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William Morris Davis: Father of Geomorphology or Father of Geology's Unrecognized Paradigm Problem

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Abstract

An often unrecognized problem is the geology and glacial history paradigm's inability to explain topographic map drainage system and erosional landform evidence, which means geology research studies rarely address that type of topographic map evidence. The problem originated in the late 19th century with William Morris Davis who is sometimes called the father of geomorphology and was one of the first geologists to interpret what in the late 19th century were newly available topographic maps. An 1889 Davis paper describes selected drainage system evidence observed on an advance copy of the 1890 Doylestown (Pennsylvania) topographic map and an 1892 Ward paper written after discussions with Davis describes additional selected drainage system evidence seen on the same map. Both papers fail to mention the majority of the Doylestown map's drainage system features including most barbed tributaries, asymmetric drainage divides, and through (dry) valleys crossing major drainage divides. Had Davis used all of the map's drainage system and erosional landform evidence he should have recognized the map evidence shows headward erosion of an east-oriented Neshaminy Creek valley captured southwest-oriented streams which headward erosion of the south-oriented Delaware River valley and its east-oriented tributary Tohickon Creek valley had beheaded. Consciously or unconsciously, Davis chose not to alert future investigators that Doylestown topographic map evidence did not support his yet-to-be-published Pennsylvania and New Jersey erosion history interpretations and instead Davis proceeded to develop and promote erosion history interpretations which the map evidence did not support.

Keywords

Doylestown Topographic Map, Drainage Systems, Geology Paradigm, History of Geology, Robert DeCourcy Ward, Topographic Map Interpretation

1. Introduction

William Morris Davis (1850-1934) is frequently recognized for the numerous contributions he made to the study of landforms and has been credited as being the father of geomorphology [1], although an often-overlooked Davis contribution probably led to what Clausen [2] describes as geology's unrecognized paradigm problem. The unrecognized geology paradigm problem developed (according to Clausen) because geomorphologists and other geologists cannot use the accepted geology and glacial history paradigm to satisfactorily explain most topographic map drainage system and erosional landform evidence and as a result, researchers usually ignore almost all of the drainage system and erosional landform evidence which the well-mapped United States Geological Survey (USGS) topographic maps show. In other words, almost all the United States topographic map drainage system and erosional landform evidence is what Thomas Kuhn [3] referred to as anomalous evidence, or evidence that an accepted paradigm does not explain.

Scientific disciplines according to Kuhn deal with anomalous evidence in one of three ways. First, the evidence may eventually be explained and the discipline's paradigm survives without any serious interruption (to date in spite of many attempts no one has shown how the accepted geology and glacial history paradigm can explain the Pennsylvania drainage system evidence that Davis in 1889 described as being so mysterious that only the most advanced student could understand it). Second, the evidence is noted and set aside (the drainage system and erosional landform evidence has been mapped in great detail and set aside, which means the drainage system and erosional landform features once they were recognized as being unexplainable evidence have for all practical purposes been ignored). Third, the anomalous evidence may lead to a new paradigm and to a battle over which paradigm should be used (Clausen's book suggests the ignored topographic map drainage system and erosional landform evidence can be used to construct a new paradigm which leads to a fundamentally different Cenozoic geology and glacial history than what the accepted Cenozoic geology and glacial history paradigm describes).

Most of the Davis landform contributions to the study of landforms were made when United States Geological Survey and associated state geological survey topographic mapping projects were just beginning and Davis early in his career published research studies about regions for which topographic maps were not available or for which he only had access to incomplete topographic map coverage. For example, his classic "Rivers and Valleys of Pennsylvania" paper [4] was published in the then new *National Geographic Magazine* at a time when few Pennsylvania topographic maps were available and Davis had to rely on less detailed maps and on observations he had made while traveling in Pennsylvania where he had been born and raised. As a result, Davis developed many of his contributions, including his famous erosion cycle model, frequently without the benefit of being able to study detailed topographic map drainage system and erosional landform evidence.

