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Preliminary investigation of faults and folds along the inner edge of the Coastal Plain in northeastern Virginia

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Abstract

Four en-echelon northeast-trending structures, including southeast-dipping monoclines and northwest-dipping high-angle reverse faults, have been mapped along the inner edge of the Coastal Plain in northeastern Virginia -- an area generally considered to be undeformed. Although displacements are small (15 to 60 m), the structures markedly affect the present distribution and thickness of Coastal Plain strata.

Structure contour maps on Cretaceous and Paleocene lithostratigraphic units show that the amount of displacement on the structures increases downward, indicating recurrent movement. The major deformation occurred in the Cretaceous and middle(?) Tertiary but some movement in the latest Tertiary or Quaternary is possible.

The structures, herein named the Stafford fault system, extend for at least 56 kilometers parallel to the Fall Line and the northeast-trending reach of the Potomac estuary. This relationship supports the hypothesis that the Fall Line and major river deflections along it have been tectonically influenced.

Introduction

Alinement of the northeast-trending reaches of the Potomac, Susquehanna, and Delaware estuaries and the uniform southwestward deflection of these rivers at the Fall Line constitute one of the most prominent geomorphic lineaments of the Middle Atlantic Coastal Plain. Many early writers, including McGee, 1888, Darton, 1891, and Fenneman, 1938 noted these features and speculated on their origin. McGee (1888 p. 616-634) appears to have been the first to suggest that the geomorphic lineament is related to the underlying geologic structure. Basing his interpretations mainly on physiographic evidence, McGee proposed down-warping of the inner edge of the Coastal Plain along "a line of dislocation coinciding approximately with the fall-line, extending from about as far south as the Rappahannock River, at least, to some point along the Hudson....".

Detailed mapping by the authors of the Coastal Plain sediments in Prince William County in northeastern Virginia and reconnaissance work to the southwest in Stafford and Spotsylvania Counties have delineated northeast-trending flexures and faults which coincide with the segment of the Fall Line paralleled by the Potomac River estuary, (Figs. 1 and 2). Deformation along these structures has resulted in up-to-the-pied-

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Figures 1 and 2 near here.

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mont (down-to-the-coast) displacement of the Coastal Plain strata and the underlying crystalline rocks similar to the downwarping envisioned by McGee. Although most of the deformation took place in the Cretaceous and the early or middle Tertiary, displacements along these structures. have appreciably affected the present distribution and thickness of Coastal Plain units within the area as well as the local geomorphic history.

Geologic Setting

The sedimentary rocks underlying the Atlantic Coastal Plain in northeastern Virginia, between Fredericksburg and Washington, D. C., consist of a southeastward thickening wedge of mostly unconsolidated sand, silt, and clay with lesser amounts of gravel and calcareous materials. Sediment thickness ranges from a feather edge along the western margin of the Coastal Plain to about 200 meters or more in the vicinity of the Potomac River. The exposed sequence includes (1) coarse fluvial sediments of the Potomac Group of Early and Late Cretaceous age, (2) relatively fine-grained marine sediments, in part glauconitic, of Paleocene, Eocene, and Miocene ages, capped by (3) a veneer of Tertiary and (or) Quaternary gravel and sand. These strata are a small part of the Mesozoic-Cenozoic sediment complex filling the Salisbury embayment, a broad structural basin whose landward portion is centered in eastern Virginia, Maryland, Delaware, and New Jersey. Northwestward, the Coastal Plain rocks lap onto metamorphosed sedimentary, volcanic, and plutonic rocks of the Virginia Piedmont.

Structures

(see plates I - V)

The four mapped zones of flexures and faults were recognized, initially, as linear zones of much steeper-than-average dips as shown by structure contours on two mapping horizons, the base of the Cretaceous beds (= base of Potomac Group) and the base of the Paleocene (= base of Aquia Formation, see fig. 3). As both mapping horizons are erosional

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Figure 3 near here.

