DEVELOPMENT OF DRAINAGE OF CATSKILLS.

RUDOLF RUEDEMANN.

INTRODUCTION.

The writer has in a former article[1] described the development of the peculiar tangential drainage of the Adirondacks. The drainage lines of the Catskills are equally strange, indicating a long and intricate evolutionary history. A marked feature of this drainage is the circuitous course of the Schoharie River, the waters of which, rising within two miles[2] of the escarpment in the east, return within ten miles of their origin after following for 175 miles the four sides of a quadrangle by way of the Mohawk and Hudson Rivers; noteworthy, also, are the acute angle turns of the West and East Branches of the Delaware and their origin within a mile of the Schoharie River (see Fig. 1) and the tangential courses of the master-streams, the Hudson, Delaware and Susquehanna Rivers in regard to the Catskill cuesta.

To the writer's knowledge the cause of these strange phenomena has thus far not been sought. Guyot (1880, p. 443) in his pioneer work on the physiography of the Catskills comments on the remarkable fact that the Schoharie flows away from the escarpment of the cuesta towards the west and is flanked on the north (Catskill creek) and south (Esopus) by creeks that flow in opposite direction. He suggests "that the plateau of the Catskills had been lifted up on its eastern part to a higher level from which its waters were sent in the opposite direction." In a general way he sees in the horizontal position of the strata and long-continued erosion the two controlling factors. Especially he gives little weight to the discovery of Hall's assistants, announced by Hall in 1875, of four low anticlines pervading the Catskills in southwest-northeast direction in conformity with the Appalachian folding.

W. M. Davis' researches on the drainage of the Appalachian folds and on the folds at the foot of the Catskills (1882) are of fundamental import in the present work. He also empha-

[1] Ruedemann, R., The Tangential Drainage of the Adirondacks, this Journal, 22, 431-440, 1931.

[2] The north branch rises 11½ miles, the south branch but 7¼ miles from the Hudson. They were still two miles nearer to the Hudson before the Kaaterskill and the Plaaterskill cut off that much from the headwaters by stream-piracy.

sizes the fact (1896, p. 747) that the Potomac, Susquehanna, Delaware and Hudson are all abnormal in flowing from the Allegany plateau across the inner lowland and out through the oldland to the Atlantic, which abnormal courses had been attained in early Tertiary time.

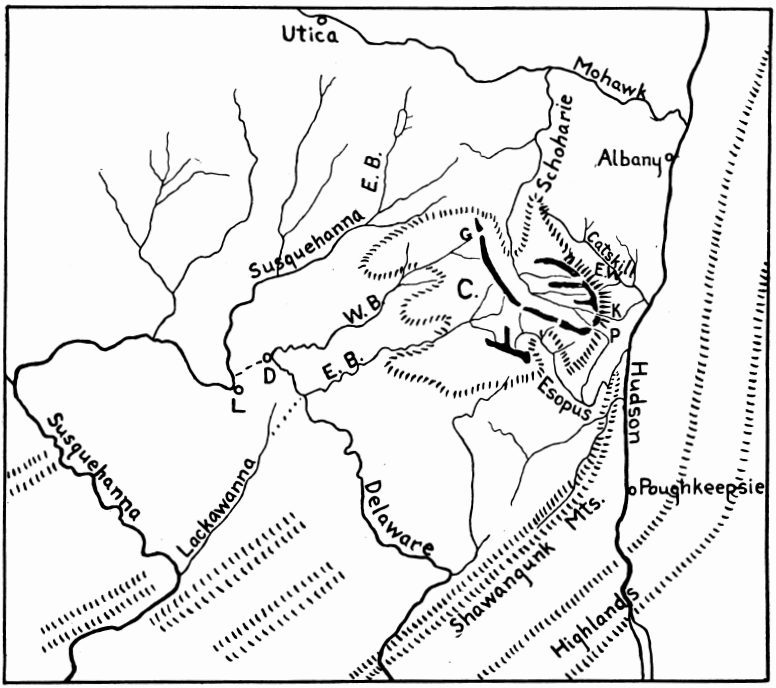

Fig. 1. Chart of the drainage of the Catskills and surrounding country. The Catskill plateau is indicated by hachures, the principal Catskill mountain ridges are in black. Abbreviations: C = Catskill Plateau; G = Grand Gorge; E. W. = East Windham; P = Plaaterskill; K = Kaaterskill; E. B. = East Branch; W. B. = West Branch; D = Deposit; L = Lanesboro.

