POST-NEWARK FOLDS AND -FAULTS: IMPLICATIONS FOR THE GEOLOGIC HISTORY OF THE NEWARK BASIN

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INTRODUCTION

The explanation of post-Newark folds and -faults depends on how one interprets the attitudes of the strata. At one end of the ideological spectrum are those who insist that the Newark strata assumed their present attitudes as a result of the operations of the same geologic machinery that caused the Newark basins to form, to subside, and to accumulate sediments. At the other end of this spectrum are those few (including the two of us) who have applied the Stenoan principle that the strata were essentially horizontal when deposited and that the modern-day lack of horizontality requires a postdepositional tectonic explanation. The ultimate in horizontal reference planes is the top of an ancient lava flow; it serves as a kind of gigantic level bubble. Three complexes of ancient lava flows and interstratifed sedimentary strata are present both in the Newark basin of northern New Jersey (the tilted, eroded edges of which now form the three Watchung Mountains) and in the Hartford basin of central Connecticut and Massachusetts. Field relationships adequately demonstrate the parallelism of these three sheets of extrusive igneous rocks. The attitudes of these extrusive sheets and their associated sedimentary strata define at least two sets of **folds**. The vertical axial surfaces of some of these folds are parallel to the basin-marginal faults (=**longitudinal folds**) and those of others are normal to the basin-marginal faults (=**transverse folds**). These folds have been offset by several sets of faults (whose existence has been universally acknowledged since the pioneering 19th-century work on them by W. M. Davis [1888a, 1898] in central Connecticut). Lateral offsets of the vertical axial surfaces of some of the transverse folds demonstrate that, along some of the faults that are demonstrably younger than the transverse folds, substantial components of strike-slip offset exist (Sanders, 1962).

This paper reviews evidence that the Newark basin-filling strata have been subjected to signficant postdepositional deformation. We think that the attitudes of the Newark strata (as shown by their strikes and dips) are products of more than one set of tectonic conditions. We contend that significant tectonic changes intervened to end the episode of deposition, and to fold and fault the Newark basin-filling strata before the close of the Jurassic period as reworked Newark sediment is not recognized in overlapping upper Cretaceous coastal-plain strata.

What has complicated the straightforward interpretation of post-Newark structural features is the prevailing tectonic view that the Newark strata are products of simple crustal tension. This view holds that the tensional machinery starts and forms half-graben blocks. As further tensional forces operate, the upper surfaces of these blocks are tilted toward the active block-marginal faults. On these tilted blocks, strata accumulate. The basal layers dip toward the basin-marginal faults but the upper layers, never rotated, remain horizontal. At depth, the basin-marginal faults curve around to coincide with older thrust faults that were reactivated during the Newark basin-forming episode. When the tensional "music" stopped, there stood the

Newark strata in their existing configurations. The whole story ends as the Atlantic Ocean begins to spread.

We review the regional geologic relationships of the Newark basin to substantiate our interpretation that the Newark strata have undergone significant postdepositional tectonism. Finally, we show how an understanding of the combined effects of the longitudinal- and transverse folds explains why the Newark basin ends toward the NE.

REGIONAL GEOLOGY

The Triassic-Jurassic strata filling the Newark basin are preserved in an outcrop belt that is bounded on the NW by the Ramapo fault and on the SE by the Hudson River from Haverstraw, New York to Hoboken, New Jersey. The regional strike of the Newark basin-filling strata is NE-SW, parallel to the long axis of the outcrop belt, and the regional dip is 10° to 15° NW, essentially at right angles to the basin's long axis. This regional attitude of the strata defines what has been referred to as a homocline (Turner-Peterson and Smoot, 1985, p. 10) or, with reference to comparable strata in central Connecticut, as "monoclinal" (W. M. Davis, 1888b). We prefer to think of the regional NW dip of the strata filling the Newark basin as defining the NW limb of a major longitudinal arch whose axis trends NE-SW and lies somewhere SE of the present outcrop edge of the dipping Newark strata (Sanders, 1962c, 1963).

