

Figure 21-1. Map showing faulting in the Mesozoic basins of Pennsylvania (modified from Berg and others, 1980). Numbers refer to localities and structures cited in the text: 1, Boyertown; 2, Cornwall; 3, Lisburn fault; 4, Paleozoics at Fairfield; 5, Paleozoics at York Springs; 6, Furlong-Flemington fault; 7, Hopewell fault; 8, Chalfont fault; 9, Shippensburg fault; 10, Carbaugh-Marsh Creek fault; and 11, Jacksonwald syncline. Numbered faults are wrench faults; the others are normal faults, down-dropped on the southeast. Overlying Quaternary, Tertiary, and Cretaceous sediments in the area are not shown.

CHAPTER 21 GETTYSBURG-NEWARK LOWLAND

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REGIONAL SETTING

The linked Newark-Narrow Neck-Gettysburg basin complex (Figure 21-1) is the largest of a series of exposed rift basins of Late Triassic to Early Jurassic age, extending intermittently from Nova Scotia to North Carolina. It is filled with fluvial and lacustrine clastic deposits. The characteristic structural form of these basins is a tilted fault block or half graben, with strata commonly dipping into major normal faults that bound the basins on the northwestern side.

CONFIGURATION OF THE BASINS

The basins form a 140-mile arc across Pennsylvania, closely following the Appalachian structural grain. They extend into New Jersey on the northeast and into Maryland on the south. The maximum width of the Gettysburg basin is 18 miles, and strata dip dominantly northwesterly at 25 to 30 degrees (Figure 21-2). It is joined on the northeast to the Newark basin by the Narrow Neck basin, which diminishes in width to 4 miles and has variable northerly stratal dips, mostly in the range of 20 to 40 degrees. The Newark basin widens to 30 miles. Strata generally dip 5° to 15°N, except where folded near the north margin (Faill, 1973b; MacLachlan, 1983).

The basins are bordered on the northwest by one or more major normal faults. Locally, but especially at the Susquehanna River, a narrow, thin belt of overlapping basal Triassic strata, having a sub-horizontal to slight southeast dip, is preserved north of the border fault (Faill, 1973b; Root, 1977) on the passive north shoulder of the rift basin. Probably most overlap conditions at the north margin represent this type of relation. Despite ideas to the contrary (Faill, 1973b), the authors consider the basins to be bordered by a continuous, complex system of normal faults.

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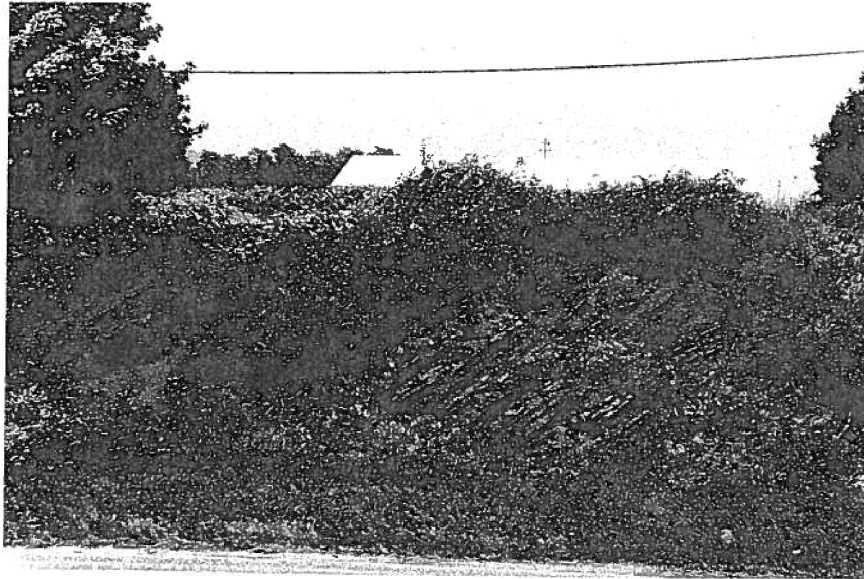


Figure 21-2. Triassic red beds of the Gettysburg basin dipping 35°NW in roadcuts just south of exit 16, Interstate Route 83, near Lewisberry, York County.