Davis did use his influence with the various geology surveys to obtain advance copies before some early topographic maps were officially released, however his publications suggest that upon receiving those new topographic maps he apparently did not use the newly available and carefully mapped drainage system and erosional landform evidence as a starting point for rethinking his previously made erosion cycle interpretations and he very rarely said anything in his publications about whatever specific topographic map drainage system or erosional landform evidence that he observed. This failure to comment on the newly available topographic map drainage system and erosional landform evidence is somewhat puzzling as Davis was in the unique position of being one of the first geologists to be able to interpret what many of the early topographic maps showed. Yet for unstated reasons whatever drainage system and erosional landform evidence Davis saw on the new topographic maps was so mysterious that Davis chose not to discuss it.

In one rare exception to his usual practice of not commenting on specific drainage system and erosional landform evidence seen on the then new topographic maps, Davis did publish a short paper in *Science* [5] in which he describes selected drainage system evidence that he had observed on an advance copy of the 1890 Doylestown, Pennsylvania topographic map (see **Figure 1** for the map location). Almost three years later, Robert DeCourcy Ward, who at the time was serving as an assistant to Davis, published a paper in *Science* [6] in which he described some additional drainage system evidence on the 1890 Doylestown topographic map which he and Davis had observed and discussed.

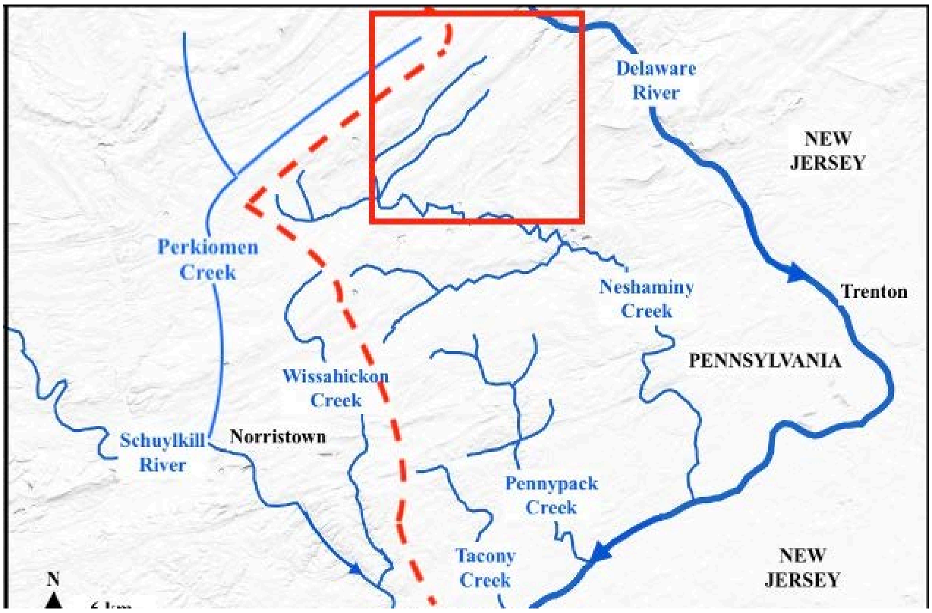

Figure 1. Sketch map showing the 1890 Doylestown topographic map location (area within red rectangle) in relation to Philadelphia, Pennsylvania and Trenton, New Jersey and to major southeast Pennsylvania drainage routes. The red dashed line shows the approximate Delaware-Schuylkill River drainage divide location.

These two *Science* papers provide a rare opportunity for present-day investigators to learn what Davis saw and also what Davis chose not to comment on when observing a new topographic map.

