

DRAINAGE HISTORY OF THE NEW YORK CITY REGION

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INTRODUCTION

The drainage history, the record of surface-water runoff, of the New York City region extends back approximately 200 ma. The oldest paleodrainage events can be deciphered from analysis of the sediment fillings of the Newark-Hartford basin(s). During that basin-filling episode, streams drained from the highland- margin blocks that were persistently elevated and into the relatively subsiding lowland block(s). During the mid-Jurassic tectonic activities that terminated the episode of basin filling, the long-established drainage network was destroyed. The next-available drainage records date from the Cretaceous erosion interval that culminated in the Fall Zone peneplane. One definite example, the lower Hudson from Jersey City, NJ to Staten Island, NY; and a second probable example, the West Haven, CT buried valley, are remnants of a pre-Late Cretaceous stream system which was destroyed by the submergence that initiated the Atlantic-cycle episode of passive-margin subsidence. Marine conditions prevailed until the middle of the Miocene Epoch, when as a result of domal uplift of the Appalachians and possible arid climate, fans of coarse sediment spread southeastward across the Atlantic coastal-plain province and prograded the shoreline seaward. During the Pliocene, large-scale emergence and regional elevation of New England inaugurated an episode of subaerial erosion that still prevails. This episode has been punctuated by at least four episodes of continental glaciation during which the ice sheet buried- and destroyed drainage networks. During the meltdown stages, proglacial lakes formed. New drainage systems, parts of which made use of pre-existing valleys, were established.

This paper summarizes the methods for reconstructing drainage history. Many features of the local drainage system that have been considered anomalous in the past by geologists adhering to the one-glacier-did-it-all viewpoint can be explained with reference to the Sanders-Merguerian resurrection- and revision of Fuller's (1914) generally discarded interpretation that the Pleistocene history of the New York City region involved four major glacial episodes (Merguerian and Sanders, 1990; 1991; 1992; 1993a, b; 1994; Sanders and Merguerian, 1991a, b; 1994a, b; 1995).

GENERAL PRINCIPLES

The "tools of the drainage-history trade," so to speak, include: (1) analyzing sedimentary deposits for: (a) features made by currents within sediments that enable one to infer which way the currents flowed when these sediments were being deposited; (b) provenance data that can be related to regional geologic history; and (c) deposits of former large lakes; (2) "prospecting" the geologic record for times when the lands stood high and were being eroded; (3) analyzing the geologic significance of anomalous relationships in the modern-day drainage pattern; and (4) finding buried valleys and then using geologic evidence to infer their ages.

Erosion Intervals in the Geologic Record

The point of "prospecting" the geologic record for times when the lands stood high and were being eroded is to seek times when drainage networks were being established and maintained. It goes without saying that no subaerial streams will be flowing when a region has been submerged by the sea.

Drainage Anomalies

Anomalous drainage is a term applied to any drainage network in which the predominant flow is not down the regional slope. Obviously, water does not flow uphill, but it can flow along the contours of the slope rather than straight down the slope. Another category of drainage anomalies includes tiny rivers flowing in large valleys. These are known as **underfit streams**. Most rivers flow away from high-standing areas of resistant rocks. By contrast, a few anomalous rivers flow across such high areas, yielding features collectively designated as **cross-axial drainage**. A **water gap** is the name given to a river valley that cuts across a resistant layer. A final category of drainage anomaly is what is known

as a **barbed tributary**, defined as a tributary that enters the master stream in such a way as to make an acute angle with a segment of the main stream that is downstream from the point of junction.

Underfit streams

An underfit stream is one that is puny compared to the size of the valley in which it flows, typically on top of a large body of valley-filling sediment. Underfit streams are typical in regions where large amounts of water flowed to erode the large valley and where, subsequently, stream discharge greatly decreased.

Cross-axial drainage

Cross-axial drainage refers to a situation in which streams do not flow away from an elongate high region (the "axis") but rather cut through it. Cross-axial drainage can result from several combinations of geologic circumstances. For example, after a stream has become well established in a valley, an anticline or fault may grow along a line trending across the stream. If upward growth is slow and stream power sufficient, the stream may maintain its course and eventually, can cut a water gap through the upgrowing feature. Such a stream is known as an antecedent stream. It is older than the axis it has cut across. Another possibility is superposition, which results from a multi-stage geologic history. First, the high area underlain by the belt of resistant rock forms as a result of differential erosion. Then the elongate high area(s) is(are) buried. A stream becomes established on the covering strata and commences downcutting. After the stream has cut through the cover, it "discovers" the buried transverse axis. But, because its course has been locked in, so to speak, on the covering strata, it is able to cut a water gap through the resistant transverse axis and may do so in more than one place.