NATURE OF THE BORDER FAULT

Low-angle extensional faulting at the northwest border of the Newark basin, demonstrating normal-fault reactivation of prior Alleghanian thrusts, was established by Ratcliffe and others (1986). They showed that the border fault just south of the Delaware River dips 25° to 30°SE (Figure 21-3). Proprietary seismic data near the Delaware River reportedly show a reflector surface, interpreted as the border fault of the Newark basin, that dips southeast at about 25 degrees. About 5 miles southeast of the border fault, in the Riegelsville 7.5-minute quadrangle, the Cabot-KBI #1 well bottomed in beds of the Triassic Stockton Formation at 10,500 feet. Proprietary seismic data suggest that basement in this area may be at a depth of 18,000 feet. At Boyertown (Figure 21-1), the border fault dips 35° to 45°SE (Hawkes and others, 1953), and at Cornwall, the border fault dips 25°SE (Lapham and

Gray, 1973). At the Susquehanna River, the Paleozoic-Triassic contact dips 45°SE, and the Triassic beds dip at 20 degrees into the contact (Wherry, 1913). Low-angle normal faulting may persist westward to the Lisburn fault (Figure 21-1).

In a structural sense, the Gettysburg basin begins at the Lisburn fault. It differs from the Narrow Neck and Newark basins to the east because it lacks the im-

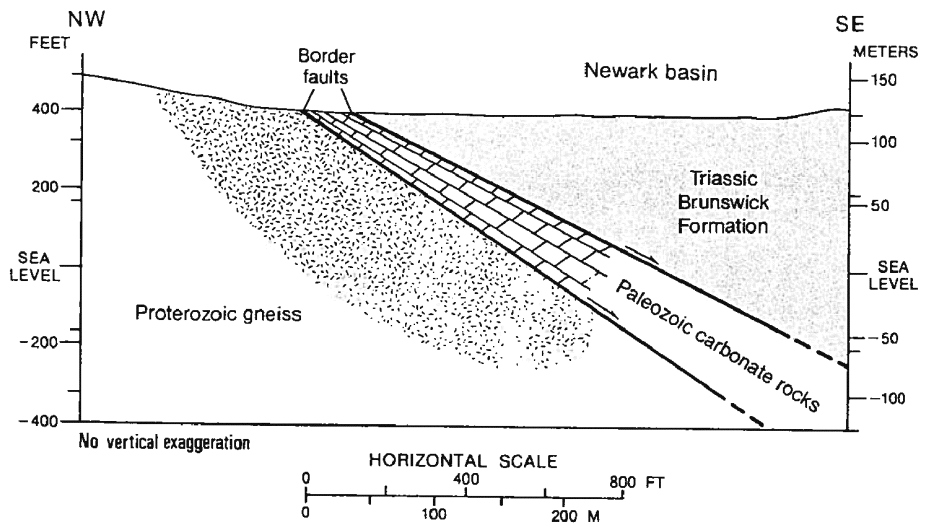


Figure 21-3. Geologic cross section across the northwest border of the Newark basin, near the Delaware River. The Mesozoic border fault here dips 25° to 30°SE and is interpreted as a normal-fault reactivation of an earlier Alleghanian thrust fault. Modified from Ratcliffe, N. M., and others (1986), *Low-angle extensional faulting, reactivated mylonites, and seismic reflection geometry of the Newark basin margin in eastern Pennsylvania*, *Geology*, v. 14, Figure 3, p. 767. Modified with permission of the publisher, the Geological Society of America, Boulder, Colorado USA. Copyright © 1986 Geological Society of America.

press of pervasive wrench tectonics apparent as echelon folds adjacent to the border fault. The straight trace of the normal fault across high-relief terrain (Figure 21-4) and the 60° to 70°SE dips of minor normal faults in the basin suggest steep normal faulting at the surface (Root, 1988, 1989). However, gravity data show the deepest part of the basin toward the present basin center (Sumner, 1977; Root, 1977, Figure 24), not adjacent to the border fault. Consideration of these structural elements led Root (1988, 1989) to model the border fault as a listric normal fault; it is steep at the surface and flattens out at depth (Figure 21-5).

NORMAL FAULTING WITHIN THE BASIN

At or near the major border faults are a series of lesser faults that formed either contemporaneous with or slightly later than the border faults. The Lisburn fault (Figure 21-1), which offsets the border fault, appears to be a later stage fault. It is presumed to be steep because associated normal faults dip 60°SE. East of the Lisburn fault and extending to Cornwall (Figure 21-1), small, probably steep, faults offset the border fault.