In the Newark basin, numerous exceptions to this regional attitude are known. These exceptions are not random deviations; instead, they define two groups of folds. The axes of one group of folds are parallel to the long axis of the basin (Sanders has named these *longitudinal folds*). The axes of the second group of folds are perpendicular to the long axis of the basin (Sanders has named these *transverse folds*). These folds are clearly defined not only by the attitudes of strata at individual exposures but also by the outcrop patterns of the various formations, most notably the Watchung extrusives (Orange Mountain, Preakness, and Hook Mountain basalts).

The longitudinal regional arch (or homocline) and the transverse folds, clearly involve not only the Triassic-Jurassic strata but the pre-Triassic basement rocks as well. We do not know whether or not the basement is involved in the longitudinal folds.

Although folds in the Newark basin-filling strata were first described by Darton (1889, 1890) and by Girard Wheeler (1939), most geologists have ignored these important geologic structures. For example, G. R. Robinson (1985, p. 117) asserted that the Triassic-Jurassic basins of eastern United States constitute "an attractive area to test, evaluate, and refine genetic models of these deposits in a setting that has undergone only minor post-rifting deformation."

THREE EXAMPLES FROM THE NORTHERN END OF THE NEWARK BASIN

We describe our studies of three localities at the northern end of the Newark Basin where the geologic relationships support our contention that the Newark basin has experienced significant post-depositional folding and -faulting and that the strata formerly extended beyond the present outcrop belt

(Merguerian and Sanders, 1993). These localities are: (1) near-basal rudites exposed along the CONRAIL tracks south of Stony Point State Park; (2) fine-textured fluvial-lacustrine strata exposed in Lowland Park, Town of Stony Point; and (3) the Proterozoic rocks in the Ramapo fault zone adjacent to the New York Thruway in Suffern.

CONRAIL tracks south of Stony Point State Park

Along the east side of the CONRAIL tracks south of the entrance to the Stony Point State Historic Park, in a low knoll are exposed red-colored rudites forming the near-basal part of the sedimentary fill of the Newark Basin. Here, in a deeply iron-stained exposure, angular clasts of gray-colored Wappinger Limestone, 3 to 6 cm in size, are set in a reddish sandstone matrix. Crudely developed beds strike roughly N60°W and dip 35°SW. Compared to the basin-marginal rudites exposed near Suffern, New York, which consist of rounded- to angular boulders of Proterozoic gneiss together with quartzite, Green Pond Conglomerate, limestone, reddish shale, and -arkose, the clasts in this exposure are surprisingly monomictic. A likely explanation for this difference is that during the early Mesozoic episode of uplift, erosion, and deposition in what is now preserved as the northern part of the Newark Basin, the adjacent elevated area had not yet been denuded below the stratigraphic level of the Cambro-Ordovician carbonate rocks that formerly covered the Proterozoic basement complex.

Lowland Park, Stony Point, NY

On the south bank of Cedar Pond Brook, Lowland Park, in Stony Point, New York, beneath the bridge for Route 9 (overhead), reddish-brown siltstones and interbedded gray limestones, lying an estimated 1250 feet above base of Newark succession and 3 miles SE of Ramapo fault, are well exposed. Lithologically, these strata are ancient fluvial mudstones and nonmarine limestones deposited in the offshore parts of a freshwater lake. On the presumption that these exposures are above the level of the Lockatong Formation, we assign them to the Passaic Formation of the Brunswick Group. If they are below the Lockatong, then they belong in the Stockton. The gray layers are fine-grained limestones deposited in a freshwater lake. The strata here strike N45°W and dip 15°SW. This attitude can be measured on several of the limestone beds. The fact that the strata here lack conglomerates indicates they were deposited well away from areas having high relief. The greenish nodules in the maroon mudstones are composed of calcite; they are caliche--the products of upward movement- and evaporation at the surface of water in the ancient soil in a semi-arid climate zone.

The fine texture of the strata at Lowland Park, and the total lack of conglomerates, indicate they were deposited well away from areas having high relief. We are close enough to the NE end of the Newark outcrop belt that if the "shoaling-basin" hypothesis were correct, these strata should show the effects of the higher area of basement against which the strata would be overlapping. Rather, we interpret the sediments as a distal facies and suggest that they once extended an unknown distance above the crystalline basement complex.