The goal of this paper is to compare the 1890 Doylestown topographic map drainage system features that Davis and Robert DeCourcy Ward observed and commented on with what several subsequent investigators observed and commented on to determine whether Davis (and Ward) saw and commented on everything the map showed or whether Davis (and Ward) knowingly or unknowingly failed to discuss map evidence that did not fit with what was the previously developed Davis erosion cycle hypothesis.

2. The Davis 1889 Paper about the 1890 Doylestown Topographic Map

A Davis *Science* paper [5] titled "A River-Pirate" describing 1890 Doylestown, PA topographic map drainage system evidence was published in early 1889 suggesting Davis had received an advance copy of the map sometime in 1888. The Quakertown, Pennsylvania topographic map of the area immediately to the west of the Doylestown map area was published in 1888 and should have been available to Davis. The Lambertville, NJ topographic map of the area to the east and the Easton, PA topographic map of the region to the north were both officially released in 1890 and Davis may or may not have had access to advance copies of those maps. The Germantown topographic map of the region immediately to the south of the Doylestown map was not officially released until 1893 and an advance copy was probably not available when Davis wrote his 1889 *Science* article. Davis in late 1888, when he wrote the "River-Pirate" paper, was probably in the position to place the Quakertown and Doylestown maps adjacent to each other to see a topographic map of a larger region and may have been able to expand that region by adding advance copies of the Lambertville and Easton topographic maps, although in his paper he says nothing about the adjacent topographic maps or any of the evidence seen on those maps.

The 1890 Doylestown map, which is seen in full in **Figure 2** and selected sections of which are seen in more detail in **Figures 3-6**, is available at the USGS topoView website. In the map's northeast quadrant, the Delaware River flows in a south- and southeast-oriented valley with northeast-oriented barbed tributaries joining it from the west and southwest-oriented tributaries joining it from the east. Southeast-oriented Tinicum Creek flows into the map's north center area from the north before turning in a northeast direction to join the Delaware River as a barbed tributary just south of the map's northern edge. South of where Tinicum Creek makes its direction change is Tohickon Creek, which flows in a northeast direction into the map's western edge area before turning in a southeast direction to cross the map's northern half to reach the Delaware River. Tohickon Creek has several northeast-oriented tributaries which drain from the asymmetric Tohickon-East Branch Perkiomen Creek drainage divide (which is