An important discovery was the recognition of two cases of stream-robbery in the Catskills by Darton (1896). Thereby the new principle of stream-piracy was introduced into Catskill hydrography, in this case in reference to the headwaters of the Schoharie which have been cut off by the Kaaterskill and Plaaterskill.

Much new observational material has been furnished by Rich (1915), who points to the unilateral drainage of most tribu-

taries, especially that of the Schoharie, and sees the cause of this phenomenon in the adjustment to the slight south and southwest dip of the rocks. Only Esopus creek has a dendritic, perfectly symmetric drainage pattern which would indicate horizontal beds in its case. He states that the Susquehanna and the Delaware flow in consequent courses down the dip toward the axis of the Paleozoic bay in which the rocks of the plateau accumulated. The Schoharie creek, he finds, is obsequent in its lower course, subsequent in its middle course and consequent in its upper course. The other rivers and creeks are mostly subsequent according fully with the structure (the cuestas, etc.). Rich also discusses the various peneplanes, the most notable of which is the 2,000-foot plain surrounding the Catskills. This has been termed the Cretaceous peneplane by Grabau (1906), while Davis (1891) suggests that the Cretaceous peneplane lies in the Catskills at about 2,500 feet. Barrell (1914, p. 104) would place the oldest peneplane on top in the Jurassic. As Rich remarks, further study is needed for the correlation of the several peneplanes recognizable. For us, the recognition of their presence in and about the Catskills is the important fact.[3]

Fairchild (1925, p. 26) recognized that the upper Delaware was once a tributary of the Susquehanna and pointed out the old connecting course between the West Branch of the Delaware and the Susequehanna between Deposit and Lanesboro, now used by the Erie railroad.

TECTONIC HISTORY OF REGION.

If we wish to reconstruct the history of the strikingly peculiar drainage of the Catskills, we have to go back to the condition of the country at the end of the Carboniferous period, when the last emergence of the area from the sea took place and the Appalachian mountains arose. There is no doubt, from the enormous erosion that since must have taken place, that on the Upper Devonian Catskill beds now forming the top must have rested thick deposits of Carboniferous age, a slight remnant of which is still indicated by a patch of conglomerate on Slide Mountain. If Chadwick's (1931) contention that the Catskill beds are mostly of Portage age is true,

[3] The three peneplanes of the Capital District have been recently discussed by the writer (1930, p. 19). They are the same as in the Catskill region. We consider the highest as the Kittatinny (Juro-Cretaceous) peneplane.

even greater erosion has taken place on top of the Catskills. These beds were dipping toward the southwest, or the center of the basin of deposition, as those of the Catskills still do to-day.[4] To the east of the Catskills the Appalachian folds arose, sweeping towards north-northeast, the roots of which

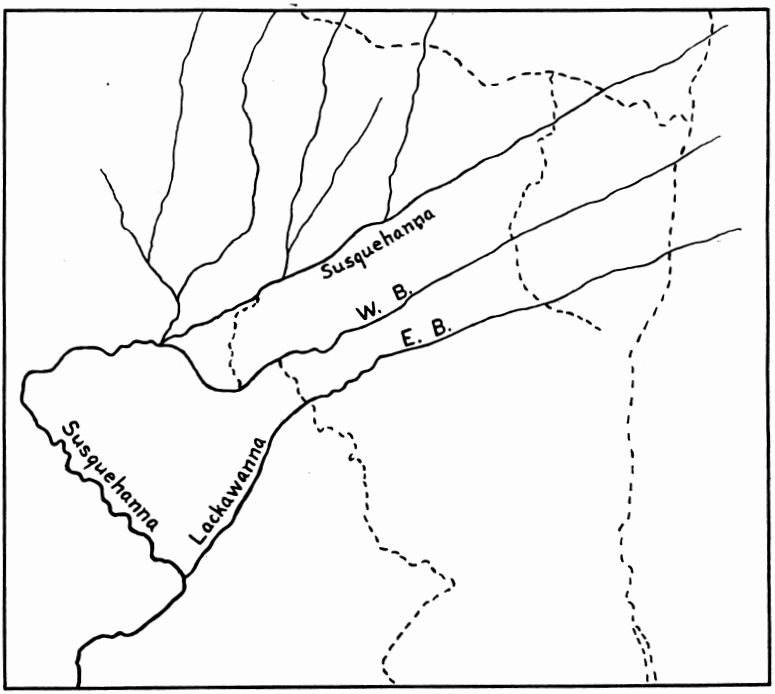

Fig. 2. Early stage of Susquehanna drainage in mesozoic time. Susquehanna headwaters reach upon the Adirondack plateau and eastern Appalachian mountain regions. Present drainage dotted.