Normal faults associated with basin development occur both transverse and parallel to the structural grain within and beyond the basin (Figure 21-1). Transverse faults are best known in the Narrow Neck basin, where there are abundant conglomerate reference beds. Faults parallel to the grain are difficult to recognize, but are at least locally abundant where exposure is superior (e.g., Watson, 1958). Relatively few faults parallel to the grain have been mapped in

the basin, but several are mapped at the south, overlap margin of the Gettysburg basin (Figure 21-1). In Maryland, several more such faults are mapped at the south margin (Root, 1988), some attaining vertical displacements of 2,800 feet. These faults form minor half grabens on the major Gettysburg half-graben structure (location map, Figure 21-5). Faults that were formed after diabase intrusion are present and appear to be part of the latest (post-folding) development of the basin.

Some faults were apparently active early in the development of the basin and affected distribution of coarse fluvial sediments (MacLachlan, 1983). The Lisburn fault is apparently such a fault; early activity produced a thick clastic wedge south of the fault, and later activity offset the border fault. Few such faults have been identified to date, indicating little syndepositional faulting within the present limits of the basin.

Normal faults, related to Mesozoic rifting, are now recognized west of the Gettysburg basin in the Precambrian and Paleozoic basement (Root, 1988) and in basement rocks north of the Jacksonwald syncline (Figure 21-1). Additional faults of this type are present to the east of the basin in the Piedmont, but complex structure and stratigraphy obscure their recognition (Root, 1988, 1989).

WRENCH FAULTING

Manspeizer (1981) interpreted the Furlong-Flemington and Hopewell faults of the Newark basin as right-lateral antithetic faults and the Chalfont fault as a left-lateral synthetic fault generated by major left-lateral wrenching of the basin (Figure 21-1). Ratcliffe

Figure 21-4. View across plains developed on northwest-dipping Triassic red beds. South Mountain, in the background, is an extension of the Blue Ridge Mountains and is formed by resistant Precambrian metavolcanics and quartzites. The Mesozoic border fault, located at the foot of the mountain, forms a straight trace. The view is to the northwest from near Dillsburg, in northern York County.



