CHAPTER 5

DYNAMIC EQUILIBRIUM AND LANDSCAPE EVOLUTION

John T. Hack

ABSTRACT

The principle of dynamic equilibrium when used to explain landscape features is not in itself an evolutionary model such as the geographic cycle. However, the tendency toward dynamic equilibrium is a universal principle that can be used to explain specific landscape features and problems, when it is assumed that the landscape has developed during a long period of continuous downwasting. This concept can be tested and compared with the multiple erosion cycle concept by examining a variety of specific features in a landscape, as the writer has done previously in the Shenandoah Valley of Virginia.

Evolutionary models can be conceived assuming (1) a stable base level, (2) a rise in base level, or (3) a fall in base level. In the first model, a gradual lowering of relief would be expected, greater effects occurring near base level than farther away, somewhat like a single cycle in the Davisian model. If base level rises, there would be a drowning of the lower valleys but very little effect upstream, and the topography would continue to lower. If base level falls, erosion would be accelerated near the new base level, and the acceleration would affect an increasingly large area. New adjustments of slope to rock resistance would be made simultaneously.

As has happened in the past, however, the model we adopt to explain landscapes must be related to prevailing thought in other fields of earth science.

INTRODUCTION

Many geomorphologists have abandoned the theory of the geographic cycle as a basis for landscape analysis, but no alternative has yet been generally accepted. In 1960, I advocated the use of the principle of dynamic equilibrium to explain the topography of erosional landscapes (Hack, 1960) and argued that the concept of multiple erosion cycles did not explain either the multilevel landscape of the Valley and Ridge province or the so-called dissected landscape of the Piedmont. Although I did not know it at the time, a criticism of the erosion-cycle concept very similar to mine had been made by an Australian geologist, E. O. Marks (1913), but Mark's paper received little notice outside Australia. The time was not then ready for such criticism.

The use of the dynamic-equilibrium principle was not new in geomorphology, for Gilbert (1877) had used it as the basis for his laws of erosion. Gilbert was quite familiar with thermodynamic principles, accepted them as physical realities, and commonly used them as a means of solving geologic problems.[1] He was not thinking in terms of models or theories of landscape evolution. He was explaining the origin of the landscape features observed in the Henry Mountains, but he realized that the explanation was of universal value, for he put it in terms of laws of nature. I thought in 1960 that I was advocating a similar approach.

In my opinion, the equilibrium concept should not be viewed as a model by itself. If one stated that the Appalachian Mountain system developed by downwasting that has been continuous since the latest orogeny, and that the variety of forms we now find are due to equilibrium of action in the erosional system — that would be a model. It must be recognized, however, that evolution is also a fact of nature and that the inheritance of form is always a possibility. The theory of the geographic cycle involving multiple peneplains, however, was inadequate as a model for the Appalachians and probably for all other similar terrains. It cannot be denied that the evolutionary changes during a cycle might look somewhat like those that Davis described, but this is quite different from the concept of multiple cycles and the inheritance of peneplain forms.

TEST OF THE CONTINUOUS DOWNWASTING MODEL

One way to test a theory or concept is to apply it systematically to explain field facts and relationships. This was the attempt in my study of the Shenandoah Valley published in 1965. Specific problems of the valley are explained by using the idea that topographic forms and processes are closely related to differences in the rocks, and the processes acting on them. The assumption was made that the erosional system had been downwasting a long time, and that it could be analyzed as though it were in a steady state. The analysis was carried as far as possible, and in my opinion it resolved many problems. Several examples are given below.

1. The specific geometries of drainage basins if examined quantitatively are related closely to the rock types, to exposure, and to other environmental factors throughout the Shenandoah Valley. The forms considered include size and shape of hollows, density of valleys, curvature of ridge tops, and

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[1]Mr. Steve Pyne, University of Texas, who is studying Gilbert's life has been very helpful in advising me concerning Gilbert's approach to problem-solving.

channel slopes of streams of various sizes. Even the hypsometric curves of drainage basins differ in different rock types.

2. Major topographic features such as the great mountain ridges are closely related to geologic structure. For example, the height of the Blue Ridge is controlled by the thickness of the metabasalt of the Catoctin Formation where it is of low metamorphic grade and relatively unsheared. Some of the gaps in the mountain ridges where detailed geology has been done have been shown to be related to geologic structures. One example is Manassas Gap at Front Royal, where the Catoctin Formation is missing because of a thrust fault.

3. The major rivers avoid the resistant rocks, and the Potomac is a particularly good example.

4. The longitudinal profile of the Shenandoah Valley, including the general altitude of the hills, is related to lithology and structure. This point will be discussed in greater detail.

5. On the lowland surface of the Shenandoah Valley, the occurrence of as well as the thickness of unconsolidated residuum are determined by the rocks directly beneath.

6. The gravel terraces and aprons of the valley lowlands are distributed in close relation to large drainage areas in the resistant rocks that are sources of the gravels. The piedmont aprons can be shown to have formed like the "sheets of fanglomerate" on the pediments of the Henry Mountains (Hunt, Averitt, and Miller, 1953, p. 190).

7. Iron and manganese deposits occurring in a belt marginal to the west part of the Blue Ridge, which formerly were believed to be associated with the Harrisburg peneplain, are better explained as concentrates related to the residuum and alluvial cover over the Cambrian dolomites. The failure of the peneplain idea to explain these deposits is evidenced by the occurrence of ore in residuum derived from a few beds in the stratigraphic section. Furthermore, the ores vary in altitude from 100 feet below the Shenandoah Valley floor to 400 feet above the valley floor on spurs of the Blue Ridge front.

All of these features of the landscape show a remarkable dependence on geologic structure and on the distribution of rocks of different physical and chemical properties. If discordant surfaces of any extent had survived, it is almost beyond belief that the relation of the landscape elements to structures could be so orderly.