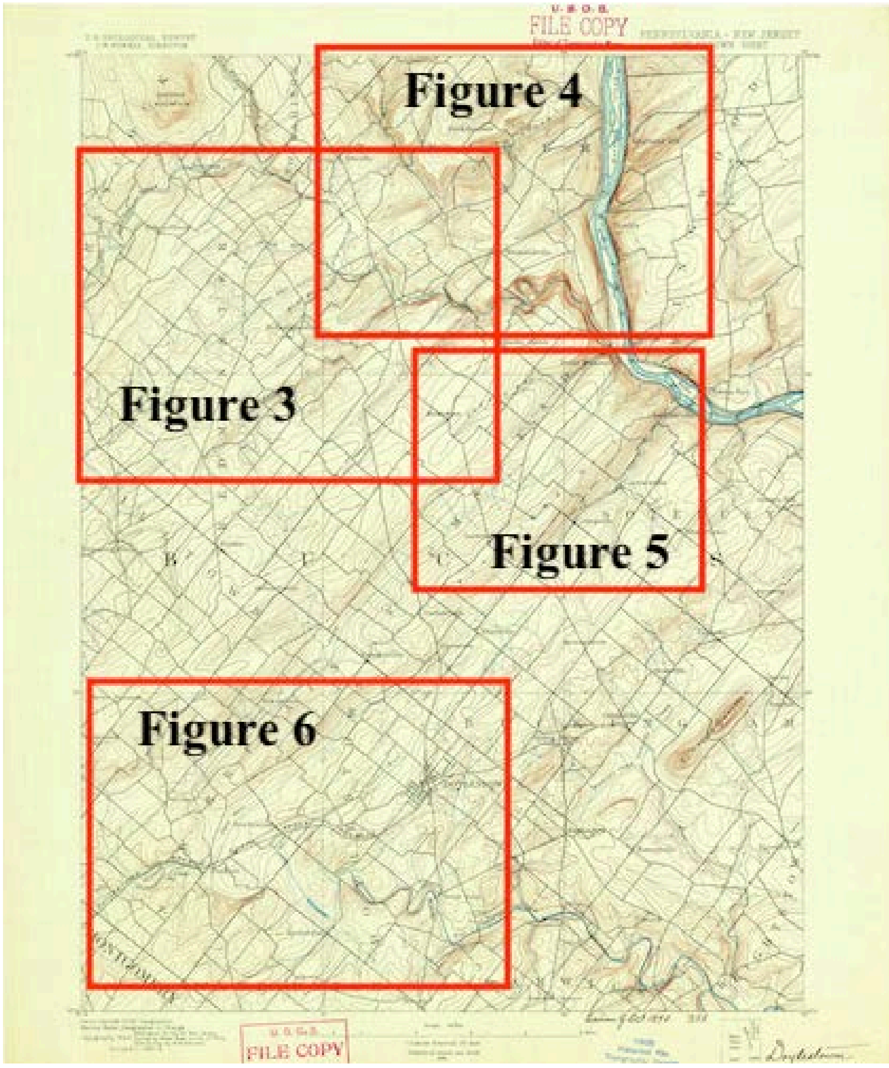

Figure 2. 1890 Doylestown topographic map from the United States Geologic Survey (USGS) topoView website showing the locations of the detailed topographic map figures used in this paper. The contour interval is 20 feet (6 meters).

also the Delaware-Schuylkill River drainage divide) and from the Tohickon-North Branch Neshaminy Creek drainage divide while other short northeast-oriented streams flow from the Delaware River-North Branch Neshaminy Creek drainage divide further to the east. The map also shows the southwest-oriented North Branch Neshaminy Creek joining the east-oriented West Branch Neshaminy Creek as a barbed tributary to form a meandering east-oriented Neshaminy Creek segment which is then joined by several additional southwest-oriented (barbed) tributaries including Pine Run and Cooks Run. Northeast-southwest oriented ridges which become more prominent in a southwest direction separate the various southwest- and northeast-oriented secondary drainage routes and northeast-southwest oriented dry valleys cross the asymmetric Tohickon-East Branch Perkiomen Creek, Tohickon-North Branch Neshaminy Creek, and the Delaware River-Neshaminy Creek drainage divides.