Barbed tributaries

The usual arrangement is that the tributary joins the main stream and makes an acute angle with a part of the main stream that is upstream of the point of junction. This follows from the fact that the slope of the master valley is downstream. Therefore, any tributary from the side tends to flow down the master valley before it joins the master stream. In so doing, it makes an acute angle with the part of the master stream that is upstream from the junction.

Buried Valleys

Buried valleys are "fossil" evidence for ancient drainage. The significance of a buried valley in drainage history depends on how closely one is able to determine its age. The age of a buried valley can be bracketed by finding the youngest strata the valley cuts and the oldest sediments in the valley fill. Complications exist because an old valley may have been filled and later uncovered in part or in whole and re-occupied by a river that was not responsible for the original erosion of the valley.

DRAINAGE HISTORY OF THE NEW YORK CITY REGION

As the following review of the drainage history of the New York City region shows, local examples exist of most of the features mentioned above. The chronology begins with the filling of the Newark-Hartford basin and includes products of several erosion intervals, at least four glaciations, and of the modern situation of gradual submergence.

Newark-Hartford Basin-Filling Episode

In the drainage history of the New York City region, the oldest clear-cut records date from the Late Triassic, when the Newark basin was being filled. Reference to the physiographic diagram of Figure 1 shows the morphologic expression in today's landscape of what is left after elevation and erosion of the Newark basin-filling strata. The longer of the two profile-sections (the one that extends diagonally across the middle of the page) displays the existing arrangement of the basin-filling strata (eroded base in contact with the metamorphic complex of the Manhattan prong, northwest dip along the line of this profile-section, and abrupt ending on the northwest against the Ramapo fault).

During Late Triassic and Early Jurassic time, the Ramapo fault separated an actively elevated block on the NW from an actively subsiding block on the SE. Sediment from the elevated block, consisting almost entirely of debris from Paleozoic formations, was transported to the SE into the subsiding basin where it accumulated to form the Newark Supergroup. Near the Ramapo fault, these sediments are coarse; but, with distance from this fault, they become finer. Cross strata also indicate that ancient streams flowed from NW to SE.