FLOOR OF THE SHENANDOAH VALLEY

Difficulties in explaining certain features of the Appalachian landscape using the geographic-cycle concept have been noted by others. In the Shenandoah Valley, an example is the sharp increase in gradient of the valley-floor surface, or Harrisburg peneplain, about 35 to 40 miles upstream from the Potomac River. This break in longitudinal valley profile occurs near Front Royal where the North and South Forks of Shenandoah River join at the north end of Massanutten Mountain. Keith (1894) noted the break in slope and postulated differential uplift of the peneplain. This idea and the possibility that more than one surface was preserved on the valley floor sufficed to explain its irregularity for many years.

As a result of detailed mapping of a part of the valley, King (1949) realized that the origin of the valley floor must have been much more complicated than was formerly supposed. South Fork is bordered by a series of extensive gravel terraces, the highest of which are much dissected. The high terrace gravels are unconformable in some places on still older gravels, which in turn are underlain by thick residuum. Although King did not deny the existence of a former peneplain such as the Harrisburg peneplain, he showed that it must be very ancient, if present at all.

When the valley floor is examined in the context of continuous downwasting and the adjustment of slopes toward equilibrium, the problem is simplified. In this explanation, the terraces or gravel deposits are present where the resistant rocks in the bordering mountains have large outcrop areas. The hard rocks shed debris at a higher rate than the secondary streams of the limestone valley can transport on the relatively low gradients. The gravel does not keep on accumulating but achieves a certain equilibrium of area. When spread in fans and terraces it is subject to solution and erosion at a more rapid rate. This argument is presented in detail elsewhere (Hack, 1965, p. 29-58).

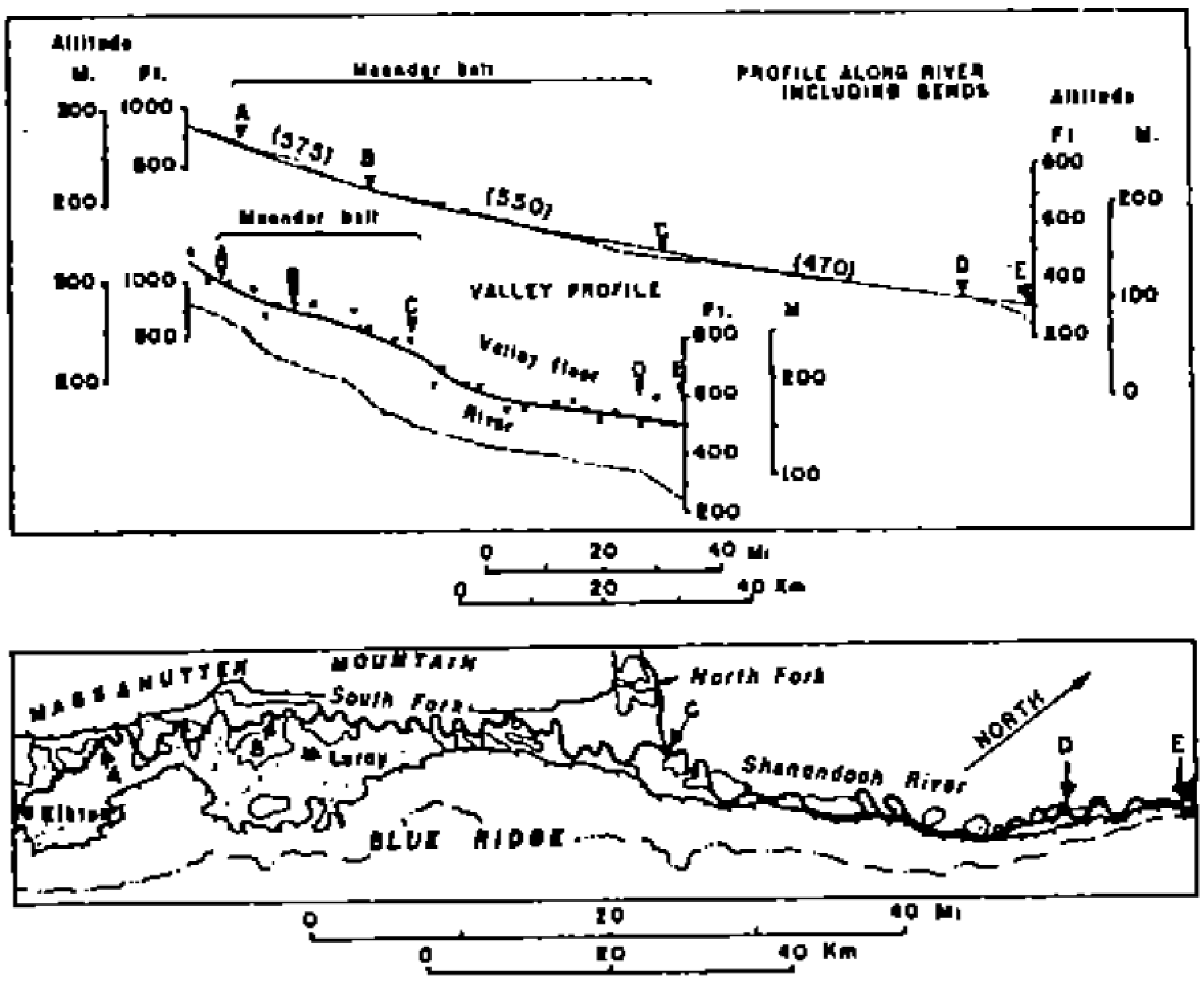

Figure 1. Profiles and sketch map of the South Fork of the Shenandoah River from Elkton to the junction with the Potomac River (at E). Actual river profile shown by short lines between dots. Profile constructed mathematically shown by fine smooth line. Numbers on the profile along river in parentheses are gradient index values. X's on the valley profile are altitudes of gravel terraces on the valley floor. The dotted pattern on the map represents gravel terraces and alluvium. Points A-E on map identify corresponding locations on the profiles.

The longitudinal profiles of the North and South Forks of the Shenandoah River provide a test of the use of the equilibrium concept as a solution. A map and profiles of the South Fork Valley and main Shenandoah Valley from Elkton to Harpers Ferry are given in Figure 1.

