UNUSUAL FEATURES OF THE NEW YORK SECTOR OF THE APPALACHIAN MOUNTAINS

JOHN RODGERS
Yale University
(1967 version, slightly amended)[1]

New York State's peculiar shape provides it with a complete cross-section of the Appalachian chain, from the Atlantic Coastal Plain in Long Island to the Central Lowlands of the continent around the Great Lakes. The cross-section can be complete partly because the Appalachians are particularly narrow here, even when one includes the Appalachian Plateau, whose northeastern extremity is the Catskill and Helderberg Mountains. The narrowness in turn results from a pronounced recess in Appalachian trends between two great salients, one in central Pennsylvania and one in southeastern Quebec and adjacent New England. The New York recess is not the only recess in the Appalachians, although it is one of the most pronounced; others are well displayed around Roanoke, Virginia, and Rome, Georgia, or are hidden under the Gulf of St. Lawrence or beneath the Gulf Coastal Plain in Alabama and Mississippi. All these recesses tend to be angular, in contrast to the smoothly arcuate curves of the intervening salients. Furthermore, the angles seem to be formed by intersecting trends of fold axes or other structural features.

Within the New York recess, the trends outline two separate angles, one from about N 65° E to about N 35° E at and southeast of the Delaware Water Gap, and the other from about N 40° E to about N 10° E at and southeast of Kingston, New York. These angles are well shown in the trends and boundaries of the narrowed Valley and Ridge province here, which extends northeast from the Great Valley of Pennsylvania and New Jersey to include, in New York State, the Wallkill and middle Hudson Valleys and the bounding Shawangunk and Schunemunk Mountains. The province continues to narrow northeastward and seems to disappear near Albany, though an Ordovician Valley and Ridge province is present in the Champlain Valley, mainly in Vermont.

Southeast of the Valley and Ridge province is the line of Precambrian "Highlands" anticlinoria that extends from the Reading Hills (Reading prong) of eastern Pennsylvania to the Green Mountains of Vermont; the New York representative is the Highlands of the Hudson. The trends of these anticlinoria also outline the New York recess and its two subordinate angles, a blunt angle near the Delaware River and a deep reentrant in western Connecticut between the general east-west trend of the Hudson Highlands coming in from New York and the general north-south trend of the Berkshire Highlands coming in from Massachusetts. This reentrant is only slightly larger than a right angle, sharper than any other observable angle in the Appalachians between the Gulf of St. Lawrence and the Gulf Coastal Plain. It is almost exactly centered between the west end of basement outcrops in the Reading Hills and their north end in the Green Mountains -- 275 kilometers (180 miles) from each. Moreover, the

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[1] The Editors of this Guidebook have kindly offered me the opportunity to bring up to date the short summary of Appalachian geology in New York State that I prepared for the guidebook the last time the New York State Geological Association met in New Paltz, in 1967. Rather than have me rewrite it completely, we decided to republish that summary and simply add some paragraphs about new insights reached in the last two decades. I have taken the liberty, however, of correcting a few misprints, incorrect statements, and infelicitous phrases in the original text.

anticlinoria seem to rise higher and higher toward the reentrant from both sides, so that one might expect the Precambrian belt to be highest and broadest there. In fact, however, the reentrant is marked by a 50-kilometer (30-mile) gap between the Hudson and Berkshire Highlands; the gap flares northwestward and is filled mainly with metamorphosed Lower Paleozoic rocks. Because the isograds are not deflected by the reentrant but strike about N 25° E across it, the Paleozoic rocks show a complete gradient from virtually unmetamorphosed along the Hudson River to sillimanite-grade in the throat of the gap. The progressive (Barrovian) metamorphism here was described by Barth and Balk in classic papers and has been studied more recently by Vidale and McClelland. Some Precambrian blocks are also exposed within the gap: Stissing Mountain far to the northwest, the fairly large Housatonic Highlands on the New York-Connecticut border, and others still farther east, where Paleozoic metamorphism has all but obliterated the metamorphic contrast between Precambrian basement and Paleozoic cover.

The Precambrian anticlinorial cores are certainly uplifted relative to the rocks in the Valley and Ridge province and, in accordance with the characteristic Appalachian asymmetry, the uplift was accompanied by relative northwestward transport. In the Green Mountains anticlinorium of Vermont and the South Mountain or Blue Ridge anticlinorium of south-central Pennsylvania, Maryland, and northern Virginia, the northwestward transport has seemed to be rather moderate, associated only with the formation of the asymmetrical anticlinoria and a few discontinuous thrust faults on their oversteepened limbs. Elsewhere, however, evidence is accumulating for recumbent folding involving large-scale horizontal transport. The case is clearest in eastern Pennsylvania, where the whole southeast side of the Great Valley from the Susquehanna to the Delaware has been shown to be the complex middle limb of one or more giant recumbent fold pairs or nappes, and in my opinion gravity data strongly support the interpretation that the Precambrian rocks of the Reading Hills and their eastward extension into New Jersey are the floating basement cores of the nappes. Similarly, Ratcliffe's work in western Massachusetts suggests that the Berkshire Highlands are also completely recumbent, overturned on the Paleozoic rocks to the west and sliced into a stack of thin, roughly horizontal thrust sheets.