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unconfomities, detailed contouring shows local relief on the unconformities as well as regional dip. The highly irregular surface which separates the non-marine Potomac Group sediments and the directly underlying Piedmont metamorphic complex reflects a long period of fluvial erosion; hence, in some areas, the amount of relief on the surface of unconformity (30 m ±) approaches the structural relief on the mapped flexures and faults. The base of the marine Aquia Formation, which in this area overlies the Potomac Group, is much more regular but it too is channeled with a maximum known local relief of 3 to 6 m. However, the disadvantages of contouring unconformable surfaces have been partly compensated by the availability of modern 10-foot-contour interval topographic maps and by the abundance of control points obtainable from outcrops--due largely to the intense dissection along the Fall Line in this area. Outcrop data have been supplemented, especially on the "down" side of structures, by power augering to depths of 150 feet (45 m).

Dumfries fault zone.-- The northwesternmost structure, herein named the Dumfries fault zone, was first observed near the town of Dumfries, a major tobacco port in colonial times. In this area, generalized contours drawn on the top of the Piedmont crystalline rocks show an oversteepened southeast-dipping gradient or "downstep" of about 150 feet (45 m) within about 0.25 miles (0.4 km) or less (Mixon and others, 1972). Across the gradient the overlying Potomac Group sediments double in thickness. The steep structure contour gradient trends north-northeast across the Quantico quadrangle, defining both the southeasternmost outcrops of Piedmont crystalline rocks and the updip limit of thick (> 300 feet [90 m]) Potomac Group sediments. Geomorphically, the structure contour gradient marks the point where wide, flat-bottomed valleys, characterized by tidal creeks and marshes, narrow abruptly to V-shaped headwaters partly incised into the Piedmont crystalline rocks. Thus, in this area, the linear zone of steeper slopes on the basement rock surface coincides with the Fall Line.

The oversteepened contour gradient on the basement rock surface has been traced by reconnaissance mapping from near the town of Woodbridge in northeastern Prince William County to Potomac Creek in south-central Stafford County, a distance of about 22 miles (35 km). The trend of the steep contour gradient cuts diagonally across the early Cretaceous depositional basin, approximately at right angles to the paleodrainage in the Dumfries and Stafford areas, strongly suggesting a tectonic rather than erosional origin.

The Dumfries fault zone is most conspicuous northwest of Stafford where lower Cretaceous sands, faulted against the more resistant lower Paleozoic Quantico Slate have been differentially eroded. The resulting 5-mile-long (8 km) fault-line scarp is evident as a lineation on topographic maps and air photos. Shallow roadcuts along State Route 630 at the southern end of the scarp show nearly vertical beds of Cretaceous sand and silt in contact with the Quantico Slate. An aburpt offset of 108 feet (33 m) of the contact between the Quantico Slate and Cretaceous sand at this locality, as determined by an auger hole on the down-thrown block, suggests a fault. In order to clarify structural relationships, a trench 15 m long and up to 2.5 m deep was dug across a slate and sandstone outcrop on the scarp about 1 mile (1.6 km) northeast of State Route 630. The trenching revealed a northwestward-dipping high-angle reverse fault which thrusts slate and phyllite over deformed conglomeratic sands of the Potomac Group (Newell and others, 1976).

The Dumfries fault zone marks the up-dip limit of outcrop of the Aquia Formation of Paleocene age (see figs. 2 and 4). The Calvert

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Figure 4 near here.

Formation truncates the Aquia beds across the structure and, on the west side, directly overlies either the Potomac Group of late Early and Late Cretaceous age or the Piedmont crystalline rocks. The abruptness of truncation of the Aquia beds and reversal of regional dip (normally to the southeast) of the Aquia-Potomac Group contact near the structure indicate faulting and (or) flexuring of the Aquia prior to deposition of the Calvert Formation. Whether or not the Calvert Formation has also been warped or faulted has not yet been determined.