The river profile measured along the channel (upper curve) between localities A and E has a length of 140 miles (225 km) as compared with 80 miles (129 km) measured down the valley (lower curves), a ratio of 1.75 to 1. The difference in length of the two curves is due to the meandering character of the stream and the ratio between the lengths is called the sinuosity. The sinuosity is highest, however, in the reach between A and C where it averages 2.3. Downvalley from C to E it is only 1.4. The major break in the valley profile (lower curves) thus corresponds with the change in sinuosity.

The river-channel profile is a remarkably smooth curve, and in the figure, a logarithmic curve is plotted over it with the formula $H=3114-527\ln L$, where H is altitude in feet and L is distance in miles from the head of the South Fork river system. The largest departures from the ideal mathematically constructed profile are in the reach above the junction of the North and South Forks (point C, Fig. 1) and the reach just above the junction with the Potomac (point E. Fig. 1), a river with much larger discharge. The gradient index values shown in parentheses permit a numerical comparison of the average gradients of the reaches. This index is a measure of the slope of a logarithmic curve defined by the equation

$$\frac{H_1 - H_2}{\ln L_2 - \ln L_1}$$

and, as shown elsewhere (Hack, 1973), correlates roughly with the power and competence of a stream.

The valley floor curve, which shows the elevation of gravel deposits on the valley floor, is irregular and flattens markedly below the junction of the North and South Forks at locality C as noted by Keith and others. It relates closely to the altitudes on the adjacent streambed, except that the depth of intrenchment increases downstream. The geometry of these curves does not support the idea of warping of a peneplain or other surface but indicates instead that the valley floor is in adjustment with the river and that the irregularity of the valley profile is a function of the sinuosity of the river.

A similar but even more pronounced change in the valley profile occurs on the northwest side of Massanutten Mountain and has been described by Hack and Young (1959). This part of the valley is drained by the North Fork, which has a sinuosity of 3; that is, the length of the meandering reach, if measured along the river, is three times the length measured downvalley. Thus, the meanders themselves impart to the valley floor a longitudinal gradient three times that upstream. In effect, both the North Fork and the South Fork flow down their valleys in series of switchbacks. The geometry of these gradient relations is wholly inconsistent with the concept of the Harrisburg as a valley floor peneplain, for the meanders having greater amplitude occur on the steepest parts of the valley floor. The coincidence between valley gradient and sinuosity is too close for the warping hypothesis to be tenable. It is really the bedrock geology of the valley that explains both the meandering and the steep slope. The high sinuosities occur where the river is in the Martinsburg Shale, a thin-bedded silty shale. The joints and cleavage in the shale are parallel to the meanders. Many other Appalachian rivers have similar exaggerated meander patterns in the Martinsburg Shale.

ACCORDANCE OF SUMMITS

Probably the kind of evidence that is most convincing to adherents of the theory of the erosion cycle is the belief in accordance of summits. The topography of the area north of Harrisburg, Pennsylvania, where much of the classic work on peneplains was done has a remarkable regularity, and from a good vantage point an observer can see many miles of mountain top that are at almost the same elevation. In Davis's time and until quite recently, knowledge of the geology was sketchy, and accurate topographic information was not easy to obtain. Now, modern geology and topographic maps at 1:250,000 scale are available, and it is a simple matter to compare topography and geology over large areas.

The mountain ridges near Harrisburg were believed to have been relics of the Schooley peneplain (Fig. 2). The ridges shown are produced by sandstones of the (1) combined Tuscarora and Juniata Formations (2) the Pocono Formation, and (3) the Pottsville Formation. Altitudes on the tops of the ridges are taken from the 1:250,000 scale Harrisburg topographic sheet of the U. S. Geological Survey. Differences in altitude are not great, but altitudes do differ significantly between the formations. Differences along each formation generally correlate with width of outcrop. The ridge formed by the Tuscarora sandstone just north of Harrisburg is 1,100 to 1,300 feet (335 to 396 m) in altitude. The ridge in the northwest corner of the figure, however, reaches 2,100 feet (640 m). This ridge includes a much greater outcrop of resistant rock.

The Pocono ridges average 50 to 100 feet (15 to 30 m) higher but vary with the outcrop area, reaching heights of more than 1,700 feet (518 m). The ridges on the Pottsville are systematically higher than the ridges on the narrow Tuscarora belt. The low altitudes [1,200 feet (365 m) or below] on the Pocono ridges are where the outcrop is narrow. A high degree of accordance does indeed seem to exist, but the details indicate that there are real differences in height systematically related to geologic structure and lithology. The explanation for the height of the ridges is that the sandstones, being