are still displayed in the folded beds at the eastern foot of the Catskills, as about Kingston and Catskill. The Catskills themselves were slightly involved in this folding as announced by Hall, the Catskills lying in a broad, gentle synclinal trough, between the Adirondack uplift and its southern continuation

[4] The writer has not taken into account a possible tilting of the region, as there is no clear evidence of such save the post-glacial one. Especially there is no migration of divides recognizable that could be attributed to tilting.

and the Appalachian folds in the east and southeast with secondary anticlines running in the general direction of the Appalachian folding of the region. The general southward dip of the strata and the gentle syncline imposed upon the beds were the controlling factors of the first consequent drainage, directing it to the southwest (see Fig. 2).[5]

PRIMARY SUSQUEHANNA.

The Susquehanna and the West and East Branches of the Delaware (W. B. and E. B. on charts) and the upper Schoharie still follow this ancient course and may, therefore, be considered as relics of the original drainage. There is no doubt that these rivers once extended much farther to the northeast upon the original peneplaned surface, beyond the present course of the Hudson River and beyond the mountains rising east of the Catskills as indicated in Fig. 2. We may call this drainage that of the primary Susquehanna. Interesting evidences of this earliest drainage beyond the present Catskill cuesta are the broad, mature valleys of the two headwaters of the Schoharie extending right up to the escarpment in the east, where more recently stream-piracy from the east set in, and the broad pass at East Windham (E. W. of Fig. 1) across the northern ridge which, as pointed out by Rich, indicates an ancient river course. This is in the direct line of the East Branch of the Delaware and may well be the remains of the old Lackawanna-East Branch drainage line that reached out upon the Mesozoic plain.[6]

The Susquehanna has too long a course to the sea and a correspondingly low gradient. As a result it became the victim of stream-robbing first by the Hudson and Delaware Rivers and finally by the Schoharie.

[5] Johnson has recently (1931) suggested that the Appalachian drainage may have been superposed from a coastal plain cover deposited on a very ancient peneplane of pre-Schooley (or pre-Kittatinny) age. This former extension of the Atlantic Coastal Plain may have amounted 125-200 miles beyond the present eroded inner margin of deposits. The assumption of such an ancient plain will also facilitate the explanation of the general course of the primary Susquehanna.

[6] There are two other well-known deep passes in the Catskills, the Stony Clove and the Deep Notch, both deep (1,800 feet below the adjoining mountains) and narrow valleys, breaking through the central ridge and connecting the Esopus and Schoharie drainages. Rich considers these as due to erosion by glacial waters.

PRIMARY HUDSON RIVER.

The Appalachian folds which trend in meridional direction east of the present Catskill cuesta and which were brought out by erosion from the Kittatinny peneplane allowed the formation of a river coming up from the nearer New York coast