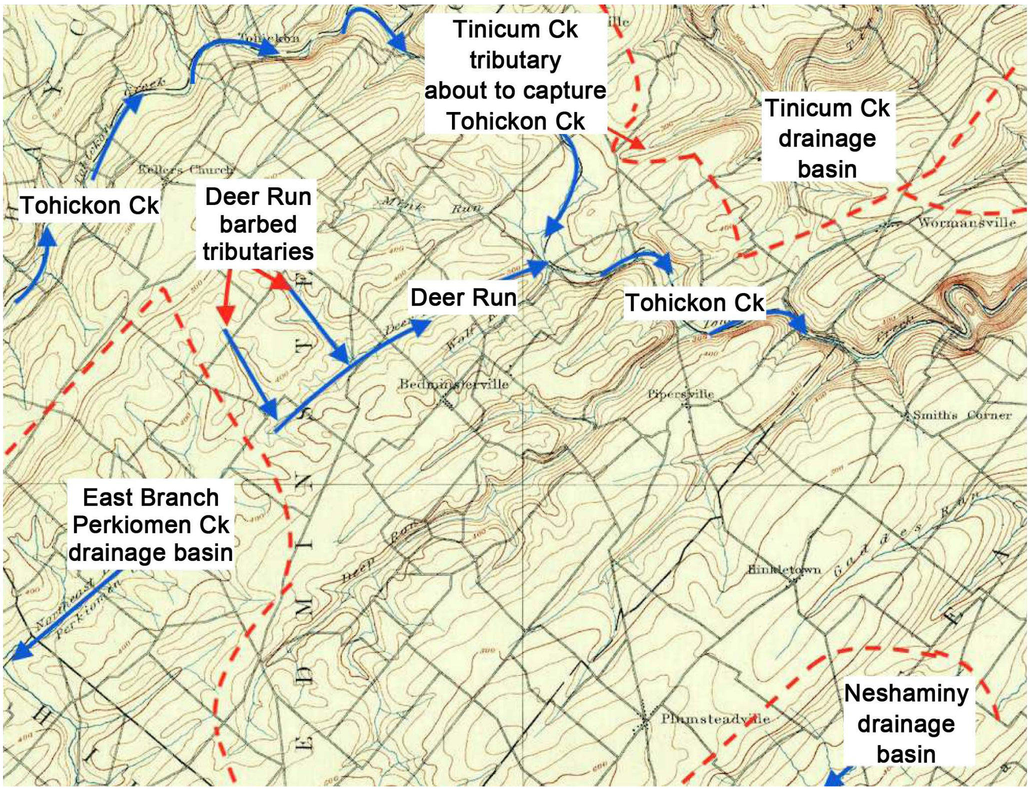

Figure 3. Modified section of the 1890 Doylestown topographic map from the USGS topoView website showing major asymmetric drainage divides (dashed red lines), the Deer Run-East Branch Perkiomen Creek area and Deer Run barbed tributaries discussed by Davis [5] and the Tinicum Creek tributary that Ward [6] said will capture Tohickon Creek.

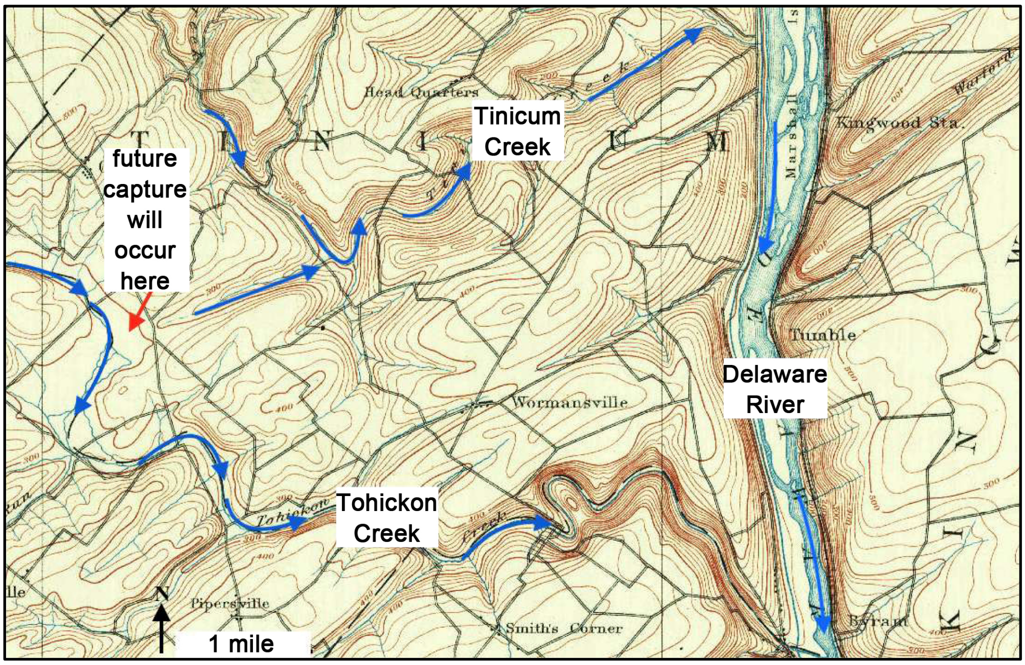

Figure 4. Modified section of the 1890 Doylestown topographic map from the USGS topoView website showing where Tinicum and Tohickon Creeks join the Delaware River and where Ward projected a Tinicum Creek tributary will capture Tohickon Creek.