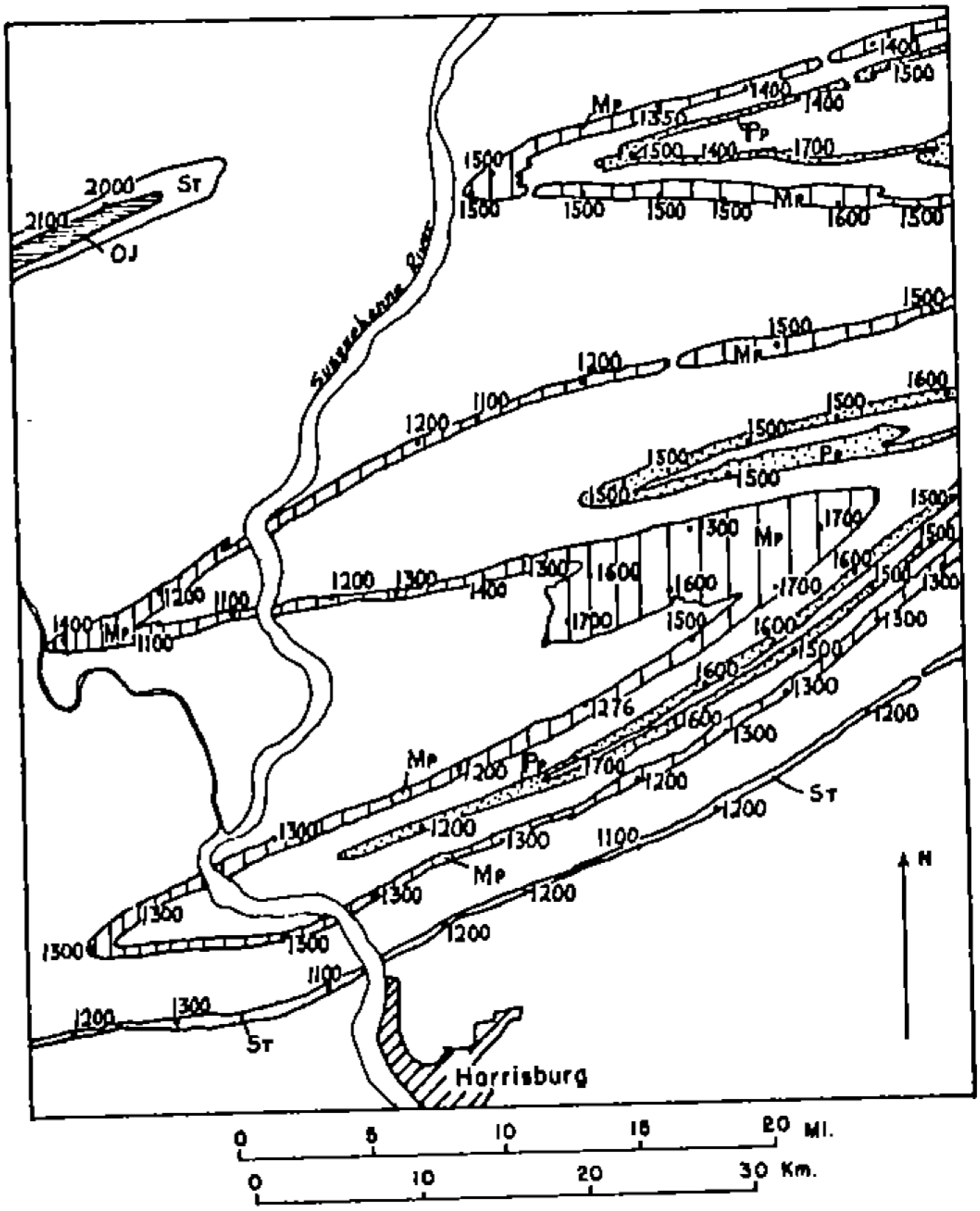

Figure 2. Map of the region north of Harrisburg, Pennsylvania, showing mountain ridges that were considered remnants of the Schooley peneplain. The figures next to dots are summit altitudes on these ridges.
Mp. Pocono Formation; Oj, Juniata Formation; Pp, Pottsville Formation; St, Tuscarora Formation.

more resistant, particularly to weathering, than the limestones and shales stand up at ridge heights in proportion to the area of the rock exposed at the present land surface. The physical properties of the sandstone, its thickness, and its altitude are all factors. When the sandstone bed flattens, as the Pocono does at the unbreached northeast end of the anticline in the figure, more resistant rock is exposed and the land surface is higher. The extreme regularity of the ridges one observes is partly a function of their height and width. A ridge that rises only a few hundred feet above the valley floor, is apt to give the impression of regularity because the distance from the crest to the base is not great enough for water to be gathered in hollows and channels. A wider and higher ridge, even though it may be in the same formation, can develop mountain hollows and first-order valleys on its flanks, and its crest is apt to be less smooth. The remarkable mountain pattern near Harrisburg, Pennsylvania, is thus due to the regularity of the folds, the consistently low thickness of the more resistant sandstones, and the spacing of the sandstones in the stratigraphic column.

The peneplain concept may be used in the explanation of the regularity and general accordance of these ridges. That is, their smooth tops are remnants of a nearly flat plain, preserved because the rocks of which they are composed are more resistant than the rocks between the ridges. However, if considered in detail, the correlation between the heights of the ridges, the specific rock formations, and their width of outcrop is still a fact and remains to be explained. The nearly flat plain, if it ever existed, must have had the same ridges on it as are there today, but they were lower. On the other hand, perhaps the peneplain was flat or had some other configuration, but during its dissection the rocks with greater resistance or wider outcrop were not lowered quite as far as the others. Either explanation is tenable, but in neither is the peneplain a necessary part.

OTHER ASPECTS OF THE GEOGRAPHIC CYCLE

Davis' model of landscape development included many ideas other than cyclicity or series of peneplains. Many of them can be used in the context of a continuous downwasting model, and they do not necessarily conflict with the tendency toward equilibrium. Even in the Appalachians, these other ideas are not necessarily invalidated by the rejection of multiple geographic cycles. Examples are the formation of wind gaps and water gaps, headward migration of divides, and stream piracies.

The adjustment of drainage to structure is truly remarkable in many places in the Appalachians, and this is perhaps the most striking feature of the region. It could have been accomplished only by piracies and divide migration on a grand scale. It is easier for some of us to believe that such a profound adjustment occurred during the erosion of many thousands of feet of rock over a long time span rather than during a short cycle in which a peneplain was dissected only a few thousand feet. Water gaps may be the result of adjustment to structures such as fault zones or fracture zones. On the other hand, they may be inherited from the past when superimposition occurred at a higher stratigraphic level and on a different structural pattern. Some wind gaps are the result of adjustment to structures. That is, they are a low place in a ridge where rock resistance has been overcome by a fault zone or other weakness. Some wind gaps may have formed, as Davis thought, by piracies.

Models Other Than the Steady State.

The continuous downwasting model in which a tendency for dynamic equilibrium is assumed does not necessarily imply a steady state. In fact, though a steady state is possible and is consistent with the idea of isostasy, it must be rare. One can speculate what would happen to a landscape under conditions of (1) a stable base level, (2) a rise of base level, and (3) a lowered base level.