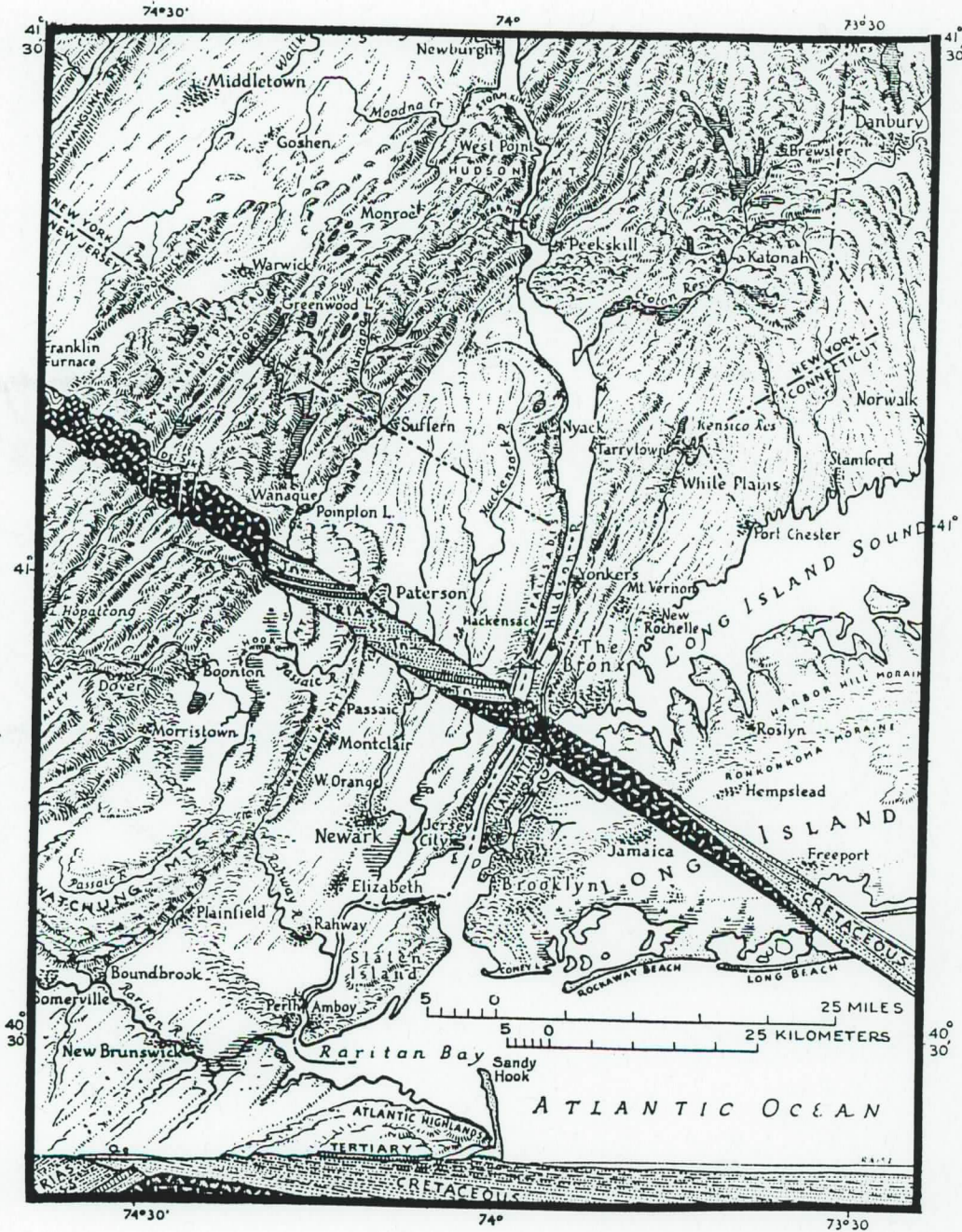


Figure 1. Physiographic map of New York City and vicinity with two cut-away vertical slices to show geologic structure and the morphologic expression in today's landscape of what is left after elevation and erosion of the Newark basin-filling strata. (E. Raisz.)

By contrast, both provenance data and the cross strata prove that some of the sediments composing the basal strata of the Newark Supergroup, namely the gray arkoses within the Stockton Formation, were derived from the southeast and were deposited by rivers that flowed westward, a direction that is down the present-day dip of the strata (Savage, 1967 ms., 1968; Glaeser, 1966; Klein, 1969). This general pattern of sediment supply and transport directions has been further supported by geochemical provenance studies based on determining radiometric ages of the feldspars (Abdel-Monem and Kulp, 1968).

Mid-Jurassic Breakup of Newark-Hartford Basins

One of the major mysteries associated with the Newark-Hartford basin-filling strata is what happened (and when) to disrupt the drainage and to end the episode of sediment accumulation in the basin(s). As mentioned, the drainage pattern that began with the initial elevation of the marginal blocks and initial subsidence of the basin block fed sediments into the basin. This drainage pattern persisted for perhaps 30 ma. Then, something happened to disrupt it. I have argued (Sanders, 1963) that the elevation of the central part of the formerly subsided basin block, as indicated by the modern-day dip of the strata, was the event which changed the drainage pattern and caused the basin-filling strata to be eroded. (Others have argued that the dip of the strata was a function of deposition in rift basins, blocks bounded by curving faults whose surface became progressively tilted toward the fault as displacement took place.)

I still prefer the view that elevation in the middle of the formerly subsiding area destroyed the Newark-Hartford basin and changed it from being an importer of sediment into a condition of being an exporter of sediment (Figure 2).

Pre-Late Cretaceous Erosion Interval: Fall Zone Peneplain and Buried Valleys

As the Newark strata were elevated and eroded, strike valleys are inferred to have formed along their bases. One example of such a strike valley is the Hudson Valley between Stony Point, New York, and the Lincoln Tunnel (Figure 3). Here, the Hudson makes about a 15° bend to its left (facing downriver). In so doing, it flows out of the strike valley at the base of the Newark Supergroup. However, the strike valley continues to the SSW. It goes under Jersey City, western Staten Island, and into New Jersey. (See Figure 2 and Figure 1, profile-section along the bottom margin of the map, just above the "30" of the label for 74° 30'.) The fact that this basal-Newark strike valley passes beneath the coastal-plain strata proves that the initial age of this valley is pre-Late Cretaceous. How long the Hudson has flowed in it is not securely known. Presumably, this whole strike valley is the same age throughout. It has been reoccupied by the Hudson from Haverstraw to Hoboken.