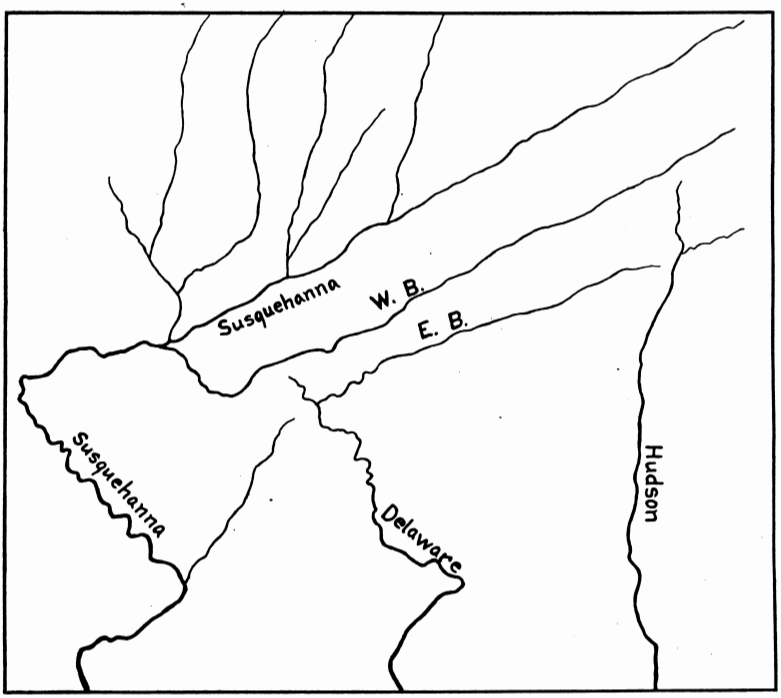

Fig. 3. Later stage. The Hudson has advanced far enough north to behead the East Branch in the east and the Delaware has captured the same stream in the middle.

(see Fig. 3) and developing a south-southwest course in the natural valleys between the folds.[7] This primary Hudson

[7] Davis (1892) believes that the Hudson valley lowland which lies on either side of the narrow trench of the river bed was excavated during Tertiary times, being begun with the Juratrias-Cretaceous (Kittatinny) peneplane and having its course determined by irregularities of this plain rather than by the attitude of the markedly folded rocks out of which the peneplane has been formed by long denudation. Tarr (1902) points out that there are other possible hypotheses. We consider the middle course of the Hudson, which is following the trend of the Taconic and Appalachian folding, as largely controlled by this folding; the lower course, where the river breaks through the Highlands, is antecedent.

River had a much shorter course to the ocean,[8] steeper gradient and greater erosive power; it hence cut off the headwaters of the primary Susquehanna, first in the east (east of the Catskills) and finally in the north by its great tributary, the Mohawk (see Figs. 3 and 4).

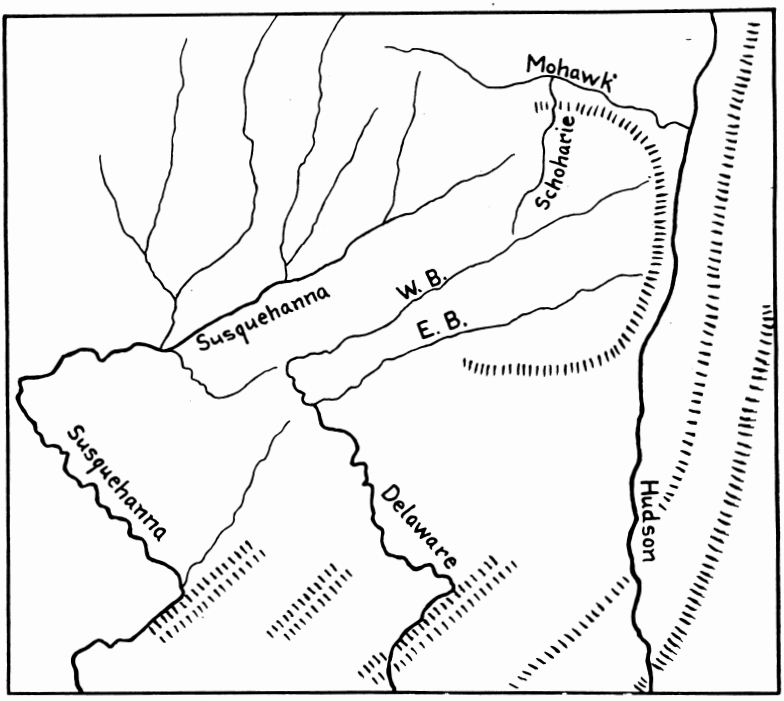

Fig. 4. A much later stage. The Hudson has reached the Adirondacks and sent the Mohawk westward, which in its turn is sending the Schoharie southward into the ancestral Catskill cuesta. The Delaware has captured the West Branch from the Susquehanna.

PRIMARY DELAWARE RIVER.