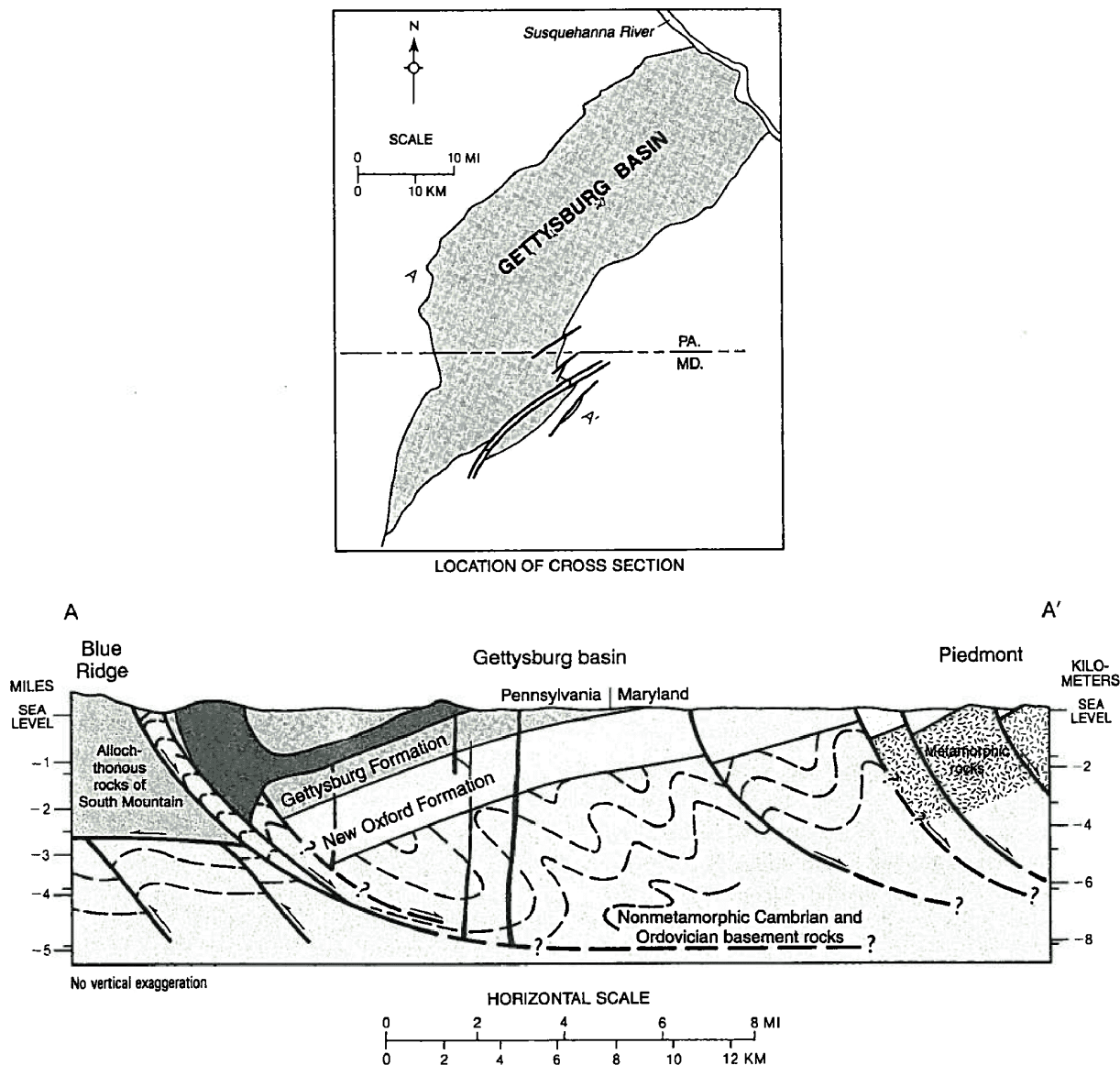


Figure 21-5. Geologic cross section through the Gettysburg basin showing the half-graben structure of the basin, uniform dip across the basin of the Mesozoic New Oxford and Gettysburg Formations, and listric normal faults at the border (reprinted with modifications from *Tectonophysics*, v. 166, Root, S. I., *Basement control of structure in the Gettysburg rift basin, Pennsylvania and Maryland*, p. 286, © 1989, with permission from Elsevier Science). Diabase sheets and dikes are shown in the darkest brown. Note the sliver of Paleozoic limestone caught up in the border faults adjacent to the Blue Ridge (South Mountain) and the minor listric faults toward the south end of the basin that form a series of smaller half grabens.

and Burton (1985) considered the former to be right-normal oblique faults. The amount of displacement on these faults is considerable; for example, the apparent vertical displacement required to uplift the Paleozoic basement block on the Furlong-Flemington fault is on the order of 20,000 feet.

The east-west-trending Shippensburg and Carbaugh-Marsh Creek faults (Figure 21-1) are major pre-Mesozoic faults (Root and Hoskins, 1977) that were reactivated during structural development of the Gettysburg basin; they have wrench-fault attributes. Right-lateral offset of the border fault and de-

flection of Triassic strata indicate 2 miles of offset on the Shippensburg fault. Paleozoic basement rocks are caught as a sliver along this fault within the basin at York Springs, Adams County (Figure 21-1). On the Carbaugh-Marsh Creek fault, wrenching offset of the border fault is much less. However, considerable wrench-fault displacement was transferred by folding of the Triassic strata and the development of two northwest-striking, left-lateral antithetic faults. One of these forms the border fault from Fairfield (Figure 21-1) into Maryland. Between the two faults, a block of Paleozoic basement is upfaulted in the basin at Fairfield.

FOLDING

Considerable folding occurs through the Narrow Neck and into the western Newark basin. Folds are best developed at the north margin of the basin and are truncated by the border fault (Figure 21-6). The most prominent fold is the Jacksonwald syncline (Figures 21-1 and 21-6), which extends southeasterly for at least 10 miles and has limb dips up to 55 degrees. A stereonet plot of poles to bedding from MacLachlan (1983) defines a syncline plunging $309^{\circ}/016^{\circ}$ (Figure 21-6). Other folds examined in the Newark basin by Lucas and others (1988) show comparable fold