Ramapo fault zone near Thruway, Suffern (Pavilion Road and newly excavated exposure on I-87)

Along Pavilion Road, the rocks are in a weathered zone but display many steeply dipping fault surfaces. The slickensides vary from large-scale corrugations to minor streaks and, given proper lighting conditions, are very obvious. Based on 13 measurements, the average orientation of the fault surface is N68°E, 75°SE. The rake of the slickensides range from 44° to 62° toward the SW indicating that the slicks plunge 43° into S58°W on average. The asymmetry of steps on the slickensides indicate that during the latest motion, the hanging wall (the missing block) moved **up the fault surface** away from the SW. Hidden beneath the obvious slickensided fault surface are traces of subhorizontal slickensides that suggest an earlier episode of horizontally directed motion which antedated the more-obvious SW-raking slickensides. Thus, the movement history along the Ramapo fault has been complex. We would define the last (most-obvious) motion sense on the Ramapo fault as being oblique slip with composite left-lateral strike-slip and reverse dip-slip movement.

The fresh cuts on the shoulder of I-87, display the lithologic variation of the Proterozoic orthogneisses that include granitoid-, dioritic-, and gabbroic rocks cut by thin blackish seams of cataclasite produced by fault motions in the brittle zone of the crust.

GEOLOGIC STRUCTURES AND THE NORTHEAST END OF THE NEWARK BASIN

Over the years, polar-opposite interpretations have been proposed for why the Newark basin ends toward the NE in Rockland County, New York. According to the isolated-basin (or "shelving-basin") model, the basin ends because the NE-striking strata lap out against a paleogeomorphologic bedrock high underlain by a pre-Newark basement complex (Figure 1a). In this view, the curving Palisades ridge is interpreted as a dike that cuts across most of the strata to connect with the nearly horizontal Ladentown extrusives found stratigraphically high in the Newark succession.

According to the transverse-fold interpretation, the pre-Newark basement has been postdepositionally elevated along the Danbury anticline of Sanders (1960) that is transverse to and ends on the NW against the basin-marginal Ramapo fault (Figure 1b). In this model, the curving Palisades ridge is a folded sill-like intrusive, both it and the strata change their regional strike from NE-SW to NW-SE and the regional dips change from NW to SW.

Thus, in view of stratigraphic- and structural evidence and from the general parallelism of the three interbedded sheets of extrusive igneous rocks, any reconstruction of the filling strata of the Newark basin must begin **with the strata in horizontal positions**. We wholeheartedly endorse this Stenoan conclusion of initial horizontality of the strata (not to be confused with original sin) which enables us to infer that their present non-horizontal attitudes have resulted from postdepositional deformation. Further, we suggest that the changeover to postdepositional compressional tectonics in the Newark basin, in what had previously been an extensional regime, may have resulted from large-scale lithospheric-plate adjustments in response to rapid tectonic changes during the mid-Jurassic Nevadan orogeny in the western Cordilleran orogen (Schweickert, Merguerian, and Bogen, 1988).