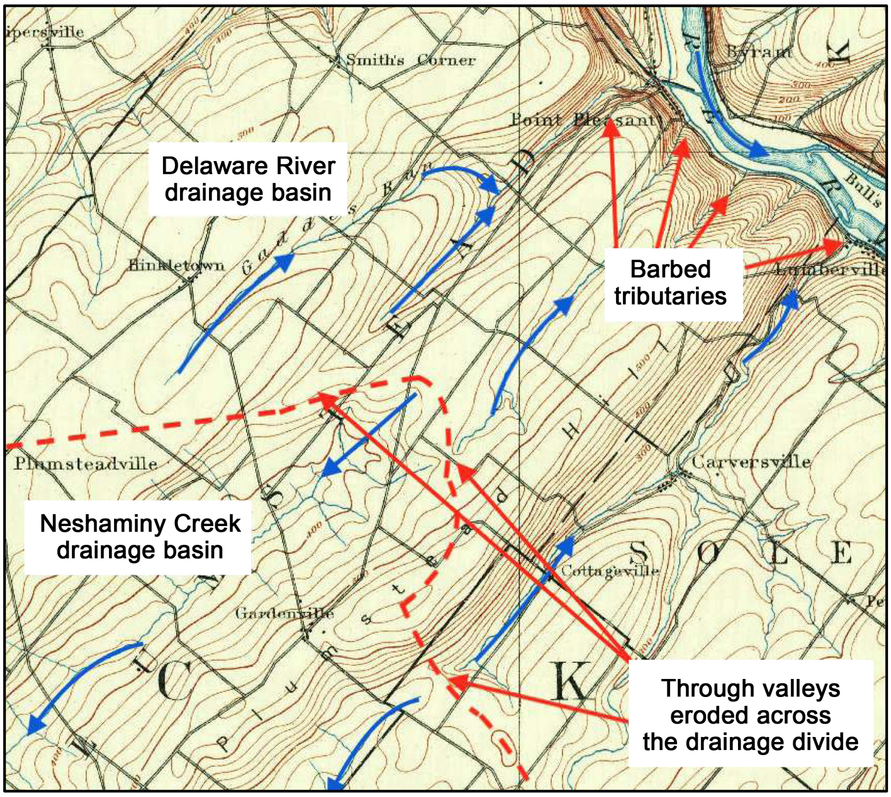

Figure 5. Modified section of the 1890 Doylestown topographic map from the USGS topoView website showing valleys crossing the asymmetric Delaware River-Neshaminy Creek drainage divide (red dashed line) which link northeast-oriented Delaware River barbed tributary valleys with southwest-oriented Neshaminy Creek tributary valleys.