Another such strike valley is the West River Valley, CT that lies between the ridge underlain by West Rock (comparable to the Palisades in New York) and the metamorphic rocks of the Western Highlands of Connecticut (comparable to the metamorphic rocks of the Manhattan Prong in New York).

Another valley, not a strike valley and now completely full of sediment and thus hidden from view and that may pass beneath the cover of the coastal-plain strata, extends on a WSW trend out of New Haven harbor and into Long Island Sound (Haeni and Sanders, 1974; Sanders, 1965, 1994).

Late-Miocene Domal Elevation of the Appalachians

Submergence of the Fall Zone peneplane in Late Cretaceous time inaugurated an episode of predominantly marine deposition that prevailed until the Miocene Epoch. Late in the Miocene Epoch, the Appalachians were elevated as an elongate dome. The domal uplift generated coarse sediments. Many of these sediments spread away from the away from the updomed Appalachians and spread eastward as a sheet of fan sediments. They pushed the shoreline seaward.

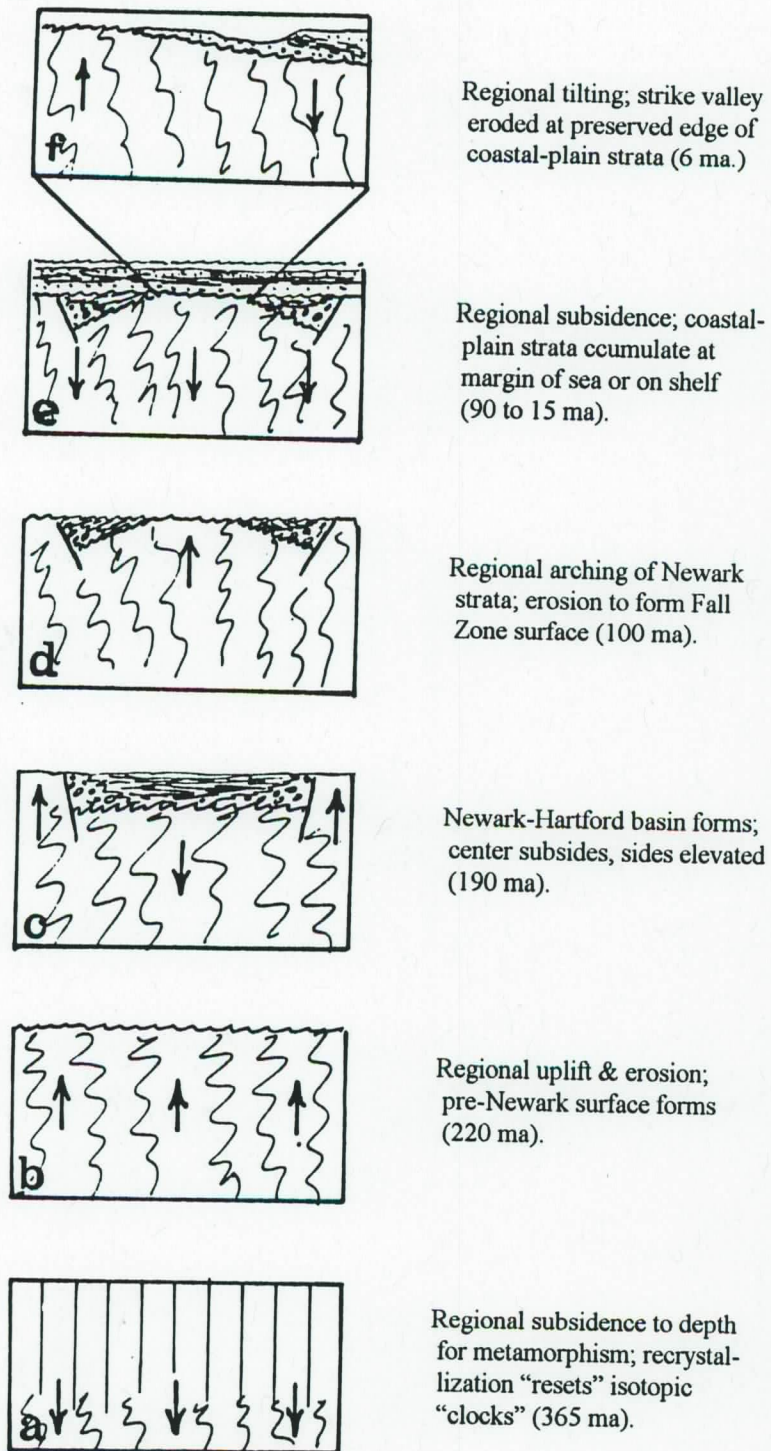


Figure 2. Stages in mid-Devonian- and later development of the New York City region shown by schematic sections. The decipherable drainage history begins with panel c. (J. E. Sanders.)