Together with the Hudson there developed still another river with a shorter course than the old Susquehanna to the south of

[8] The Hudson River is now, at Catskill, but 112 miles from New York Bay, while the sources of the Susquehanna are 500 miles from Chesapeake Bay. Moreover the Hudson is at tidewater at Catskill while the Susquehanna is not navigable from its mouth upward. It is, of course, unknown how much farther out these rivers once may have extended; if the submarine channel of some 60 miles is added to that of the Hudson, the much greater length of Chesapeake Bay has to be added to the pre-glacial Susquehanna course.

the Catskills. That is the Delaware River which to-day has a course of only 375 miles as against the 500 of the Susquehanna and but 245 to tide, the latter ascending 130 miles to Trenton. While not as favorably situated as the Hudson, which besides comes to the foot of the Catskills with abundant water-supply from the Adirondacks, the Delaware has still only half the course of the Susquehanna to tidewater. The Delaware worked its way upward to the foot of the Catskill cuesta and cutting back northwestward (see Fig. 3) across the strike of the softer beds of the western Catskills succeeded in cutting off the tributaries of the primary Susquehanna which now form its West and East Branches. Fairchild (1925, p. 26) has already pointed out that a deep preglacial valley leads from Deposit (D on Fig. 1) where the West Branch makes its acute-angle turn in continuation of the West Branch course, to Lanesboro (L on Fig. 1) in the Susquehanna valley, a depression that has been made use of by the Erie railroad. Likewise the East Branch, when continued in its course beyond Hancock, leads directly to the upper Lackawanna making it probable that it also is a former branch of the old Susquehanna lost by stream-piracy to the Delaware. The headwater of the West Branch is to this day connected with the Schoharie by a deep broad notch at Grand Gorge (G of Fig. 1) which partakes of the nature of the wind-gaps of the Appalachians and, as noted before, the East Branch when continued leads to the broad pass at East Windham, also a wind-gap and ancient river-course leading beyond the Catskills.

KITTATINNY PENEPLANE.

As denudation progressed in Mesozoic time, a peneplane, the Kittatinny, was finally established in early Cretaceous or possibly already in Jurassic time, remnants of which are still recognizable on the top of the Catskill Mountains. When the country was subsequently raised again, the Hudson River in the east and its tributaries were provided with new erosive power. They were able to lower the country to the north, east and south of the Catskills by two thousand feet, and to produce the two thousand-foot picturesque "mural front" at the east. The Catskill Mountain stock is now a subquadrangular cuesta (overlooking its subdivision into three parts by deep valleys) with high scarps bounding it at the northeast,

east and southeast, making that part in Guyot's words: "a mighty citadel overlooking by 2,000 feet all the surrounding country," while toward the west it sinks more gradually into the next lower peneplane. This high prominence of the eastern portion of the Catskill cuesta is due to the greater coarseness and resistance of the beds in the east than in the

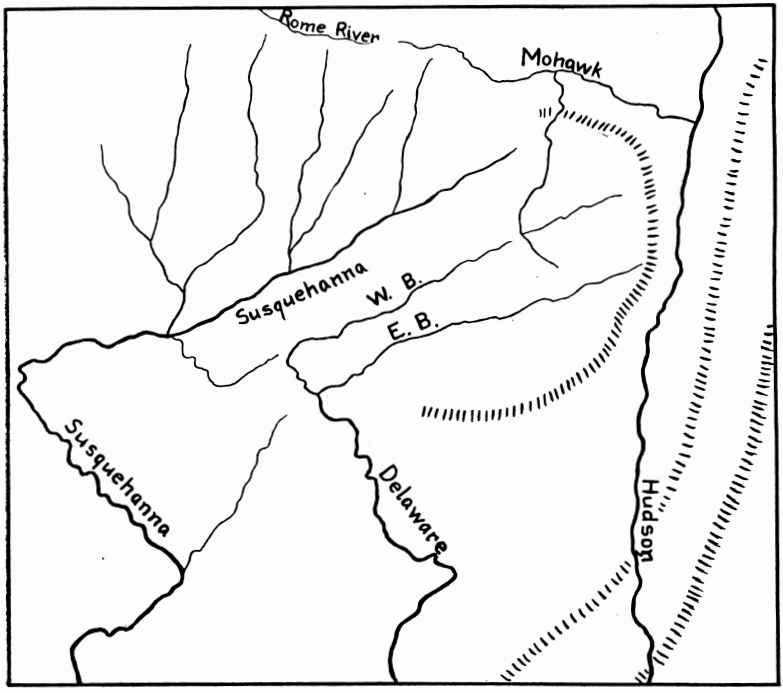

Fig. 5. The Schoharie has beheaded the West Branch of the Delaware and is proceeding towards the East Branch. The Mohawk and Rome Rivers are beheading the Susquehanna and its tributaries in the north.

