BB = Big Bethel; CK = Chuckatuck; YS = Yadkins; CBIS = Chesapeake Bay impact structure.

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Figure 2. Generalized stratigraphic section for southeastern Virginia. Bold horizons are discussed in text.

Quaternary	Pliocene-Pleistocene deposits
Pliocene	**Chowan River Formation**
	Yorktown Formation
Miocene	**Eastover Formation**
	Lower Chesapeake Group formations
Oligocene	Old Church Formation
Eocene	Chickahominy Formation
	Exmore Breccia (late Eocene)
	Lower Pamunkey Group formations
Paleocene	
Cretaceous	Potomac Group
Lower Mesozoic rift-basin deposits	
Paleozoic and Precambrian crystalline rocks	

seismic deformation associated with the impact structure is ambiguous.

REGIONAL SETTING

The ~90-km-diameter Chesapeake Bay impact structure underlies the lower Chesapeake Bay region (Poag et al., 1994). The impactor penetrated Eocene to Cretaceous sediments and the underlying pre-Mesozoic crystalline rocks (Fig. 2) and created the water-saturated Exmore Breccia (Koeberl et al., 1996). This breccia, which contains abundant shock metamorphism, is ~300 m thick in the annular trough (outer ~30 km) and thins rapidly to zero outside the outer rim (Koeberl et al., 1996; Poag, 1997). A zone of normal-faulted slump blocks is beneath the breccia pinchout, and faults displace Miocene and older strata (Poag, 1996). Postimpact strata drape over the outer rim and thicken toward the center of the crater, indicating ongoing crater subsidence during late Tertiary time (Poag, 1996).

Generally, Tertiary formations in southeastern Virginia are thin, tabular sheets of marine sand, silt, and shell debris that thicken and dip gently seaward. Along the outer rim of the impact structure these strata exhibit abrupt changes in thickness, lithology, and interformational and intraformational angular relationships, as observed in the Yadkins, Chuckatuck, and Big Bethel pits and in outcrop and subsurface on the York and James Rivers (Fig. 1B). Gentle folds in late Tertiary sediments have long been recognized on the lower coastal plain (Harris *in* Ward, 1993; Mansfield, 1943; Ward and Blackwelder, 1980), but their genesis has remained obscure.

DATA

To determine if the anomalous structures are aligned along the rim of the Chesapeake Bay impact structure we (1) made field observations of upper Miocene–Pliocene strata in southeastern Virginia, and (2) conducted shallow-marine seismic surveys along the York and James Rivers (Fig. 1B). These surveys, made in September 1996 aboard the R/V *Langley* of the Virginia Institute of Marine Science, utilized a Huntec "boomer-type" system at a 1 s repetition rate. Analog data were recorded with a single-channel, 5-m-long, 10 element "eel" and processed through a preamplifier and an ORE GeoPulse filter/amplifier with a 200–1500 Hz bandpass. Data were recorded on EPC-4800 and EPC-3200 graphic recorders to 250 ms. Vibrations from traffic and construction precluded land seismic surveys near locations of anomalous structures on the York-James Peninsula.

STRUCTURAL ANOMALIES

Structural troughs, marked by reversals of regional dip, occur along the York and James Rivers. Along the south bank of the York River above Yorktown, Eastover, and Yorktown, strata dip (0.6 m/km) eastward; downstream the dip of these formations is reversed (Harris *in* Ward, 1993). The dip angle of upper Yorktown strata (beds a to f of Mansfield, 1943) (Fig. 3) exposed in the bluffs near Yorktown decreases progressively upward from ~8.8 m/km to 1.4 m/km, producing a fan-like effect. Bed e is a linear body of large-scale crossbedded biofragmental sand (Fig. 3). Angular unconformities separate bed f from older planar strata below and Pleistocene beds above.

A similar angular unconformity exists within upper Yorktown Formation beds in the Big Bethel pit (Fig. 4). In the northern and southeastern parts of the pit, the large cross-bedded biofragmental sand body rests directly on a *Crepidula*-bearing sand, and to the southwest it overlies inclined oyster shell–bearing sand and silicic-carbonate sand facies. The basal contact of the biofragmental sand body strikes N23°W and dips 3°SW. Pleistocene sediments rest with angular unconformity on the Yorktown Formation.