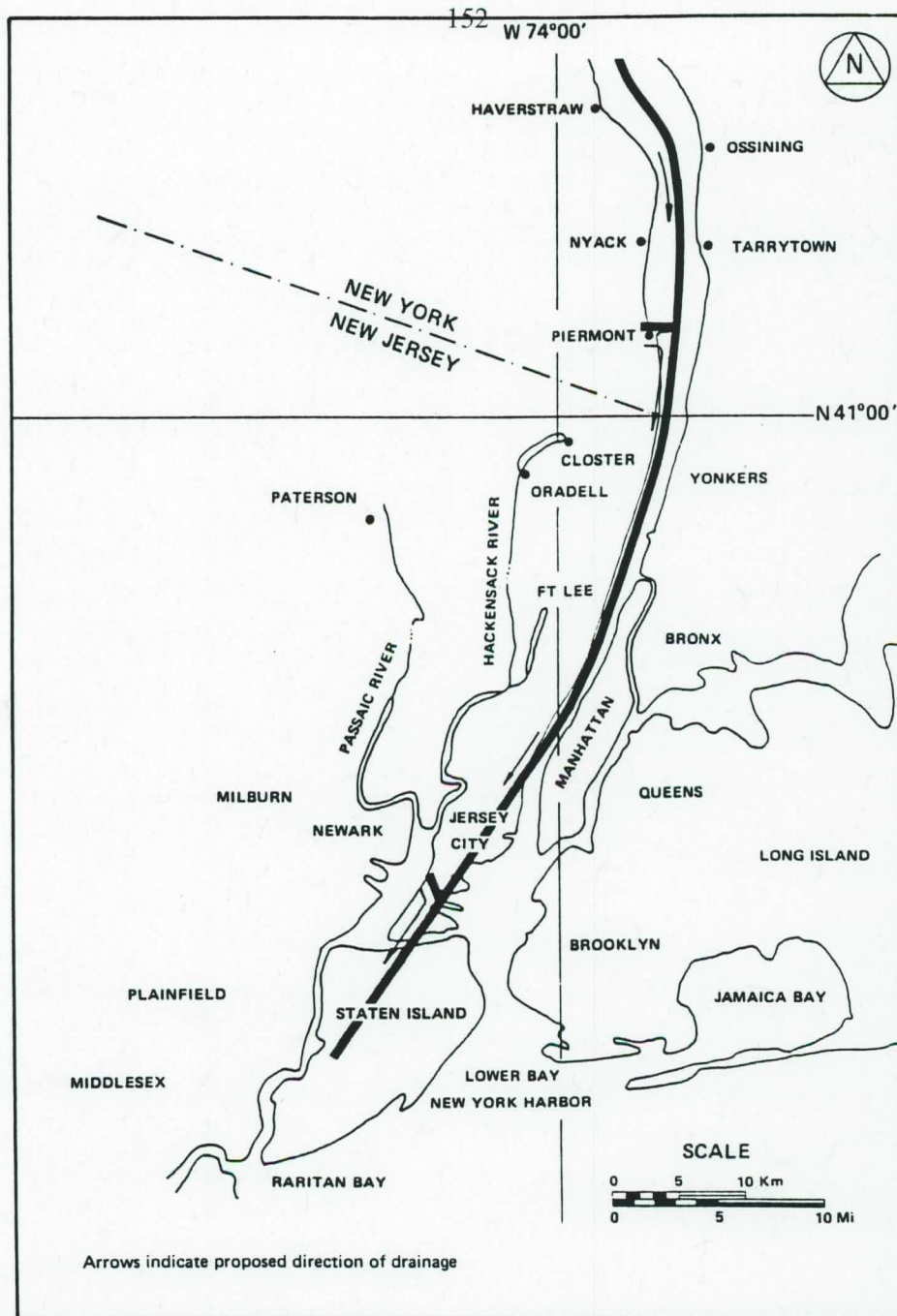


Figure 3. Strike valley at base of Newark strata (thick black line) as it is inferred to have been in pre-Late Cretaceous time prior to the Late Cretaceous submergence. The modern Hudson River follows this strike valley from Haverstraw to the Lincoln Tunnel (opposite "M" of Manhattan). (Jon Lovegreen, 1974 ms. fig. 19, p. 148.)

Pliocene Emergence and Uplift of New England

During the Pliocene Epoch, the New York region experienced a pronounced emergence. Probably this emergence marked the first of the numerous swings of sea level that characterized the Ice Ages. In any event, elevation of New England and general erosion prevailed until the first Pleistocene glacier arrived (from about 6 million years ago to about 1.5 million years ago).

As a result of the tilting- and eroding of the coastal-plain strata and intensified stream activity associated with the drop of sea level, a major strike valley was eroded at the base of these strata. This strike valley, known as the inner lowland, is comparable to those that formed at the base of the Newark strata. An adjoining strip of high ground constitutes the coastal-plain cuesta (Figure 4). Locally, ocean water has submerged part of this basal-Cretaceous strike valley to form Long Island Sound. From Trenton, NJ to Wilmington, DE, the Delaware River flows in this strike-valley lowland.