To what extent the same overturning and recumbency has occurred in New York State is uncertain; the northwest side of the Hudson Highlands has generally been interpreted as a high-angle reverse fault, although floating blocks of Precambrian basement are known northwest of it. One might suggest instead that some of the high-angle faulting is (Triassic ?) normal faulting, dropping the Precambrian rocks in the core of the recumbent anticline down beside the Paleozoic strata of the underlying middle limb. One might further suggest that the horizontal displacement involved in the recumbent fold is measured by the depth of the western Connecticut reentrant in the line of anticlinoria -- nearly 40 kilometers (25 miles). Indeed, the recess is possibly the locus of maximum overturning and horizontal transport in the entire region from western Massachusetts to eastern Pennsylvania.

Another unusual feature of the New York sector of the Appalachians is the Taconic slate mass, the main body of which lies entirely on the north side of the New York recess. This mass has been the subject of controversy for well over a hundred years because, although its apparent stratigraphic and structural position above surrounding Middle Ordovician carbonate strata demands a Middle or Late Ordovician age, it contains fossils ranging back to Early Cambrian. This mass no longer seems as unusual as it used to, however, for

similar masses now recognized from Newfoundland to the Susquehanna River have raised the same problems and have evoked the same answers; i.e., either rapid facies changes in restricted basins surrounded by carbonate shelves or allochthonous thrust sheets or slide masses from another facies realm to the east (either stratigraphic complexity and structural simplicity or vice versa). Comparison with allochthonous slide masses elsewhere, notably in the Alpine chains of Morocco, Italy, and other Mediterranean countries, has convinced many of us of the truth of the latter answer, but I doubt if the debate is over.

The northern and central Appalachian arcs on either side of the New York recess seem to have had rather different orogenic histories. In the central (and southern) Appalachians, the obvious deformation, as in the Appalachian Plateau and Valley and Ridge provinces, is late Paleozoic, post-Pennsylvanian and perhaps post-Early Permian. Recently, however, stratigraphic, tectonic, and radiometric evidence for older orogeny there has slowly been accumulating, suggesting major deformation also in the early Paleozoic, probably in the Ordovician for the most part. The extent of this orogeny southwest of New York State and southeastern Pennsylvania is still quite uncertain, except that it affected mostly the Piedmont region on the southeast side of the chain. In the central and southern Appalachians, therefore, orogeny seems to have migrated northwestward toward the interior of the continent, at least during the Paleozoic. In the northern Appalachians, on the other hand, evidence of multiple deformation is abundant and has long been known. The late Paleozoic deformation, though present, is confined to the southeast side; the early Paleozoic deformation is most obvious along the northwest side; and the most widespread and most intense period of orogeny was middle Paleozoic, largely Devonian. Thus orogency here generally migrated away from the continent. The relative unimportance of the late Paleozoic deformation in the northeren Appalachians is a reason, I believe, for refusing it the title Appalachian Orogeny or Revolution. I prefer to call it by Woodward's term "Alleghany orogeny", so that it can take its proper place beside the Acadian and Taconic among the Appalachian orogenies, of which the roster is probably not yet complete.

Situated between these two different arcs, the New York recess should contain evidence of multiple orogeny, and it does. A Precambrian ("Grenville") orogeny is represented by the contrast between the igneous and metamorphic basement of the Highlands and the overlying sedimentary Paleozoic rocks. The Taconic orogeny is represented by the angular unconformity between the Middle Ordovician and the Silurian along Shawangunk and Schunemunk Mountains on either side of the Wallkill Valley; on the Shawangunk side the Silurian rocks have not overstepped the Middle Ordovician, but on the Schunemunk side they overlap onto the Precambrian. In the absence of Carboniferous rocks anywhere between the Lackawanna syncline in northeastern Pennsylvania and the Narragansett basin in central Rhode Island (except for some granite intrusions in southwestern Rhode Island and southern Connecticut), the Acadian and Alleghany orogenies cannot be clearly distinguished in the New York recess, but both are certainly present in Rhode Island and probably, to judge by radiometry, in Connecticut and the Manhattan prong.