At the Yadkin pit, dipping planar-bedded, biofragmental sands of the Yorktown Formation are overlain with angular unconformity by fossiliferous sands of the upper Pliocene Chowan River Formation. Yorktown beds strike ~N65°W and dip south-southwest at more than 1°. The Chowan River Formation also dips to the southwest, and in the eastern and northern parts of the pit, it has been removed by Pleistocene erosion.

The westward and southwestward dips of the Yorktown and Chowan River strata, with dip angles decreasing upward in the sections, indicate that subsidence was accompanied by a pro-

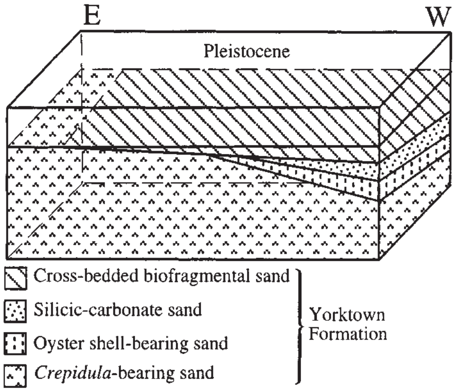

Figure 4. Schematic diagram of stratigraphic relationships within Yorktown Formation and overlying Pleistocene deposits at Big Bethel pit, Hampton, Virginia. West is to right for compatibility with Figure 3. Thickness of Yorktown strata shown schematically is ~5 m. Dip of base of oyster shell–bearing sand is ~3°SW. Location shown with BB in Figure 1B.

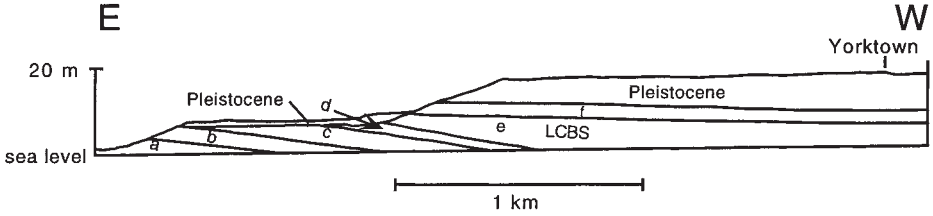

Figure 3. Cross section of bluffs along south bank of York River near Yorktown. Location shown with heavy line on south bank of York River near Y in Figure 1B. Beds a–f are Yorktown Formation. Strata dip westward and are truncated by younger deposits. LCBS = large cross-bedded biofragmental sand body. Modified from Mansfield (1943).

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gressive down-to-the-west and down-to-the-southwest rotation of beds at these sites during late Pliocene time. Each structure clearly is incongruent with the general structural grain of coeval Coastal Plain strata, and each strikes roughly parallel to the crater rim (Fig. 1). These observations suggest that subsidence, through much of Pliocene time, at each of these sites was locally governed by ongoing slumping of fault blocks on either side of the outer rim of the Chesapeake Bay impact structure.

STRATIGRAPHIC ANOMALIES

Large bodies of westward-dipping, megacross-bedded biofragmental sands that intertongue landward with fine-grained lithofacies are present at Yorktown (Johnson, 1972) and at Chuckatuck (Johnson and Coch, 1969) (Fig. 1B). These bodies are lenticular in cross section, reach a maximum thickness of more than 20 m, range in width from 1 to 2 km and in length from 3 to 6 km, and are composed almost entirely of unlithified shell debris. The westward-dipping mega-cross-beds exceed 6 m in thickness and dip westward at angles of as much as 38°. The large, cross-bedded, biofragmental sand body at Yorktown trends north-south, and the sand body at Chuckatuck trends N25°W; both approximately parallel the crater rim. The uppermost beds of both biofragmental sand bodies dip outward from the crater center at 1°–2°.