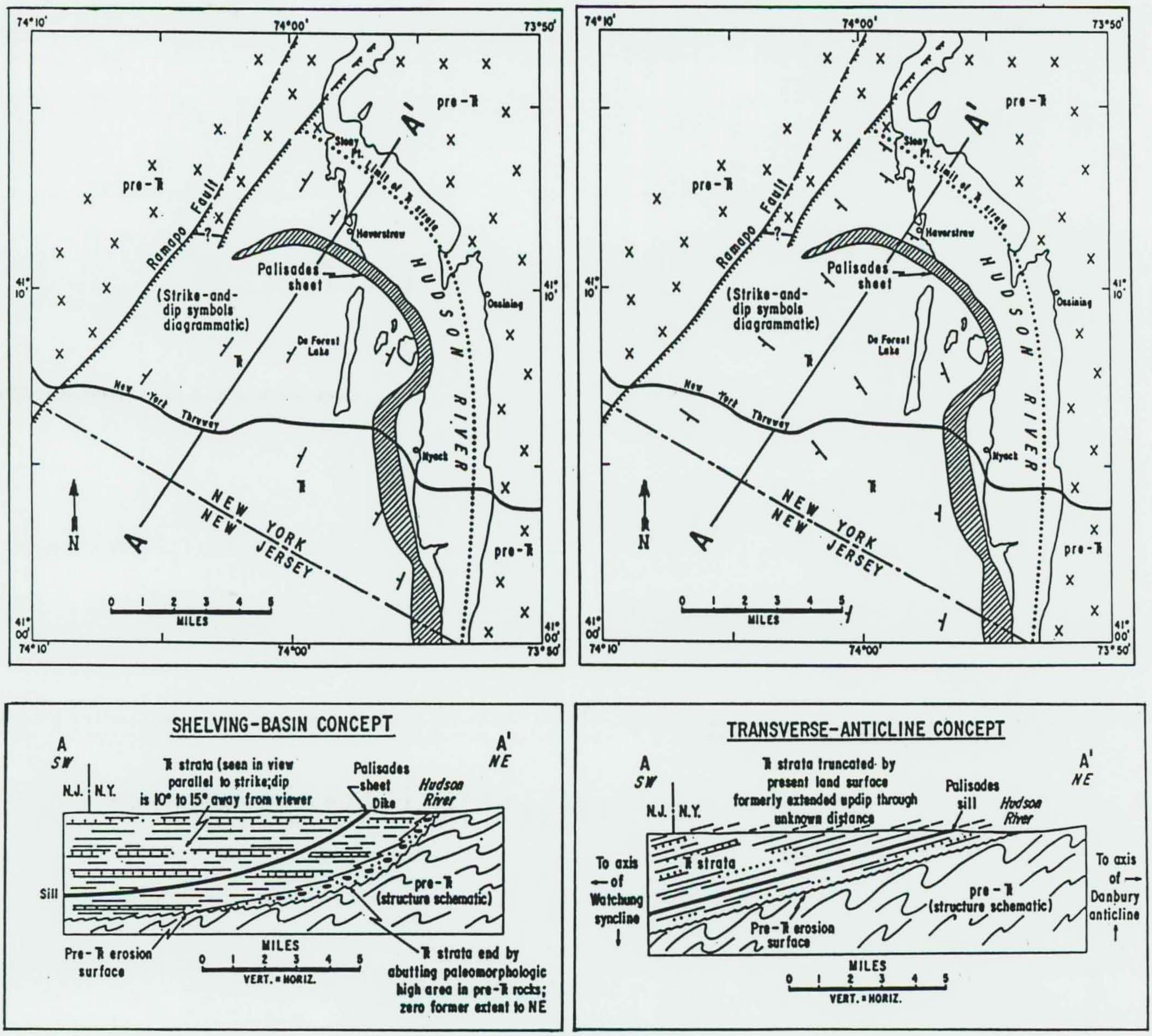

Figure 1. Schematic geologic maps of NE end of Newark basin in Rockland County, NY (above) and profile sections from Hudson River at Haverstraw to NY-NJ state line showing contrasting interpretations of the geologic relationships. (J. E. Sanders, 1974, figs. 7 and 8, p. 24-27; original artwork by staff of BP Alaska, New York office, courtesy John Conolly.)