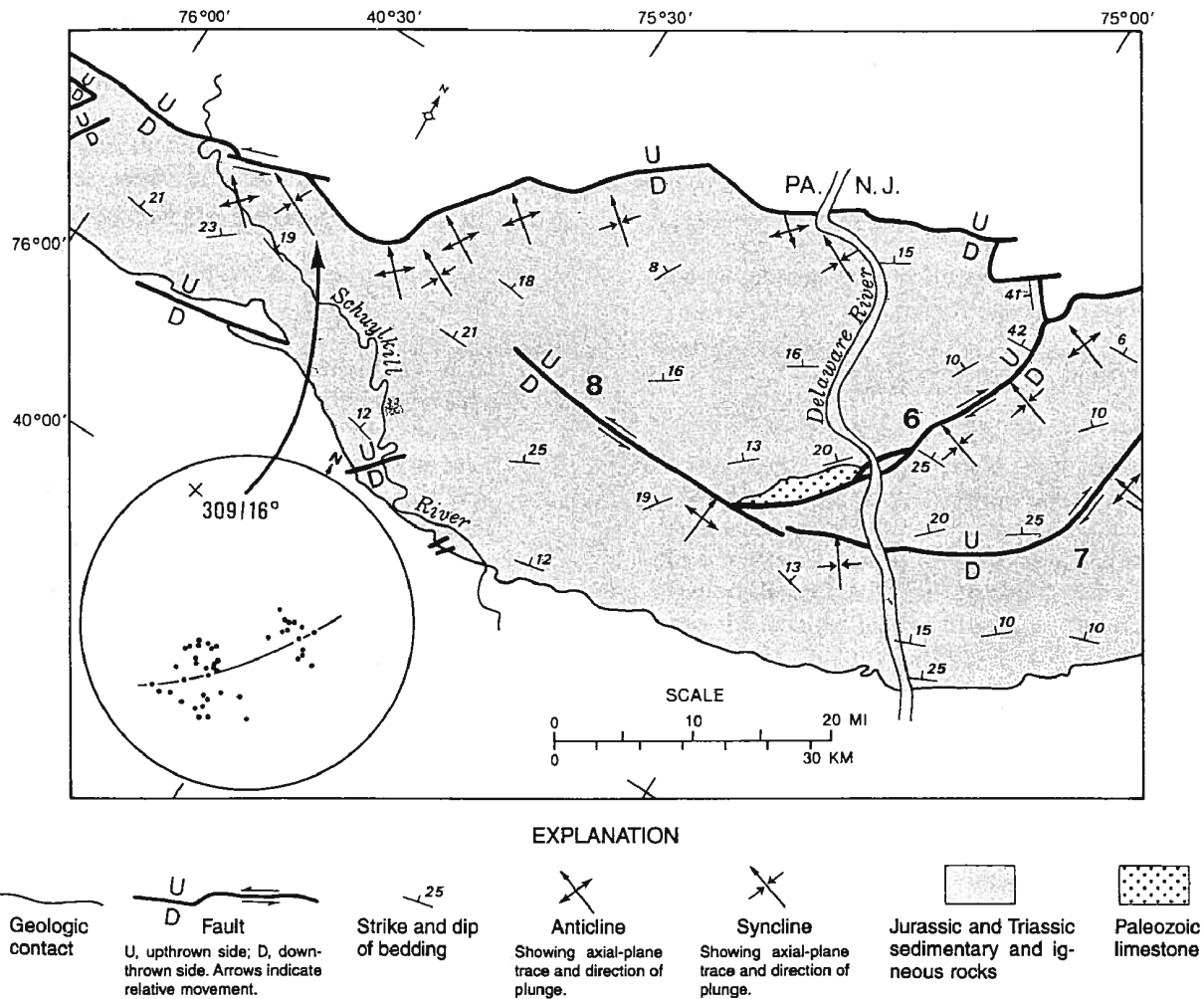


Figure 21-6. Structure map of the Newark basin showing major Mesozoic faults and the large number of associated folds (from Olsen, 1980b). Refer to Figure 21-1 for the names of the numbered faults. The inset stereonet plot shows poles to bedding in the Jacksonwald syncline (from MacLachlan, 1983). The poles define a chevron fold plunging $309^{\circ}/016^{\circ}$.

orientations and are characterized as upright folds having subangular hinges and straight planar limbs, typical of chevron folds. The fold trend in the Newark basin is oblique to the basin margin and all older structures but is consistent with the left-lateral motion proposed by Manspeizer (1981).

The few folds mapped in the Gettysburg basin are related to the Mesozoic reactivations of the older, east-west-trending Carbaugh-Marsh Creek and Shippensburg faults (Root, 1988, 1989). At the southern end of the basin, principally in Maryland, are several northerly trending, en echelon folds related to the development of the antithetic northwest-trending border fault at Fairfield (Figure 21-1). The largest fold extends for 8 miles through Maryland and just into Pennsylvania, southeast of Fairfield. The other folds are less than 2 miles in axial length (Root, 1988).