Fall Hill and Hazel Run Faults.-- Reconnaissance mapping south and east of the Dumfries fault zone has disclosed additional northeast-trending up-to-the-Piedmont structures which have deformed both Cretaceous and lower Tertiary rock units. Outcrop and borehole data indicate that displacement of the contact between the crystalline bed-rock and the Cretaceous sediments ranges from 30 to 50 metres. Structure contours on the base of the overlying Aquia Formation also show up-to-the-Piedmont displacement but the amount of offset is only about half as much. Projection of the structures along strike southwestward to the Coastal Plain-Piedmont boundary has pinpointed outcrops showing two northwest-dipping high-angle reverse faults which thrust Piedmont crystalline rocks over Lower Cretaceous sediments. One of the structures, herein named the Fall Hill Fault, has been mapped from the Rappahannock River to the town of Stafford, a distance of more than 13 kilometres (fig. 1). The fault is well-exposed in shallow road cuts in the western edge of Fredericksburg and in a deep ravine north of the Rappahannock River. The other structure, named the Hazel Run Fault, extends from Fredericksburg about 8 km southwestward at least as far as the Coastal Plain-Piedmont boundary . Displacement on the Fall Hill and Hazel Run faults appears to be greatest in the vicinity of Fredericksburg; the faults appear to die out northeastward as gradually diminishing monoclinal flexuring.

Brooke structure.-- A fourth zone of flexuring and faulting(?), about 7 kilometres southeast of the Dumfries structure, passes through the small community of Brooke (fig. 1). The structure as mapped in reconnaissance is a broad southeast-dipping monocline which deforms Cretaceous and Tertiary strata. Generalized structure contours along a 10-kilometre segment of the monocline show that down-to-the-coast displacement of the base of the Aquia Formation is 100 feet (30 m) over a distance of about one mile (1.6 km). Normal regional dip on the base of the Aquia in this area is only about 10 to 20 feet/mile.

Folding appears to be most aburpt along the southeast side of the monocline. Preliminary field mapping indicates that the zone of steepest flexuring marks the present-day up-dip limit of two lower Tertiary stratigraphic units, the Nanjemoy Formation and its Marlboro Clay member. The Calvert Formation of early and middle Miocene age unconformably overlies the Eocene Nanjemoy Formation on the southeast side of the monocline (figs. 2 and 4). On the northwest side of the monocline, the Calvert beds directly overlie the Aquia Formation. The Nanjemoy Formation and its Marlboro Clay Member have been eroded from the upwarped side of the Brooke monocline during late Eocene to early Miocene time. These relationships indicate a middle Tertiary episode of deformation in this region. The abruptness of truncation of the Marlboro-Nanjemoy section suggests that the deformation of the Tertiary strata along the southeast side of the Brooke monocline may include some faulting. As the Coastal Plain sediments are several hundred feet thick across the Brooke structure, a determination of the nature and amount of displacement of the basement rock surface would require deep drilling or geophysical profiling. Possible offset of 200± feet (60 m) of the contact between the Potomac Group beds and the crystalline rocks is suggested by data from deep water wells on the Quantico Marine Base, about 8 miles (13 km) northeastward along the projection of the Brooke structure (Mixon and others, 1972).

Comparison with Brandywine fault system

Similarities between the Stafford fault system and the parallel Brandywine fault system, about 15 miles (24 km) to the east in southern Maryland (Jacobeen, 1972) suggest that the two structures may be tectonically related. Both fault systems consist of en echelon flexures and high-angle reverse faults which deform the crystalline basement rocks and the overlying Coastal Plain strata. Major structures in both zones trend N30° to 35°E, approximately parallel to the Coastal Plain margin between Fredericksburg and Washington, D. C. (see fig. 1). Amount of displacement on individual structures in each fault system is of the same order of magnitude, ranging from a few feet up to a maximum of about 250 feet (75 m).

The sense of movement on the Stafford fault system is down-to-the coast whereas displacement on the Brandywine fault system is up-to-the-coast. Thus, the two fault systems apparently define a 25 kilometre-wide block of Coastal Plain sediments which has been depressed relative to blocks on either side.