If a landmass is uplifted and remains stable for a long period, it is eventually reduced by erosion and weathering to a level close to base level. During the reduction, an evolutionary sequence of changes occurs. If the rocks are homogeneous and of the same resistance, the topography that forms is determined by the drainage pattern and various erosional processes. Because discharge increases downstream and the ability to transport erosional waste is greatest in the larger streams, the lower end of the drainage system erodes more rapidly than the distal parts until an equilibrium of slope is achieved. This is the cause of the general concave-upward form of drainage systems.

As the interstream areas can rise only a certain distance above the streams, depending on the relative energy of the processes acting on them and the materials of which they are composed, a system of ridges develops. The relief in the system gradually becomes more gentle but is never eliminated.

Differences in rock resistance and the universal tendency for equilibrium of action cause differences of form to develop early in the evolutionary process. A differentiation of slopes, relief, drainage patterns, and other aspects of form takes place. These differences of form are never eliminated but do change if the erosion surface encounters different rocks at lower levels.

This kind of topographic evolution is not too different from that described by Davis, except that Davis believed that ultimately nearly all the topography would become bevelled. For example, he visualized the Piedmont of Virginia as an uplifted peneplain, a point of view clearly explained in his essay on the peneplain (Davis, 1909, p. 356-357). It is more likely that large parts of the Piedmont are close to the ultimate form that can be attained by a former mountainous area as a result of continued downwasting, except for parts near the coastal plain which have increased relief because of a drop in base level. In my opinion, the ultimate landscape in an area of stable base level is an orderly network of ridges and ravines that has a low relief. Such a landscape is well drained and is almost entirely in slope, though the average slope may be very low (Hack, 1960, p. 89). The more resistant rocks form a terrain of higher relief than the nonresistant rocks, and the differences are never completely erased.

Rise in Base Level.

Consider now a second case, that of a rise in base level and the effect of this change in a normal landscape that has already achieved a degree of adjustment. Imagine, for example, that sea level simply rises a thousand feet or so and floods the lower part of an area. Although the potential energy for erosion will be lowered, the area to be eroded will also be lowered, and upstream areas will probably be little affected by the rise. This conception is in harmony with the idea that river profiles and the general behavior of streams that are fashioning slopes are determined by upstream conditions rather than downstream conditions. Rubey (1952, p. 134) stated:

> "The slope at different points and the shape of the profile are controlled by duties imposed from upstream, but the elevations at each point and the actual position of the profile are determined by the base level downstream."

That this idea is now widely recognized is shown by the fact that the analysis of draining basins since Horton's (1945) work has been based on the ordering and measuring of streams and stream segments, proceeding from the head downstream.

The independence of streams from their base levels is also shown by the fact that tributaries do not enter master streams at grade. In fact, their slopes may increase as they approach the master stream, depending on the relative size of the two streams, the occurence of bordering terraces, and other factors.

The construction of a reservoir causes a rise in base level. The effect of one such reservoir has been discussed by Leopold, Wolman, and Miller (1964, p. 436-437). The obstruction of the Rio Grande River by the Elephant Butte Reservoir was thought by some to have caused increased sedimentation and a rise in river level 30 miles upstream from the reservoir. Analysis of sediment data show, however, that the gradual rise of the river began about 1901, antedating the reservoir by 14 years. The upper Rio Grande thus appears to be now depositing a greater load than it did before about 1901. Deposition is probably related to the cycle of gully erosion upstream that began about the turn of the century.

Lowered Base Level.

The third postulate is that of a lowered base level. The effects caused by this circumstance can be studied in the Appalachian region, for we know that the sea covered some of what is now the Piedmont during Tertiary time and withdrew in the Miocene. The amount of lowering can be fairly estimated in the vicinity of Washington, D. C., where Darton (1951) studied the overlap relations at the inner edge of the Coastal Plain. Figure 3 is a sketch map of this region which shows the extent of the Miocene outcrop as interpreted by Darton (1951, pl. 1).

The highest outcrops of probable marine origin shown on this map are at Tyson's Corner northwest of Alexandria, more than 10 miles (16 km) from the inner margin of the Coastal Plain. These outcrops underlie a group of hills 520 feet (150 m) in altitude that form the highest part of the Piedmont in the immediate vicinity. Ten to 20 feet (3-6 m) of fine sandy and silty clay that closely resemble the clay of the Calvert Formation of Miocene age are the lowest sediments exposed; they rest on crystalline rock at an altitude of