Wrenching along the eastward extension of the Shippensburg fault within the Gettysburg basin and south of the fault block of Paleozoic basement at York Springs (Figure 21-1) formed a fold pair. For a distance of 7 miles in an east-west zone, folding occurs as a regional deflection of the northeast-striking Triassic beds into nearly east-west-striking beds (Root, 1989). A stereonet plot of bedding attitudes here defines a fold plunging $335^{\circ}/032^{\circ}$.

IGNEOUS STRUCTURE

Numerous vertical diabase dikes, not shown on Figure 21-1, trend north to northwesterly across the basin. The dikes, which are up to tens of miles long, have been considered the result of regional extensional reactivation of an inherited basement weakness (Smith and others, 1975). A less likely explanation is that they are products of regional left-lateral wrenching (Swanson, 1982).

Extensive diabase sheets occur, generally in an elliptical pattern elongated along strike (Hotz, 1952). The sheets are folded concordantly with enclosing strata on their up-dip margins in the central parts of the basins, but they generally show discordant relations toward the north margin.

The diabase sheets and associated Lower Jurassic basalt flows (Cornet, 1977) are truncated by the border fault, demonstrating that emplacement clearly preceded faulting and most likely preceded folding as well. Paleomagnetic studies of the diabase sheets by Volk (1977) suggested that most of the emplacement occurred when the enclosing strata were still horizontal or only rotated less than 10 degrees.

INTERPRETATION AND DISCUSSION

The following structural inferences are derived principally from surface data:

1. During deposition of the Mesozoic strata, the Narrow Neck basin may have structurally separated the Gettysburg basin from the Newark basin by a slight amount.
2. Within each basin, syndepositional faulting was negligible. This derives from the lateral persistence of thin lacustrine units (Olsen, 1985b) and the lack of significant unconformities in each basin as shown by the general concordance of bedding attitudes.
3. The generally uniform northwest dip of strata across the basin militates against progressive downfaulting and significant rotation of the basin concurrent with deposition. However, if only minor rotation (less than 5 degrees) occurred, then syndepositional faulting at the northwest margin could have been active at times and not be apparent in the present dips (Root, 1988).
4. Major basin rotation and development of the border faults are related to regional, post-Early Jurassic (probably Toarcian) rifting. This was slightly preceded by folding and igneous activity.
5. Overall deformation in the Gettysburg basin is of an extensional character. Vertical Mesozoic diabase dikes in the basin are thought to indicate the principal plane of stress, which represents principal extension oriented at about $105^{\circ}/285^{\circ}$. This simple model seems to fit in the Maryland portion of the basin, at least, where this direction is normal to the trend of the border faults (Root, 1988).
6. The Newark and Narrow Neck basins are structurally more complex than the Gettysburg basin, and their calculated stress fields are more speculative. Ratcliffe and Burton (1985) proposed that simple extensional reactivation of a complex system of curvilinear thrust-ramp structures can explain the deformational structures and fault geometry of these basins. Their figures indicate a principal extension oriented at about $160^{\circ}/340^{\circ}$. Lucas and others (1988) recognized one model that involves normal rifting in the northeast-trending Mesozoic rift basins and produces left-

lateral transtension in the easterly trending Narrow Neck and Newark basins as a consequence of their orientation relative to the stress field. This particular model is appealing because it has the principal extension oriented at about $110^{\circ}/290^{\circ}$, similar to that suggested for the Gettysburg basin.

7. The striking congruence of the configuration of the Mesozoic basins and arcuation of the older Appalachians suggests a genetic relation between the two (see discussion by Swanson, 1986). Based on a study of the relation of cleavage in basement rocks to the Mesozoic border faults in the Gettysburg basin, Root (1989) concluded that the Mesozoic rifting was developed along the late Precambrian rift zone that formed the original margin of the Appalachians.

PROBLEMS AND FUTURE RESEARCH

Lack of subsurface data from deep oil- and gas-well drilling and detailed seismic work impedes substantive elucidation of the structural evolution and origin of these basins, particularly regarding the nature and distribution of local orogenic clastic wedges,

extent and sequence of syndepositional faulting within the basin, and nature and variation of the regional stress field. These problems form the provenance of future studies.

RECOMMENDED FOR FURTHER READING

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