Displacement on major faults and flexures along both the Stafford and Brandywine fault systems increases with depth, indicating recurrent movement through time. Most of the deformation along both fault systems appears to have occurred during the Cretaceous and again in post-middle Eocene to pre-middle Miocene time. Slight additional deformation in the late Tertiary along the Brandywine fault zone is suggested by minor flexuring of Miocene strata across an anticlinal structure near Danville, Maryland (Dames and Moore, 1973, p. 2.5-18 and 19 and Jacobeen, 1972, p. 3). Late Tertiary or Quaternary movement on the major structures of the Stafford fault system has not, as yet, been clearly documented. However, alinement of the Stafford fault system with the conspicuous geomorphic lineament formed by the northeast trending reaches of the Potomac, Susquehanna, and Delaware estuaries is suggestive of at least some deformation in latest Tertiary or Quaternary time. Small reverse faults offsetting stream terrace deposits near Rock Creek in Washington, D. C. (Darton, 1950) and the upland gravel near Fredericksburg, Virginia (Dames and Moore, 1973, p. 2.5-15) indicate that some compressional deformation has indeed occurred in this area at least as recently as the Pliocene and Pleistocene.

Relationship to pre-existing basement structures

The high-angle reverse faulting along the Stafford and Brandywine fault systems indicates that these structures formed in a compressional stress field. It seems likely, therefore, that the causative forces relate to basement rock tectonics rather than simple uplift of the Piedmont due to erosion or subsidence of the Coastal Plain induced by sedimentary loading. Alinement of the Stafford and Brandywine fault systems respectively with the Farmville basin and Richmond basin Triassic fault trends (see fig. 1) suggests a possible relationship between the Coastal Plain deformational belts and zones of weakness in the crystalline basement rocks characterized by normal faulting in the Triassic. This would imply a change in the regional stress field--from tension in the Triassic to compression in the Cretaceous and Tertiary.

Richmond-Brandywine Triassic belt.--Several workers have proposed that Triassic structures and sediments extend from the Richmond Triassic basin northeastward beneath a cover of Cretaceous and younger Coastal Plain sediments (Spangler and Peterson, 1950; McKee and others, 1959). A thickness of at least several hundred feet of Triassic rocks in this part of Virginia is documented by deep drill holes near the towns of Bowling Green and King George (Cedarstrom, 1945, p. 30; Brown and others, 1972). Test drilling in the Brandywine area of southern Maryland has also encountered Triassic rocks (fig. 1, this report; Jacobeen, 1972). Thus, it is apparent that a more or less continuous belt of Triassic sediments extends from the Richmond area to Brandywine, Maryland. Although the limits of the Triassic subcrop have not been defined by drilling, a pronounced east-dipping gravity gradient (Johnson, 1973, sheet 10), on-line with the Richmond basin border faults and just northwest of the Bowling Green-King George wells, may mark the northwestern edge of the buried basin. Alinement of the Brandywine structures with the gravity gradient and the Richmond basin border faults suggests that the Brandywine fault system may reflect reversal of movement along a zone of crustal weakness marked by the buried Triassic fault system.

Stafford-Farmville structural trend.--The relationship of the Stafford fault system to Triassic or older basement structures, admittedly speculative, is based mainly on the alinement of the Stafford faults with the Farmville basin Triassic fault trend (fig. 1) and the analogy with the Brandywine fault system. The Piedmont metamorphic terrane between the Stafford and Farmville areas has been little studied, and no through-going structures have been mapped, as yet. However, a possible structural tie between the two areas is indicated by a conspicuous geophysical lineament, evident on a regional aeromagnetic map of the Virginia Piedmont, that is between and on-line with the two fault systems. The lineament results from the juxtamposition of two strikingly different magnetic map patterns: one, on the northwest, dominated by medium to high intensity, linear, northeast-trending anomalies and the other, on the southeast, characterized by more subdued anomalies with a dominantly north to northwest grain. The aeromagnetic lineament, a corresponding sharp break in radioactivity values, and marked differences in lithology across the lineamant have been noted by a recent study of the Spotsylvania area (Neuschel, 1970, p. 3578, figs. 2, 3 and 4). On this basis Neuschel postulated a major basement fault extending from Spotsylvania southwestward to the vicinity of Apple Grove in Louisa County. Subsequent aeromagnetic mapping indicates that the magnetic lineament is remarkable continuous from Spotsylvania to the Farmville Triassic basin (I. Zeitz, U.S. Geol. Survey, oral commun., 1976). One may speculate that the Stafford fault system, the fault suggested by Neuschel, and the Farmville basin Triassic fault trend mark a major zone of deformation in the basement rocks that records recurrent movement in pre-Mesozoic, Mesozoic and Cenozoic time.