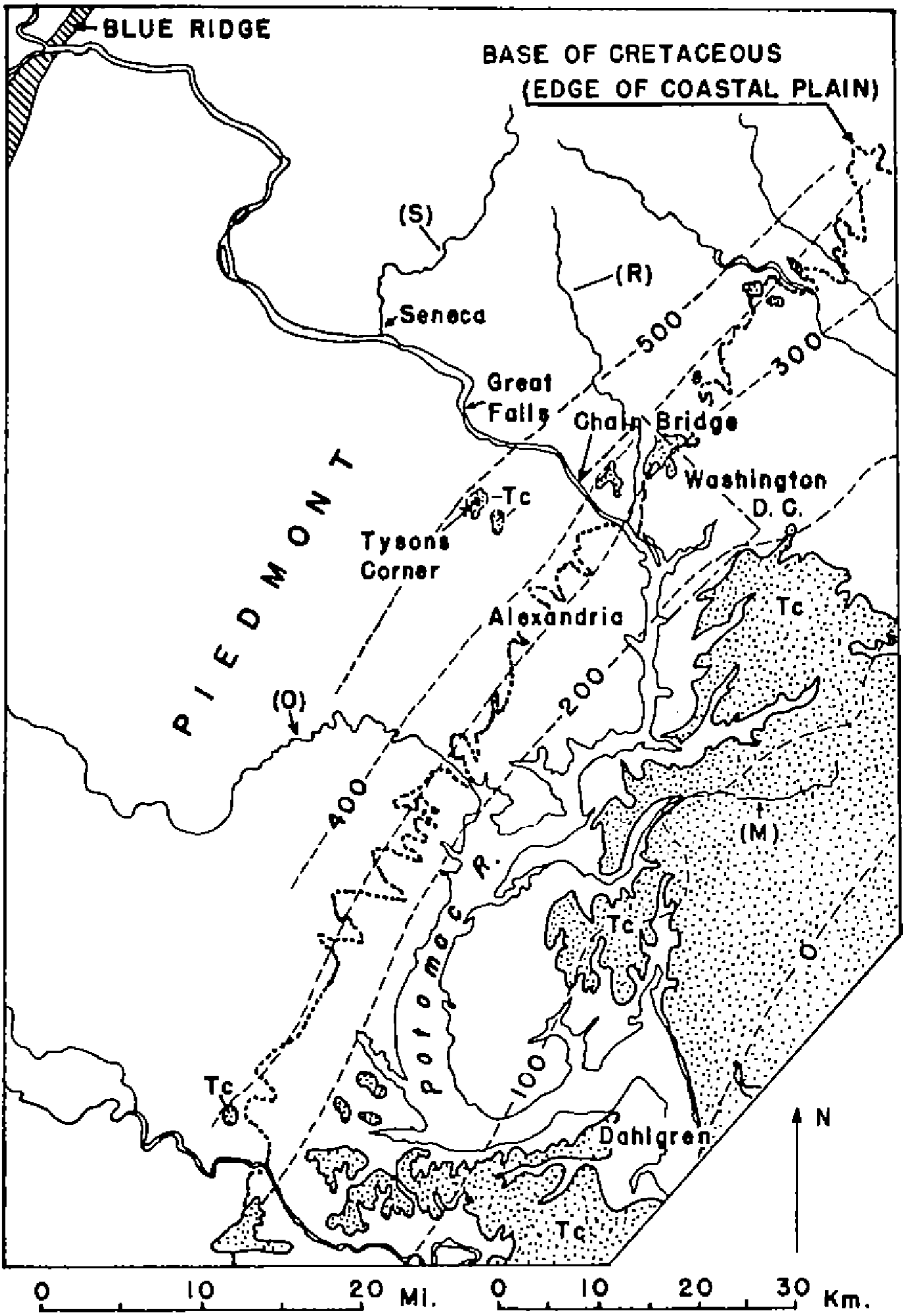

Figure 3. Map of the Potomac River in the Piedmont and part of the Coastal Plain near Washington, D.C. The fine stippled area (Tc) shows the outcrop of Miocene marine sediments and overlying gravels where present as mapped by Darton (1951). Contours are on the base of the Miocene. The heavy dotted line is the edge of the Coastal Plain as marked by the base of Cretaceous sediments. (S) Great Seneca Creek; (R) Rock Creek, (O) Occoquon Creek and its headwater, Cedar Creek; (M) Mattawoman Creek.

about 470 feet (143 m). The clays are overlain by sand and gravel that have generally been regarded as of Pliocene age, though they may be Miocene. These deposits are river gravels laid on the clayey sediments by the ancestral Potomac River (Wentworth, 1930; Schlee, 1957). Similar Coastal Plain outliers occur in northwest Washington, D. C., where they are unconformable on Cretaceous deposits and can be projected downdip toward deposits of known Miocene age in southwest Washington, D. C.

The Tysons Corner deposits show that the Potomac River flowed at an altitude of 500 feet (152 m) above present sea level in late Tertiary time. If Darton's (1951) 500-foot (152-m) level is projected northeastward (Fig. 3), it crosses over the Potomac Valley downstream from Great Falls where the river is now flowing at an altitude of 50 feet (15 m). Thus, the river has eroded a vertical distance of 450 feet (137 m).

Downstream, in what is now the tidewater section, the Potomac was lowered to a depth below present sea level. The amount of lowering can be determined at several localities from records of borings made for bridge foundations. The boring logs permit identification of the interface between the Tertiary sediments and the Quaternary fill (Hack, 1957). The locality farthest downstream is at Dahlgren, Virginia (Fig. 3), where the Pleistocene riverbed is at -160 feet (-49 m). This locality is about 70 miles (112 km) downriver from Chain Bridge, the head of tidewater. The lowest sea level during the Pleistocene was far downstream from this point, however, on what is now the Continental Shelf and is estimated to have been at -230 to -295 feet (-70 to -90 m) (Flint, 1970, p. 322-328).

The profile of the present Potomac River from the Blue Ridge Mountains to Dahlgren is shown in Figure 4. The river leaves the Appalachian Valley at an altitude of 300 feet (91 m) at least 200 feet (61 m) lower than sea level during Miocene time, as shown by the deposits at Tysons Corner. The Potomac River passes through the Blue Ridge at a steep gradient; gradient index values are higher than any the writer has measured in the upper Potomac Basin (Hack, 1973, Fig. 6). The gradient becomes lower in the Triassic rocks downstream from the Blue Ridge, but steepens again at Seneca where the river enters crystalline rocks. At this point, the river descends several very steep reaches to the Coastal Plain, where the now-submerged profile is quite gentle.

The high gradient index values below the Blue Ridge suggest that the river may have been rejuvenated in the entire section. The wide range in values is related to partial adjustment to rocks of different resistance. The Piedmont upland near the river averages about 150 to 200 feet (46 to 61 m) above river level as far downstream as Great Falls, where the river descends 100 feet (30 m) rather abruptly, entering a spectacular gorge that extends almost to Memorial Bridge on the Coastal Plain. The gorge indicates that in this reach the adjacent Piedmont surface has not achieved the same adjustment as the Piedmont above Great Falls.