The composition, shape, and geographic distribution of the large cross-bedded biofragmental sand bodies, and their relationship to intertonguing sediments, require shoaling conditions seaward and a deeper basin landward (Fig. 5). As blocks near the crater wall slid along rim faults, the outer edges subsided and the inner margins were elevated, causing gentle folding of the overlying later Tertiary sediments and the formation of offshore shoals and landward basins. The large-scale cross-beds, fed by comminuted shell material generated on the shoal to the east, prograded outward into the basin. As the inner margin of the block was further elevated by continued rotation of the fault blocks, the older sediments were truncated by submarine scour (Fig. 5). This movement and subsequent erosion and deposition produced progressive truncation of older beds across individual slump blocks toward the crater. This deformation was ongoing because it created shoal-water conditions during the deposition of both the Yorktown and Chowan River formations.

YORK RIVER STRUCTURES

Shallow seismic surveys on the York River reveal a north-south–striking graben ~1.5 km wide that overlies the seismically imaged boundary fault of Poag (1996) (Fig. 6) (Vaughn, 1997). The graben is present at two-way travel times of as low as ~50 ms. Thinned strata and pinchouts at 140 and 90 ms (A and B, Fig. 6) between draped

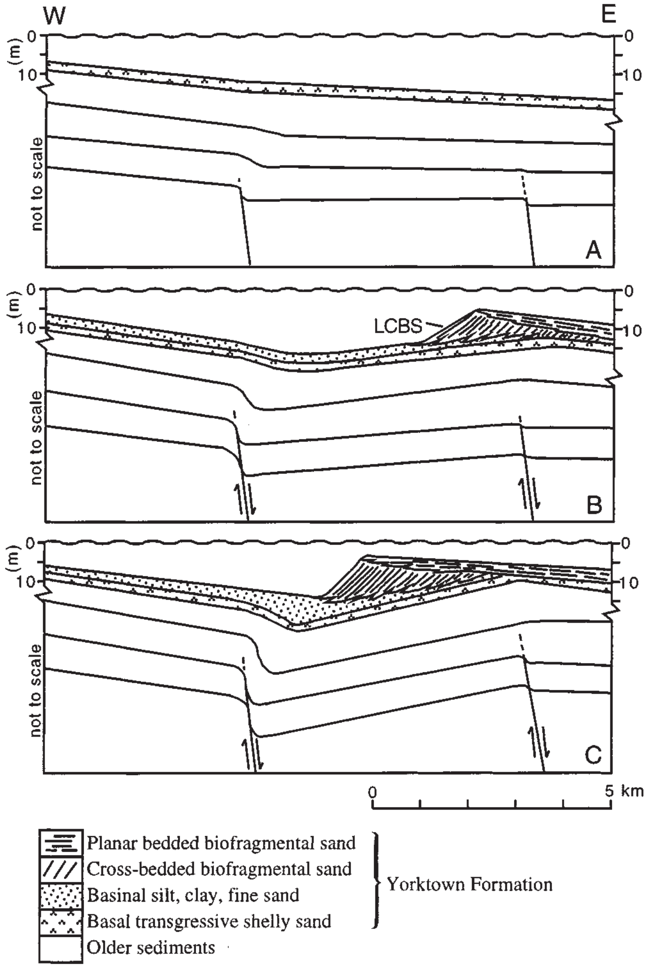

Figure 5. Schematic showing formation of large cross-bedded biofragmental sand bodies and basinal deposits at Yorktown and Chuckatuck, locations shown with Y and CK, respectively, in Figure 1B. A: Marine transgression during period of tectonic quiescence while lower middle Yorktown was deposited. B: Development of basin and shoal and deposition of accompanying sediments in response to rotation of underlying slump blocks during deposition of middle Yorktown Formation. C: Growth and migration of cross-bedded biofragmental sand upward and eastward across basinal sediments during deposition of upper Yorktown Formation.