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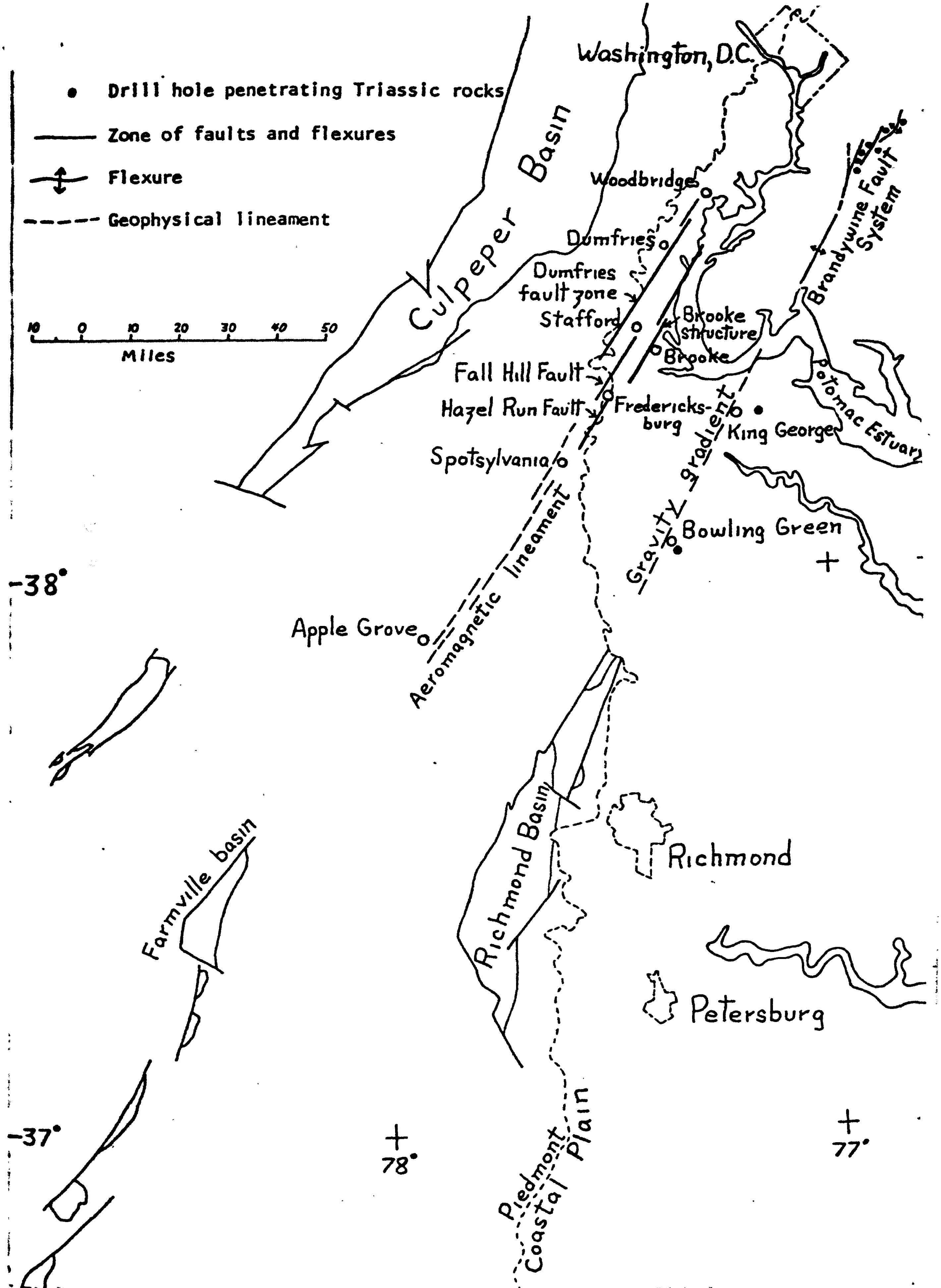