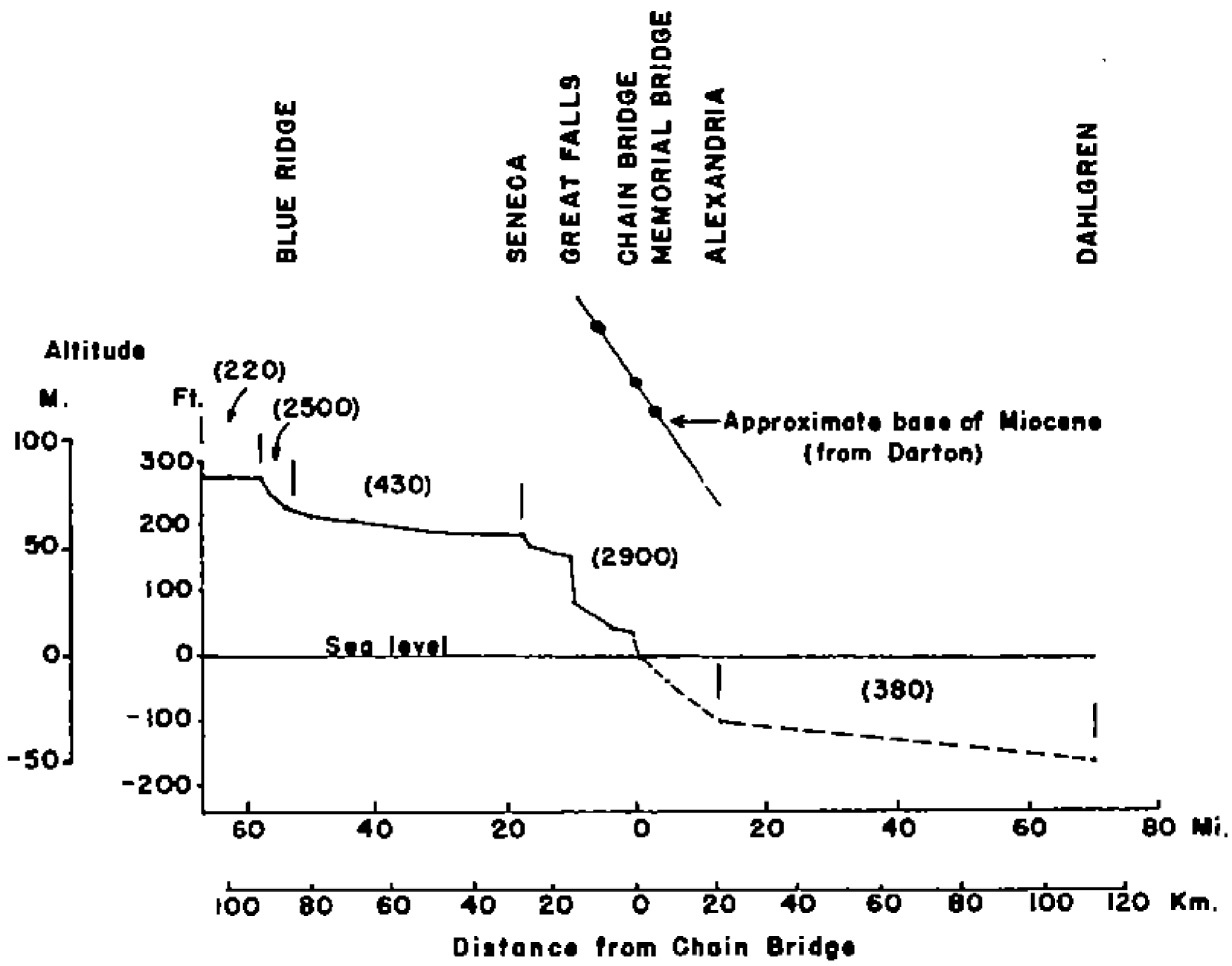

Figure 4. Profile of Potomac River from the Shenandoah Valley to Dahlgren, Virginia. Gradient index, or SL values, are shown in parentheses.

More can be learned from profiles of the tributaries, examples of which are shown in Figure 5. The tributaries above Seneca enter the Potomac at low slopes with gradient index values less than or the same as the Potomac itself, suggesting that they have achieved an adjustment to the main river. The profile of Great Seneca Creek (S, in Fig. 3) is an example. Below Great Falls, however, the profiles of the tributaries are not adjusted to the main river, as indicated by steep reaches near their mouths. Rock Creek (R) and Occoquan Creek (O) are examples.

Mattawoman Creek (M) is an example of a stream that is entirely of post-Miocene origin, for it enters the river from the east in an area almost entirely covered by Miocene as well as Pliocene and even younger sediments. The lower part of Mattawoman Valley is drowned. However the river is well graded and has a profile that is almost a straight line with few irregularities. It enters tidewater without changing its graded condition, but in order to join the Pleistocene Potomac at an altitude of -100 feet (-30 m) or lower, it would have to steepen its course considerably in the reach that is now drowned. Note that gradient index values increase downstream, an indication that the competence of the river increases. As the river flows in fine-grained sediments in its lower course, the increasing competence is not caused by the material transported by the stream. In its lower course, the stream is braided, probably as compensation for the steep slope. One can expect that in time the profile will become more concave.

The foregoing brief analysis of stream data in the Piedmont part of the Potomac Valley indicates that the valley has been lowered by erosion a significant amount in post-Miocene time. Only a few remnants of upper Tertiary deposits remain in the Piedmont landscape. The response to a lowered base level has been a readjustment of the profiles of many of the streams in the lower basin. As shown by the anomalously steep reaches, however, the adjustment as yet is only partial, especially near the outer (eastern) edge of the Piedmont, where the main river itself is in a narrow gorge. The withdrawal of the sea, of course, was probably discontinuous and interrupted by periods of sea-level rise, like the present.