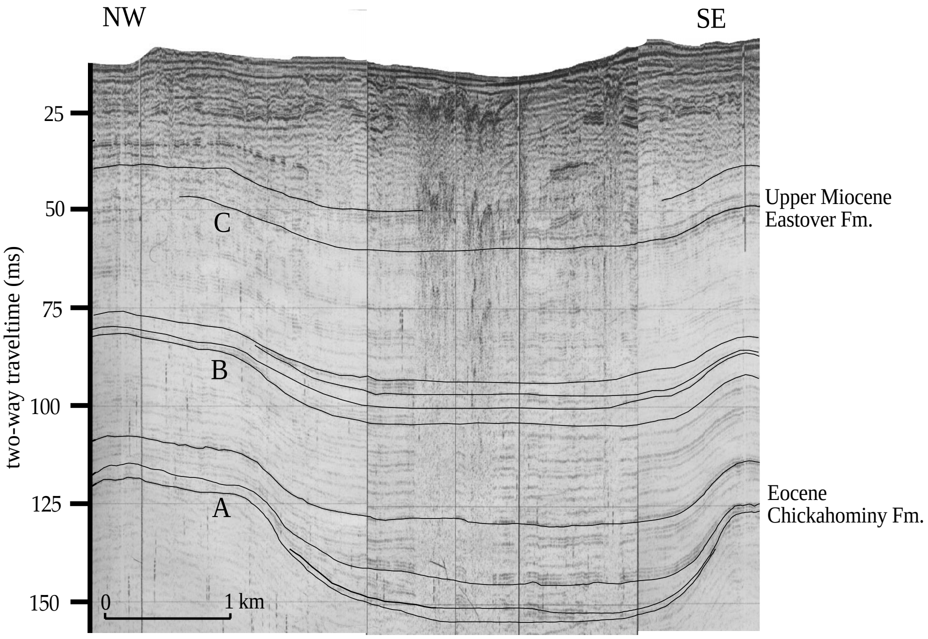

Figure 6. Seismic record along York River. See Figure 1 for location. Strong reflectors at A, B, and C are not multiples of earlier arrivals. Pinchouts at A and B show that reflector dips, although vertically distorted, are not artifacts of velocity pull-up. Age interpretations are based on correlations with drilling records from wells south of York River. Well locations shown with solid circles in Figure 1B.

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layers of relatively uniform thickness suggest that graben subsidence in Miocene time was intermittent (little graben subsidence relative to surroundings during deposition of uniformly thick layers), the most recent event postdating upper Miocene reflectors (C, Fig. 6). These structures suggest that the outer rim continued to serve as a focus of deformation through the Miocene. Complex shallow structures (<30 ms, Fig. 6) preclude interpretation of younger deformation.

SEISMICITY

The four reported earthquakes in southeastern Virginia (Sibol et al., 1996, 1997) (Fig. 1A) occurred less than 40 km from the outer rim of Poag et al. (1994). Although this spatial coincidence is suggestive of ongoing deformation associated with the impact structure, the overall low level of seismicity near the impact structure is indistinguishable from that of the regional coastal plain of Virginia and North Carolina (Sibol et al., 1997).

DISCUSSION AND CONCLUSIONS

A series of subparallel linear bodies of biofragmental sand exhibiting large-scale, westward-dipping cross-beds formed on offshore shoals created by rotation of slump blocks on the perimeter of the Chesapeake Bay impact structure during the late Pliocene. These bodies intertongue with fine-grained basinal deposits to the west and southwest, and later migrate westward across these basin sediments. The angular stratigraphic relationships within and between upper Cenozoic formations, and the progressive truncation of older deposits toward the impact structure center, attest to continued deformation near the crater outer rim during deposition of the late Tertiary sequence.

The Yorktown large cross-bedded biofragmental sand body and the inclined and truncated strata at Big Bethel pit are inside the crater rim of Poag (1996), whereas the Chuckatuck biofragmental sand body and Yadkin structures are more than 20 km outside Poag's crater rim. The Chuckatuck and Yadkin structures increase the width of the documented fracture zone of the impact structure to ~65 km from the center of impact. The outer rims of large impact structures are often quite irregular with extended zones of megablock slumping (e.g., Jansa et al., 1989; Koeberl and Anderson, 1996; Spray, 1997).

The strata in the upper ~150 m respond to differential movement with draping (Fig. 6) in contrast to the faulting that characterizes deeper strata (Poag, 1997). Faults at shallow depths (<150 ms) are rare within 10 km of the outer rim in seismic surveys on the York or James Rivers.

The driving forces from lithostatic loading for megablock slippage and compaction of Exmore Breccia are small. Sediment overburden is generally less than ~300 m. Nevertheless, the structures described here, the thickening of post-impact strata into the crater, and the widespread faulting in Eocene-Miocene sediments over the impact structure (Poag, 1996) suggest that fault slip may be significant.

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