Figure 1. Map showing alinement of Stafford and Brandywine fault systems with Triassic Basins and geophysical lineaments

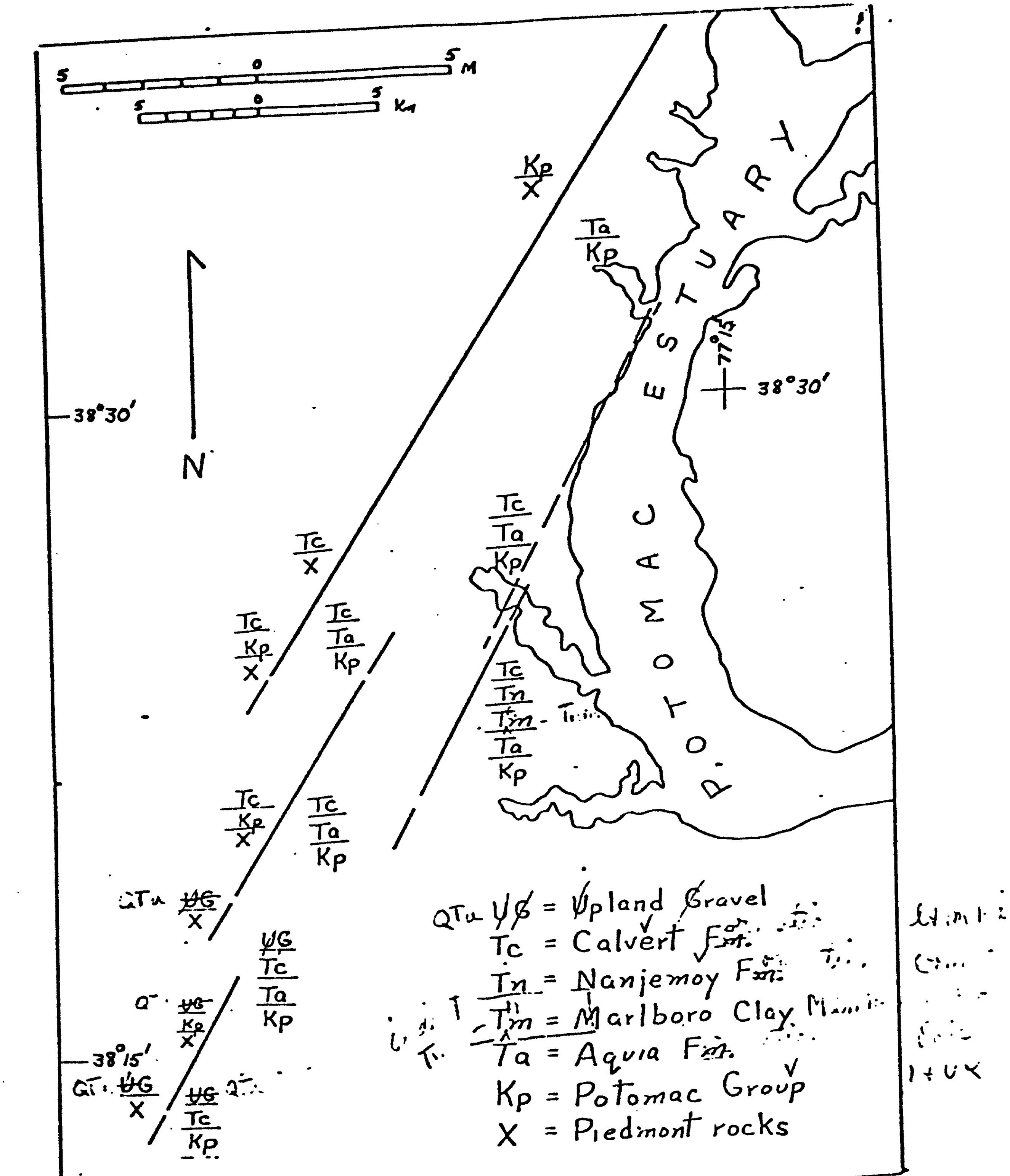

Figure 2.--Variation in stratigraphic section across structures of Stafford fault system as observed in outcrop. NW-SE differences due to down-to-the-coast displacement of Coastal Plain beds and westward onlap of Calvert Formation. SW-NE differences due to varying amounts of displacement along structural strike and relief on unconformities.