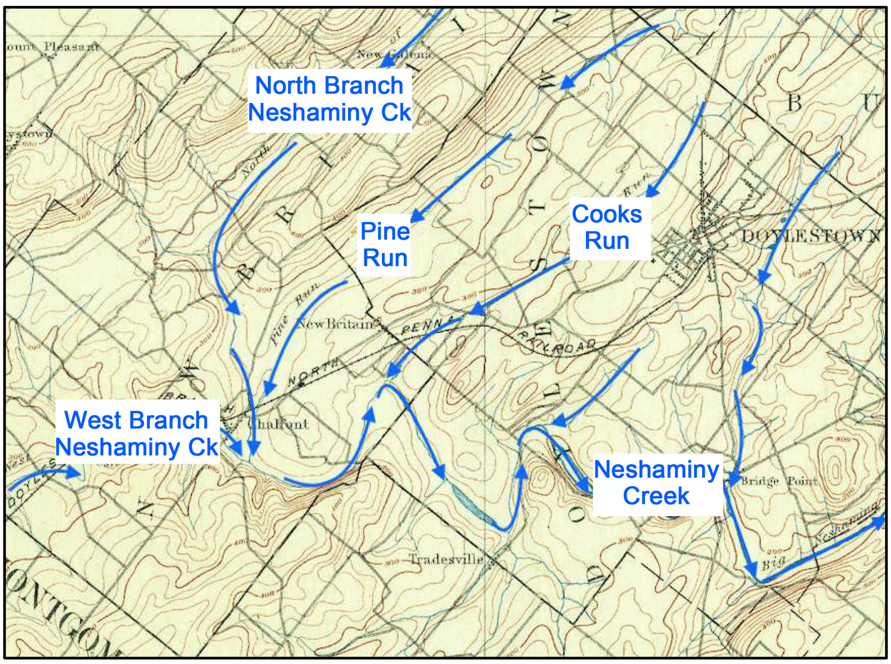

Figure 6. Modified section of the 1890 Doylestown topographic map from the USGS topoView website showing southwest-oriented barbed tributaries flowing to the meandering east-oriented Neshaminy Creek.

Davis in his 1889 *Science* paper (p. 108) notes the map was originally surveyed by the Philadelphia Water Department and published by the Geological Survey of Pennsylvania and he next provides an introduction which describes the general map area as follows: "The country hereabout was in ancient times a surface of faint relief, at a lower stand than now, traversed by idle streams; but, in consequence of elevation to a greater altitude, the streams have revived their lost activities, and set to work to sink their channels and open out their valleys in the process of reducing the land to its proper level again, even with the sea; for land finds its level, like water, but more time is required before the level is assumed. The streams that drained the country when it was elevated adopted such faint inequalities as they then found for their first settlement, and have since been engaged in perfecting their courses as best they could, cleaning them out, deepening them, and adapting them to the best transportation of land-waste. In the processes of adjustment thus called forth, every stream struggling for its own existence, it sometimes has happened that a stream with steep head waters has seized drainage area from the head waters of an adjacent drainage basin; because other things being equal, the waste of the surface is fastest on the steepest slopes, and hence the steeper streams have gnawed more quickly into the land-mass than the flatter ones, and the divide between a pair of competing streams has consequently been pushed in the direction of the fainter descent."

Davis continues by describing map evidence in **Figure 3** area that caught his attention. He first noted Deer Run, which is a northeast-oriented Tohickon Creek tributary, flows on the same line as southwest-oriented East Branch Perkiomen Creek and has a much steeper gradient than the East Branch Perkiomen Creek. He proceeds by saying "it appears that the two streams flowing on the same line but in opposite directions, both follow the same bed of shaly sandstone in the rock formation (triassic, *sic*) that underlies the district; there is, therefore no inequality of structure on the two sides of the divide to determine a difference in the rate of headward weathering. In so short a distance as a mile or two, it cannot be thought that there is any difference in rainfall or other climatic element of significance; and if exposure to sunshine be a factor of value in aiding the denudation of a surface by strengthening the diurnal variations of temperature in the soil and increasing the number of winter thaws, this advantage would be with the Perkiomen." Davis then notes side streams flowing to the East Branch Perkiomen Creek headwaters were captured as the Deer Run headwaters eroded headward in a southwest direction and adds: "Now, it is noticeable that all tributaries thus acquired [by Deer Run] would enter the head of its main channel in a back-handed manner, like the barbs at the point of an arrow, indicating by this abnormal arrangement their early training in accordance with the habits of the Perkiomen family, where they were brought up." Davis next points out that Deer Run at its head now has three such barbed tributaries, "and thus it [Deer Run] must stand convicted not only of piratical intentions for the future, but of piratical practice in the past."