west. The Catskill beds were deposited in a delta of a late Devonian river coming into the Albany Bay (continuation of Clarke's Albany Bay of Portage age or still the same bay according to Chadwick) from higher land in the northeast. The writer (1930, p. 129) has concluded that the barren Rensselaer grit, forming the Rensselaer plateau east of the river with its irregular streaks of feldspar-bearing conglomerate, is a continental deposit of the stream that furnished the

material for the Catskill delta. If this view is correct, the coarseness of the material increased from southwest to northeast as it does yet in the Catskills and also beyond the present Catskill escarpment, but this coarser material succumbed to the Hudson River, leaving the eastward rising cuesta of the Catskills as a monument of the delta separate from the Rensselaer grit plateau in the east.

HARRISBURG PENEPLANE.

As denudation proceeded, a new erosion plane, the Harrisburg peneplane, was formed which completely surrounds the Catskill cuesta, at 2,000 feet being well recognizable in the Helderbergs and the Rensselaer plateau (see Ruedemann, 1930, p. 19). When again the country was raised in early Tertiary time, undoubtedly much above the two thousand feet now recognizable in the Harrisburg peneplane, as is indicated by the deep gorge of the Hudson River in the Highlands and its submarine course of sixty miles beyond New York Bay, the Hudson River received new erosive power and sunk its bed two to three thousand feet beyond this last peneplane, bringing the tops of the Catskills to a height of four thousand feet above tide-water almost at the foot of the mountains. The Hudson's mighty tributary, the Mohawk, was now able to send a branch, the Schoharie, southward through the Harrisburg peneplane into the Catskills. The broad valley of the Schoharie, 1 to 2 miles wide in places in the northern Catskills and in the Harrisburg peneplane, testifies to the age and former power of this stream. The Schoharie was able to cut off the headwaters of the Susquehanna and the Delaware, as is proven by the fact that it passes within a mile of the heads of the West and East Branches of the Delaware, having a typically asymmetrical or unilateral drainage pattern by lacking large tributaries on the south and west in the Catskills and thereby testifying to its piracy relationship with the Delaware and Susquehanna Rivers (Fig. 6). That the two headwaters of the Schoharie represent old courses now abruptly cut off by the eastern escarpment and once extending far out to the east of the Catskills is unmistakably shown by the fact that the two branches start, as already pointed out by Darton, in broad matured valleys that lie some 1,800-1,900 feet below the tops of the Catskill peaks north and south of them, while they themselves run out to the "mural front," where a 2,000 feet

drop takes place (see Kaaterskill topographic sheet, Darton's figure and our Fig. 6). This is an entirely unnatural condition for the headwaters of rivers in mountain regions, where they normally are torrential and concave in outline and with declivities steepest in that section.

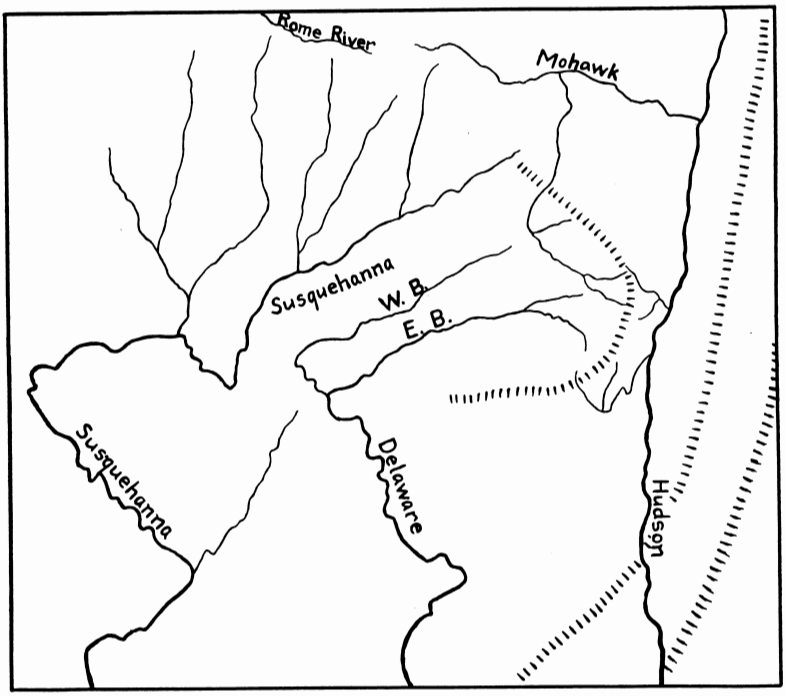

Fig. 6. The Schoharie has succeeded in capturing the headwater of the East Branch of the Delaware. The Catskill cuesta is approaching its present size. The small, steeply graded tributaries of the Hudson, east of the Catskills are advancing towards the mountains. The last stage is shown in Fig. 1.