Johnson (1931) thought that some of the drainage anomalies associated with the Palisades- and Watchung ridges derived from the initial appearance of the inner lowland and coastal-plain cuesta. He postulated that the Hudson was not able to cut through the coastal-plain cuesta, but instead was forced to flow SW in the inner lowland. Once locked into a SW course, further downcutting through the unconformably overlying cover of coastal-plain strata would cause it to encounter the Newark rocks. As a result, the Hudson cut Sparkill Gap across the Palisades ridge, crossed Watchung Ranges several times via the Paterson gaps and back again through the Millburn Gaps, and joined the Raritan River near Somerville, NJ. Any such superposition would have to have taken place during the Pliocene episode of great regional uplift not during the Cretaceous, as Johnson supposed.

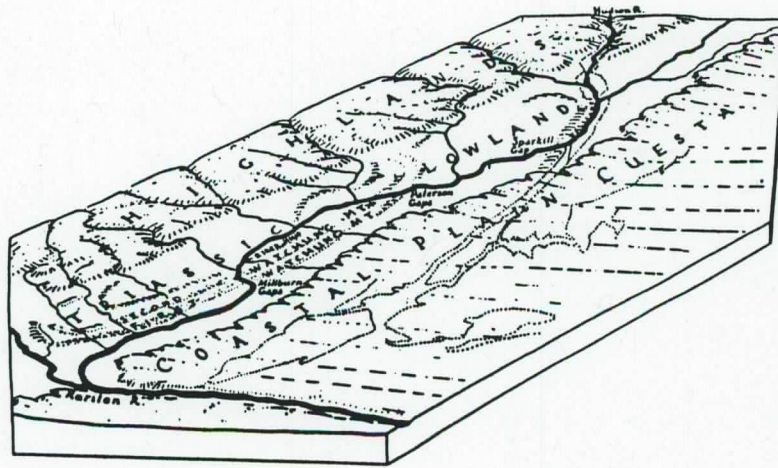


Figure 4. Block diagram showing Douglas Johnson's concept about the blockage of the ancestral Hudson River by the inner coastal-plain cuesta and its superposition across the Watchungs. Further discussion in text. (Drawn by E. Raisz for D. W. Johnson, 1931.)

Based on his compilation of engineering boring logs, Lovegreen inferred that during the late Pliocene, several large rivers flowed southward beneath western Long Island (Figure 5).

Drainage Implications of Concept of Multiple Pleistocene Glaciations

The Pleistocene Epoch included several times of erosion and the start of new drainage networks. Each arriving glacier covered and possibly obliterated previous river systems. As each glacier melted, a possibility existed for establishing new drainage networks. Although these Pleistocene times of erosion were short (possibly not longer than a hundred thousand years), they included powerful agents of erosion: glacial ice and torrents of meltwater.