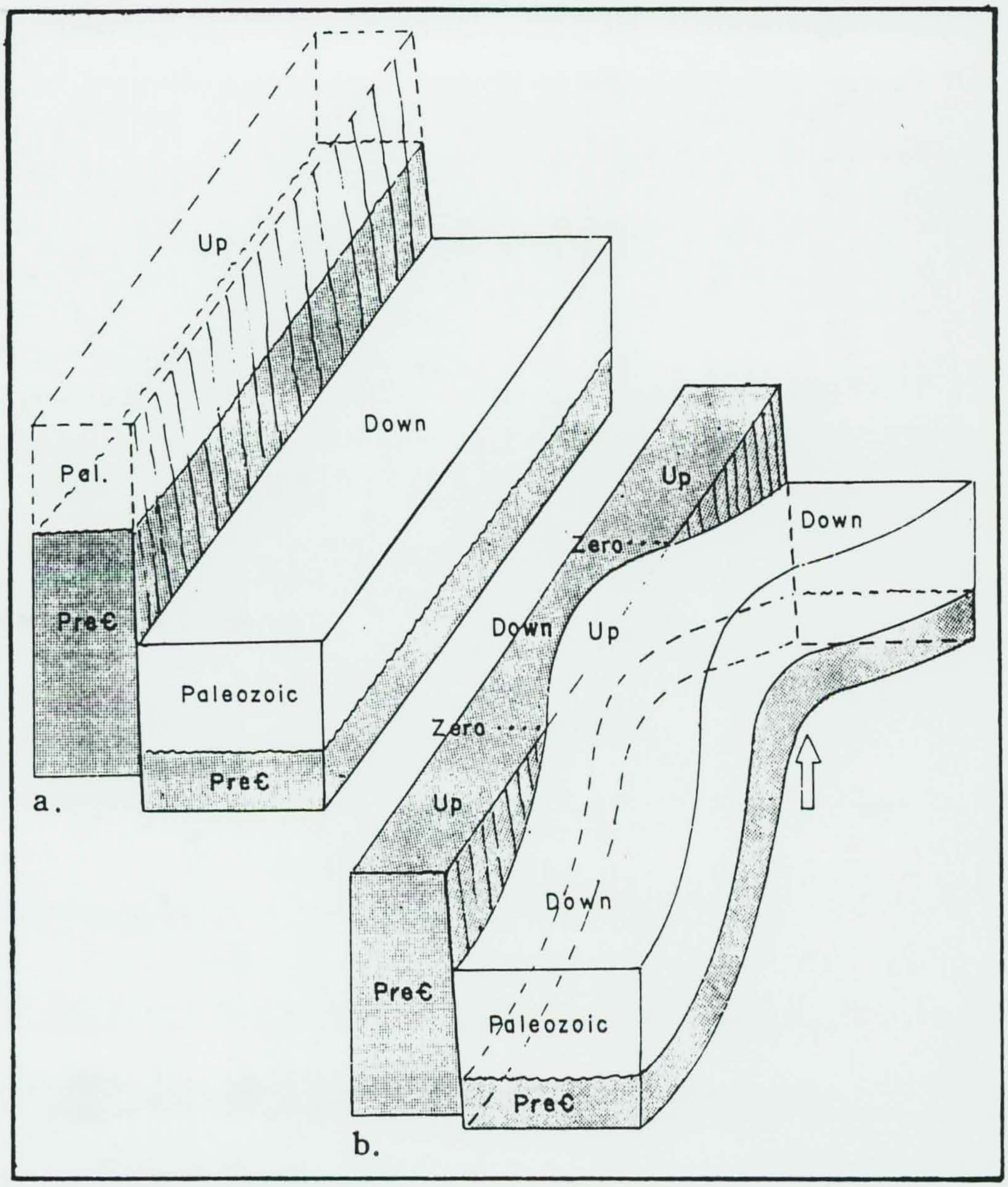

Figure 2. Schematic blocks showing the NW end of the Danbury anticline where it ends against the Ramapo fault. Paleozoic, not subdivided, shown in white; Proterozoic rocks, not subdivided, shown by light stipple. In a, the right-hand block has been lowered along the Ramapo fault during the period of sedimentation in the Newark basin (Newark basin-filling strata not shown). During the mid-Jurassic deformation, the Danbury anticline formed (b), causing a sector of the formerly dropped block to be raised by an amount greater than it was previously dropped (the exact amount is whatever was required to give a SW dip of about 12° to the Newark strata in Rockland County, NY). Notice that after the Danbury anticline has formed, the displacement on the Ramapo fault diminishes to zero toward the NE, then reverses (at the axis of the Danbury anticline). Still-farther to the NE, the sense of movement returns again to zero and then increases farther toward the NE. (Merguerian and Sanders, 1993, fig. 6, p. 90.)

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