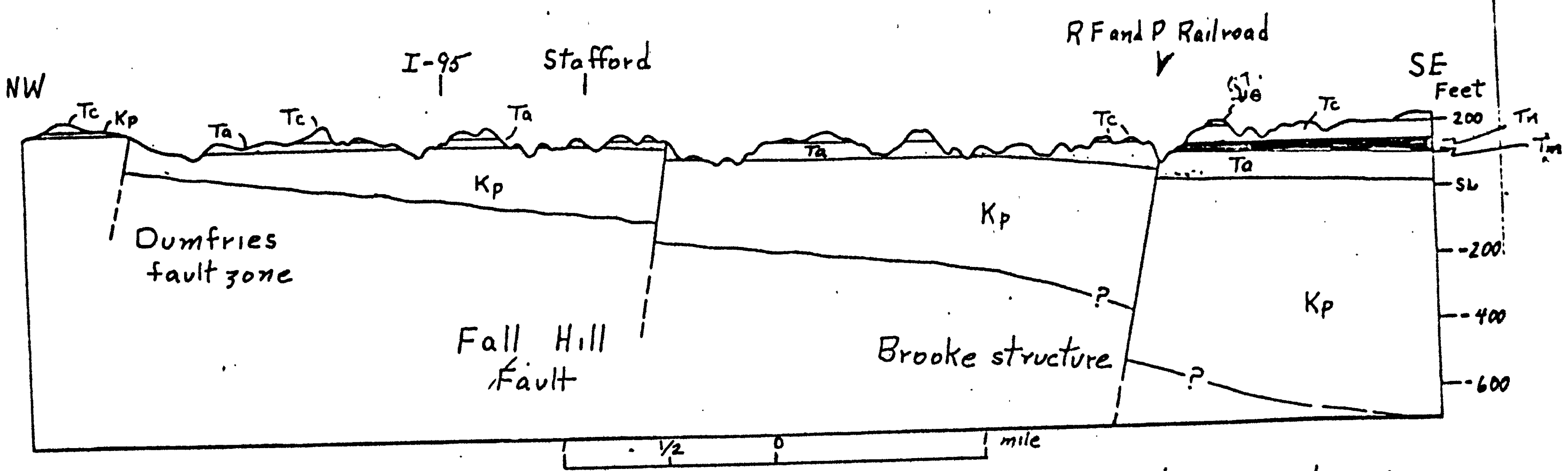

Figure 4. Cross section across inner coastal plain in Stafford area showing step-like down-to-the-coast displacement of lower Cretaceous and Tertiary ~~rock units~~ strata and Piedmont crystalline rocks. Kp = Potomac group; Ta = Aquia Formation; Tm = Marlboro Clay; Tn = Nanjemoy Formation; Tc = Calvert Formation; UG = Upland grave