Figure 6 is a map of the major modern rivers in the New York City region. In the region between Franklin, NJ and Kingston, NY, the map displays a first-order postglacial drainage anomaly. The headwaters of the Wallkill River are in Mohawk Lake southwest of Franklin, NJ. The waters flow northeastward and are augmented by waters from other NE-flowing tributaries. East of Rosendale, New York, the Wallkill is joined by another drainage network having headwaters in the Catskill, but flowing northeastward in the Siluro-Devonian strike valley. The combined Wallkill-Rondout flow drains into the Hudson River at Kingston as a barbed tributary. (See Figure 6.) No flow northward was possible until after the ice had melted away.

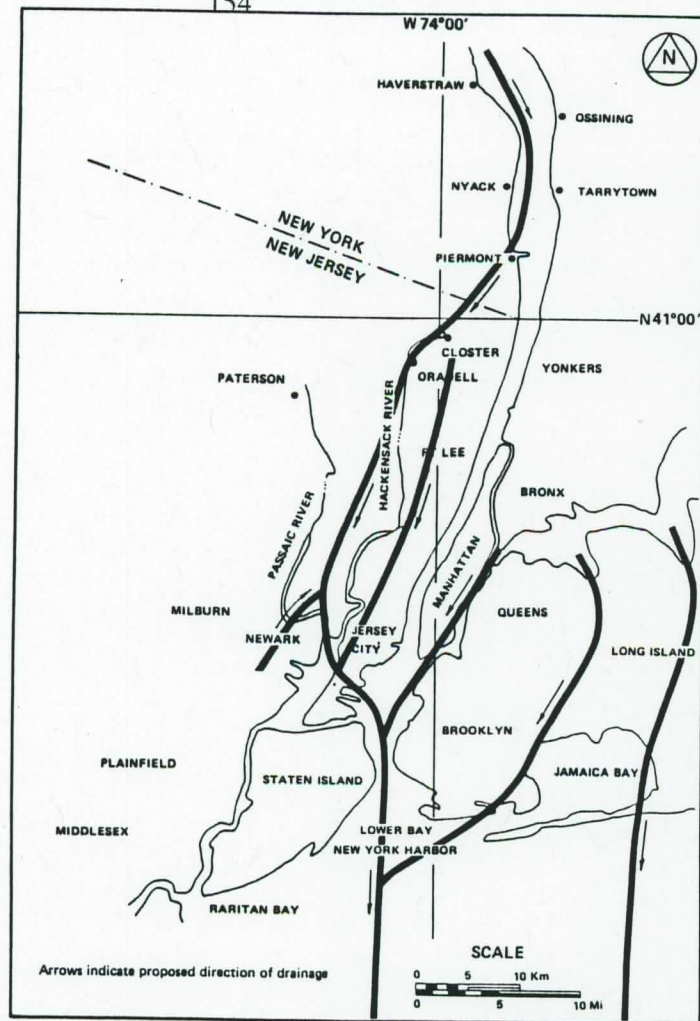


Figure 5. Inferred drainage channels, Late Pliocene (before first glacier arrived). (Jon Lovegreen, 1974 ms., fig. 22, p. 151.)

Another factor working against postglacial drainage to the north is isostatic rebound. The weight of glacier ice is inferred to displace parts of the asthenosphere. After the ice has melted, the displaced parts of the asthenosphere flow back again, and the surface of the lithosphere is elevated. The amount of depression of the surface of the lithosphere is greatest where the ice was thickest. Thus, after the ice has melted, the greatest amount of so-called glacial rebound likewise takes place where the ice was thickest.

Isostatic rebound has been demonstrated in the Hudson Valley by determining elevations on shoreline features built by postglacial lakes. These were horizontal initially but now are inclined toward the south. This inclination has resulted from greater amounts of rebound in the north, where the glacier was thicker. Comparable postglacial rebound has been inferred for northwestern New Jersey.

As far as postglacial drainage is concerned, therefore, both the residual effects from the meltwater channels and the isostatic rebound should have established a regional drainage toward the south. Some neotectonic feature, such as an active syncline pitching toward the northeast, seems to be required as a mechanism for explaining the direction of the Wallkill drainage.