The intersecting trends in the New York recess may provide further clues for unscrambling the effects of the different orogenies. Presumably the trends coming up the northwest side of the Valley and Ridge province out of Pennsylvania must be Alleghany, at least those of the folds in the anthracite basin and their continuations. Evidence in Pennsylvania suggests, however, that the great recumbent folds on the southeast side of the Great Valley are pre-Silurian - i.e., Taconic - and the rapid overlaps of the Silurian strata around Schunemunk Mountain and its southwestward continuation in New Jersey can be interpreted in the same terms. (Indeed, Ratcliffe in western Massachusetts reports evidence for recumbent folding of Lower Ordovician rocks before the deposition of Middle Ordovician.) On the other hand, the broader trends of the northern Appalachians are Acadian, certainly for some distance west of the Connecticut River and quite possibly all the way to the Hudson. Very probably the folding in the Silurian and Devonian west of the Hudson, north of the angle at Kingston, is also of this age, but whether the corresponding folds between Kingston and the Delaware Water Gap are Acadian or Alleghany is debatable. Their trend is also that of the high-angle faults in the New York and New Jersey Highlands; those faults may well be Triassic in part, but as W. M. Davis showed long ago in Connecticut, Triassic faults tend to follow pre-existing strikes. It is even possible that these trends were first marked out in the Taconic orogeny, the western limit of which must trend from Albany to eastern Pennsylvania, well to the west of the eastern edge of the overlapping Silurian and possibly just east of the abrupt eastern termination of the folds in the anthracite basin and along the aberrant trend of the Lackawanna syncline.

To summarize, the New York sector of the Appalachians is unusual because it includes much of a major recess in the chain, notable (like other Appalachian recesses) for the angular intersection of structural trends and also for extreme horizontal transport along the northwest margin of the chain's metamorphic core. One of the first geologists to emphasize the angularity was Arthur Holmes, who used it as an argument for continental drift, for he saw the westward convergence of Caledonian and Hercynian trends in the British Isles finally completed by their crossing in the New York recess where, as noted above, the polarity of orogenic migration during the Paleozoic reverses.

(New Material Added in 1985)

There is another way of thinking about the recesses and salients of the Appalachians (or any other mountain chain), by looking at them not from the continental but from the oceanic side. Seen from that side, they would appear molded around promontories and embayments along the margin of the Paleozoic North American continent, which in turn reflect the (post-Grenville) pattern of rifting and subsequent sea-floor spreading that created that margin during latest Precambrian time. A number of features then find natural explanations. The stratigraphic section is generally thinner across promontories than in embayments, because the former tend to rise by isostasy (cf. the high southwestern angle of the Arabian Peninsula in Yemen), whereas the latter tend to sink. Such thinning is clear in the lower Paleozoic shelf sediments on the New York promontory = recess, especially in the Lower Cambrian, both the carbonate strata and the underlying clastics; the latter are almost pure quartzite, in contrast to the "dirtier" sediments in the lower parts of the thicker sequences on either side. When orogeny smashed the Paleozoic sedimentary rocks against the more rigid continent, the thicker strata in the

embayments = salients found it easy to deform by classical thin-skinned decollement tectonics, but the thinner strata on the promontories were less fortunate; the projecting parts of the continental basment were stressed more strongly and probably heated up more, so that they played a larger role in the deformation. The contrast between smoothly curved fold trends in the embayments and more angular, commonly intersecting trends near the promontories suggests an analogy with the way ocean waves advancing toward an irregular coastline sweep into bays with smoothly curving crests but beat on headlands in characteristic interference patterns.

The allochthony of the Taconic slate mass and the other masses mentioned above now seems firmly established. Many of us now believe, moreover, that the same rocks can be followed eastward into the high-grade metamorphic rocks of the Manhattan prong and its northeastern continuation in Connecticut, where they form the bulk of the Manhattan schist and its correlatives. Only the lowest part of the old Manhattan would remain autochthonous; now distinguished as the Walloomsac formation, known from a few fossils to be Middle Ordovician, it is unconformable on the underlying (Cambrian to Lower Ordovician) Inwood marble and bevels down across the various members of the Inwood to rest in places on the basal Cambrian clastics or the Precambrian basement. That this unconformity is particularly clear in the New York recess emphasizes once again the tendency of continental promontories to resist subsidence.

The supposed continentward migration of orogenies south of New York is less clear now than it used to seem. Although the Alleghany orogeny certainly deformed the entire Valley and Ridge province from Pennsylvania southwest and played a major role in <u>transporting</u> into their present position the rocks of the present Blue Ridge and Inner Piedmont (and probably also those of the Highlands from New York southwest into the Reading prong), the deformation and metamorphism of the main bulk of those rocks is earlier, largely Ordovician or perhaps in part Devonian. Only at the southeastern margin of the Piedmont does Alleghany deformation and metamorphism reappear, from Georgia to Virginia and again in southeastern Connecticut and southern Rhode Island, and perhaps in some places between (around Philadelphia, for example?). In the northern Appalachians the general retreat from the continent, orogeny by orogeny, is still accepted, though within each orogeny the reverse trend is established or probable. It is still true however, that southwest of New York the outermost folds were formed in the Alleghany orogeny, northeast of Albany in the Taconic. Reflecting on this difference, Shatsky in 1945 suggested that the presence of a great foreland basin -- the Appalachan Plateau or the Alleghany synclinorium -- in the southern and central Appalachians and the absence of anything comparable in the northern Appalachians is related to the change in polarity.

Concerning the fold trends that converge in Europe but cross in the New York recess, I now know that Arthur Holmes got the idea from E. B. Bailey, who got it from Marcel Bertrand, who stated it quite clearly in 1887! The more things change the more they remain the same.