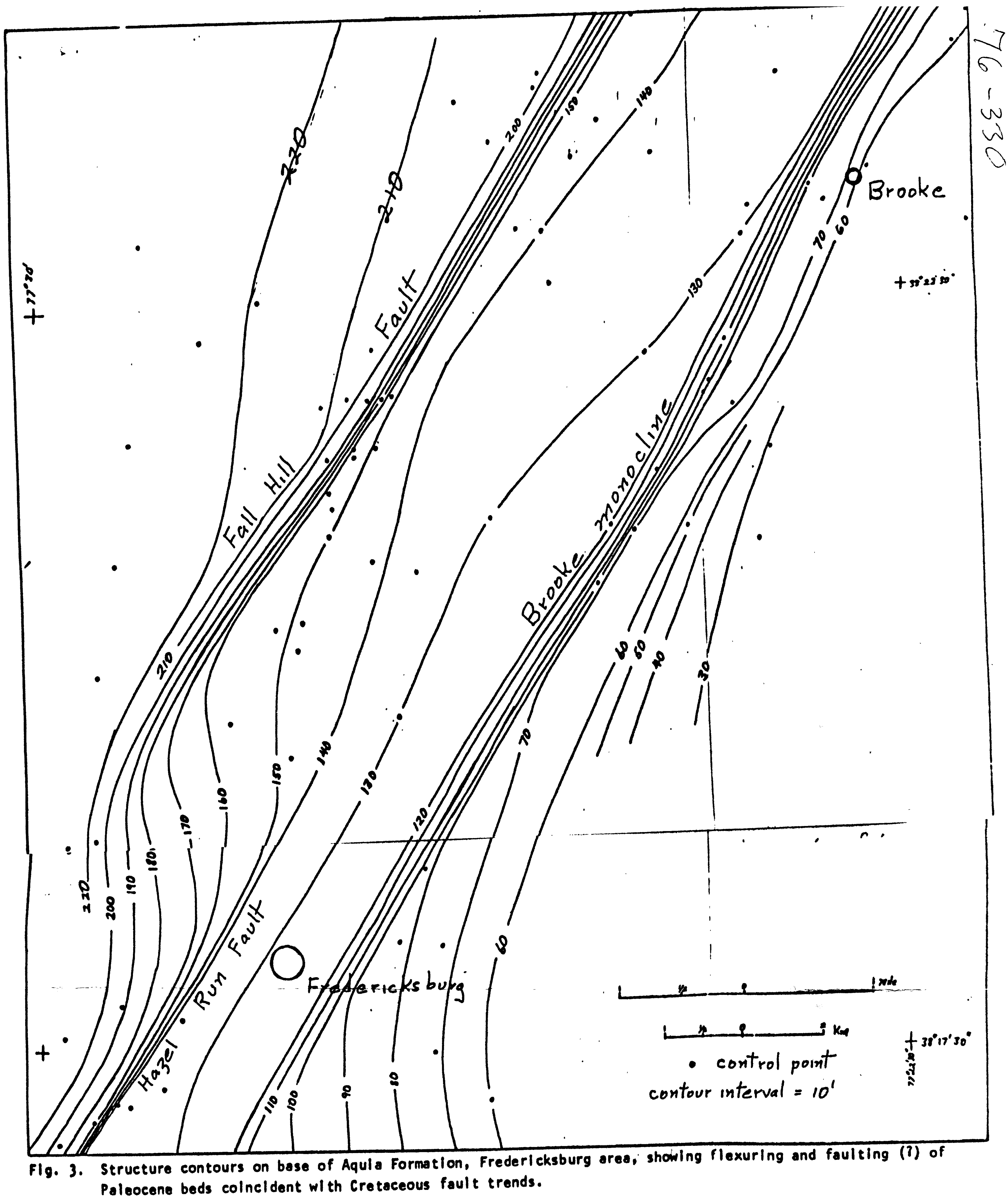

Fig. 3. Structure contours on base of Aquia Formation, Fredericksburg area, showing flexuring and faulting (?) of Paleocene beds coincident with Cretaceous fault trends.