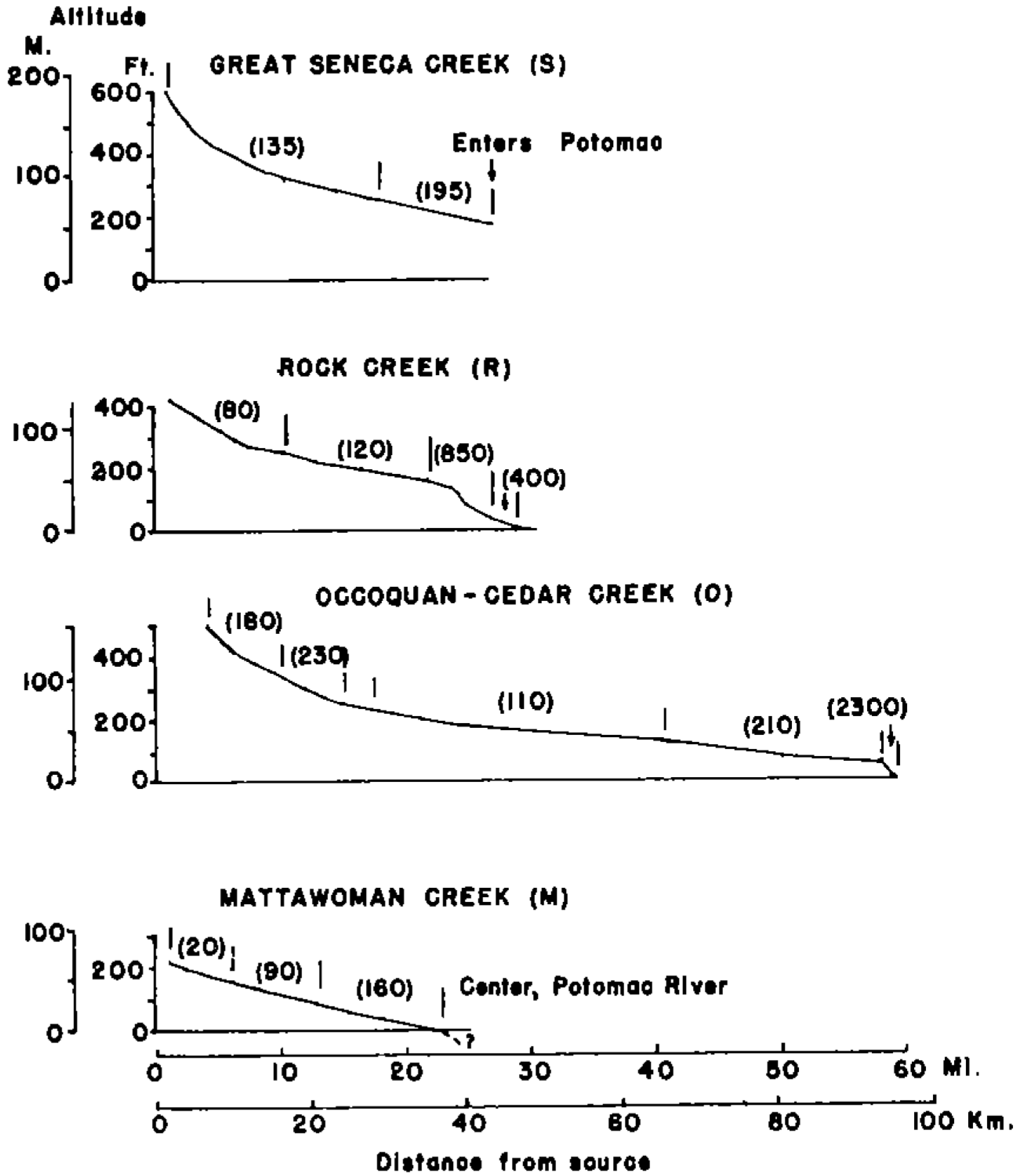

Figure 5. Profiles of four streams tributary to the Potomac River. SL or gradient index values are shown in parentheses.

SEARCHING FOR A MODEL

Chorley (1963) pointed out that the prevailing geomorphic theory in the past has been related to large systems of thought that embraced a major part of earth science. For example, in the 19th Century the ruling eustatic theory involved the ideas of continental stability and oceanic instability. Many interpretations in geomorphology were based on the eustatic theory. One example is the belief in the absolute horizontality of Coastal Plain terraces that were thought to be traceable from New Jersey to Florida. Another example is the former interest in seaward-facing terraces in the Piedmont and in New England.

Davis's geomorphology, or at least its almost universal acceptance, is closely related, according to Chorley (1963) to the concept of epeirogeny (Gilbert, 1890). Certainly the recognition of peneplains and their deformation was a concept ideally suited to define and study vertical movements of the continents. Although the recognition of peneplains may no longer be acceptable, the definition of true erosion surfaces can continue to be a valuable tool in a broader understanding of earth processes.

Plate tectonics is a new and profoundly important theory that though only 10 to 15 years old is now affecting all fields of geology. Geomorphologists are certain to become concerned, and the sooner they do, the better. I have read as well as heard the statement by devotees of the concept that topography is a "now thing." I am philosophically in complete sympathy with this idea, but analysis of Appalachian landforms and the perfection of their adjustment compels the belief that these mountains have been around for a long time. They may of course be now in motion and at a rapid rate — up or down, or in some other way.

Some simple but puzzling geomorphic facts concerning the Appalachian region can be cited as germane to this problem. The Appalachian Mountains can be divided into three parts that are quite distinct and different from each other.

The Southern Appalachians, extending to the Roanoke River at the north, have their highest area, by far, in the Blue Ridge, which here is a large part of the range. It is bordered on the east by an escarpment that appears to be retreating northwestward. The drainage is almost entirely to the Gulf of Mexico via the Mississippi and Alabama Rivers. The Central Appalachians extend from the Roanoke River to the Hudson River. Their drainage, except for the Plateau area, is entirely to the Atlantic, and the high parts of the range are found on the southeast as well as the northwest margins. The Blue Ridge belt is narrow and restricted to only the most resistant rocks; it ends in Pennsylvania south of the Susquehanna River, where the Valley and Ridge province widens and swings around to almost an eastward trend. Structural style is different here, as though this part of the mountain chain was exposed at a higher structural level in the crust or not lifted as high as the other parts. The Northern Appalachians are again different. Here, the areas of high mountains are in the zone of igneous and metamorphic rocks, and unmetamorphosed sediments form only a narrow zone bordering Lake Champlain. There is no plateau area, and the Adirondacks appear to be a vertical uplift that has no counterpart to the south. Here, as in the Southern Appalachians, the crystalline rocks form high mountains. Are these differences wholly related to the emplacement of the mountains and the break-up in Triassic time, or are they related to later events which we as geomorphologists might be able somehow to decipher?

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