CONCLUSION

Modern rivers are flowing in lowlands some of which have been in existence for hundreds of millions of years, and others of which are only a few tens of thousands of years old. After the last glacier melted, the rising water of the modern ocean has drowned and submerged low-lying regions.

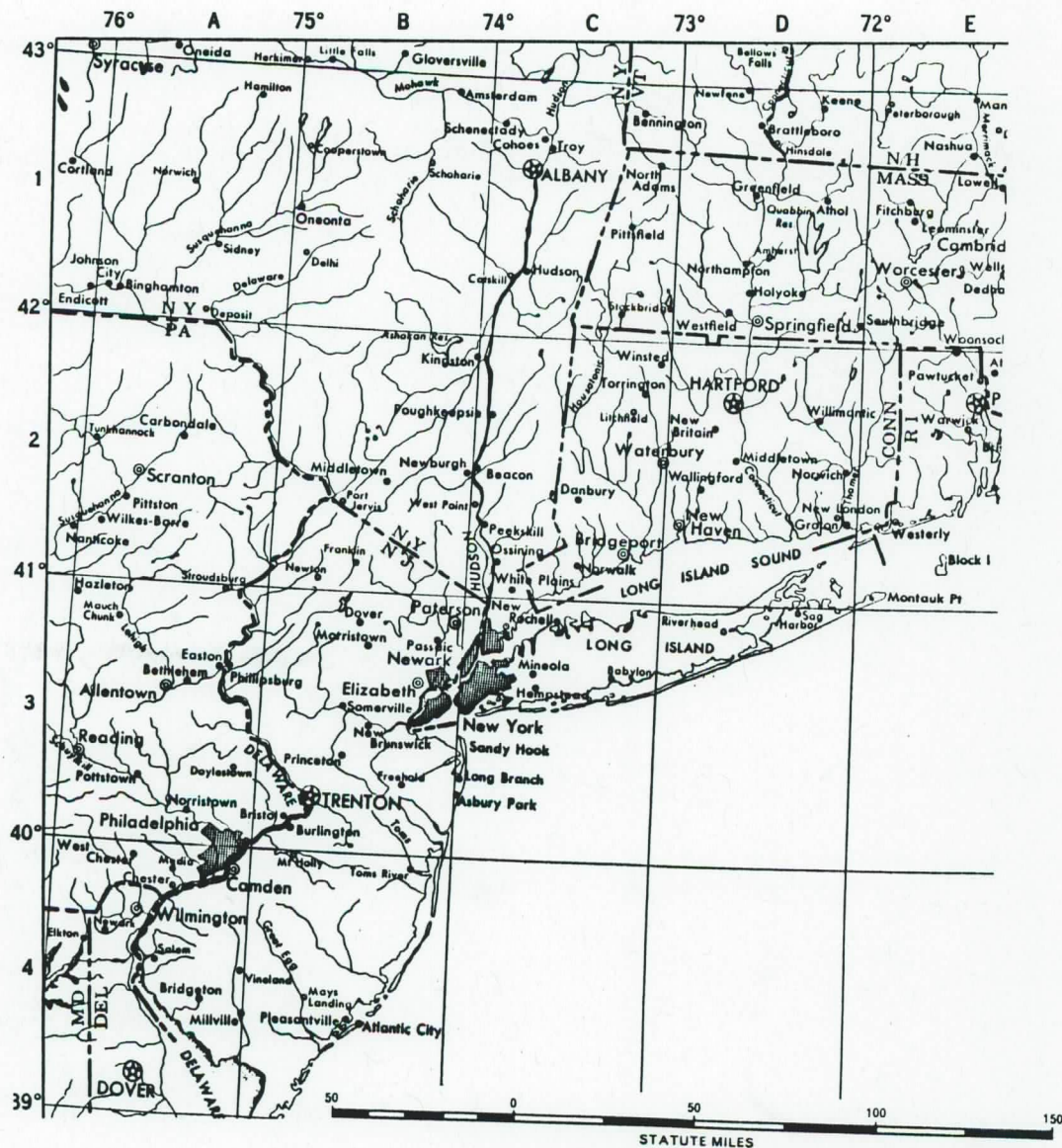


Figure 6. Map of modern drainage in the New York City region. (Robert F. Collins, 1960, United States basic map, third series, New Haven sheet, no. 13, first edition.)

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