FINAL STAGE OF HISTORY.

The final stage in this curious history is that the Hudson River, which has reached so deep a level that it is an estuary with tides at the foot of the Catskills and as far up as Troy, is now sending from the east new shorter, very steep rapidly eroding streams into the Catskills, such as the Kaaterskill, Plaaterskill and Esopus which proceed to cut off the Schoharie and East Branch of the Delaware. Darton has already well

described the stream-piracy that has taken place between the Kaaterskill and Plaaterskill on one hand and the Schoharie on the other.

These brooks have besides their steep gradients the advantage over the westward flowing streams of eroding against the dip and of thereby being able to take full advantage of the alternating harder and softer beds, rapidly removing the red shales and undermining the sandstones. This advantage is strikingly shown by the extremely high falls (Kaaterskill Falls, Haines Falls and Plaaterskill Falls) with which these rather insignificant brooks begin, and by which they have the advantage of a drop of two thousand feet within the first 1 to 2 miles of their course (see Fig. 1).

STREAM-PIRACY THE CONTROLLING FACTOR.

It thus seems that the entire abnormality of the Catskill drainage can be explained by systematic stream-piracy that proceeded first from the south and east and finally also from the north against the old consequent Susquehanna drainage, transforming the original symmetric southwest drainage into a more or less asymmetric north and south drainage.

BIBLIOGRAPHY.

Barrell, Joseph, 1914. The Upper Devonian delta of the Appalachian geosyncline, this Journal, **37**, 87-109, 225-253.

Chadwick, G. H., 1931. Catskill formation, Abstract, Bull. Geol. Soc. Am., **42**, 242.

Darton, N. H., 1896. Examples of stream-robbing in the Catskill Mountains, Bull. Geol. Soc. Am., **7**, 505-507.

Davis, W. M., 1882. The Little Mountains east of the Catskills (N. Y.), Appalachia, **3**, 20-33.

....., 1883. The folded Helderberg limestones east of the Catskills, Harvard Coll. Mus. C. Z., **7**, 311-329.

....., 1890. The rivers of northern New Jersey with notes on the Classification of rivers in general, Nat. Geogr. Mag., **2**, 81-110.

....., 1891. The geological dates of origin of certain topographic forms on the Atlantic slope of the United States, Bull. Geol. Soc. Am., **2**, 541-42, 545-586.

....., 1892. The geographic development of northern New Jersey, Boston Soc. N. H. Proc., **25**, 418-420.

....., 1895-1903. Current notes on physiography, Science.

....., 1896. Physiographic features of the Middle Susquehanna region, Pa., Science, n.s. **3**, 786-787.

....., 1899. The drainage of cuestas, Geol. Ass. London, Proc., **16**, 75-93.

Fairchild, H. L., 1925. The Susquehanna River in New York and evolution of western New York drainage, N. Y. State Mus. Bull., **256.**

Guyot, A., 1880. On the physical structure and hypsometry of the Catskill mountain region, this Journal, **19,** 429-450.

Hall, James, 1875. On the geology of the southern counties of New York and adjoining parts of Pennsylvania, especially with reference to the age and structure of the Catskill mountain range, Am. Ass. Adv. Sci. Proc., **24,** pt. 2, 80-84.

Heilprin, A. and L., 1906. Lippincott's New Gazetteer, Philadelphia, London.

Johnson, Douglas, 1931. Theory of Appalachian Evolution, Abstract, Bull. Geol. Soc. Am., **42,** 196.

Rich, J. L., 1915. Notes on the physiography and glacial geology of the eastern Catskill Mountains, this Journal, **39,** 137-166.

Ruedemann, R., 1930. Geology of the Capital District, N. Y. State Mus. Bull. **285.**

Tarr, R. S., 1902. The physical geography of New York State. New York, MacMillan Co.