Following his discussion of how Deer Run is capturing East Branch Perkiomen Creek headwaters Davis briefly mentions that other investigators have noted similar capture situations in the western territories [of the United States] and in Europe and proceeds by saying, "It is only in false allegory that we can blame Deer Run for having taken what once belonged to the Perkiomen; and instead of calling of it a piratical act, which at best is but an *ad captandum* term, it should better be regarded as a sharing of another's burden of labor, and a willing assumption by the more active stream of its fair proportion of the work to be done by the whole river system to which it belongs" At the beginning of his concluding paragraph Davis says: "When the district was lifted from its former lowly estate, the streams found a new task set before them. They at once set to work at it with the best disposition in the world. But, in their immaturity, they accepted without question such guidance as the faint relief of the surface afforded, only to discover later on that the primitive division of territory was unadvisable as a permanency, because it was not adapted to the best accomplishment of the work assigned to them." Davis concluded his paper by saying "It is undoubtedly true that Deer Run has taken something of what once belonged to the Perkiomen, but it was not seriously that the name of river-pirate was given to it."

Deer Run barbed tributaries are obscure features on the 1890 Doylestown topographic map and Davis must have spent considerable time studying the map to locate them. The map includes six much more obvious northeast-oriented barbed tributaries flowing to the south-oriented Delaware River, four much more obvious southwest-oriented barbed tributaries flowing to east-oriented Neshaminy Creek, and a Tohickon Creek change from a northeast to a southeast direction-none of which Davis mentioned. When studying the map Davis must have noted the northeast-southwest orientation of most of the secondary drainage routes and of the northeast-southwest oriented ridges located between the northeast-southwest oriented secondary drainage route valleys and the fact that northeast-southwest oriented dry valleys now cross the Delaware River-East Branch Perkiomen Creek and the Delaware River-Neshaminy Creek drainage divides, yet again he says nothing about any of these much more obvious features. Davis was aware that the drainage divide between Deer Run and the East Branch of Perkiomen Creek is an asymmetric drainage divide, although he does not use the term nor does he mention that Perkiomen Creek is a Schuylkill River tributary which means the Deer Run-East Branch Perkiomen Creek drainage divide is also the asymmetric Delaware-Schuylkill River drainage divide which to the east of Deer Run turns in a southwest direction to follow the North Branch Neshaminy-East Branch Perkiomen Creek drainage divide and to west of Deer Run turns to follow the Tohickon-East Branch Perkiomen Creek drainage divide also in a southwest direction.

To find the rather obscure Deer Run barbed tributaries on his advance copy of the 1890 Doylestown topographic map Davis probably was looking for map evidence that would support and not challenge his previously published erosion cycle ideas. According to Chorley *et al.* [1] Davis first presented the erosion cycle concept in 1884 at the American Association for the Advancement of Science

1884 annual meeting with that presentation being published the following year [7]. Davis further refined his erosion cycle ideas in his much longer "Rivers and Valleys of Pennsylvania" paper [4] which may have been in preparation when the advance copy of the Doylestown topographic map was received. The 1890 Doylestown topographic map gave Davis the unique opportunity to interpret what at that time was much more accurate and detailed drainage system and erosional landform evidence than anything that had been previously available, yet Davis did not take advantage of that opportunity and consciously or subconsciously must have looked for evidence that would support his erosion cycle hypothesis or at least that could be explained in ways that would not challenge his erosion cycle ideas. Using terminology described by T. C. Chamberlain [8] Davis must have interpreted the evidence on his advance copy of the Doylestown topographic map with a ruling theory in his mind and apparently was not willing to let the map evidence lead him towards the exploration of alternate hypotheses.

Had Davis been willing to let the newly available and well-mapped Doylestown topographic map evidence lead his investigation (rather than trying to fit the map evidence into his erosion cycle model) he would have seen many more barbed tributaries than just the rather obscure Deer Run barbed tributaries that he does describe. The knowledge and reasoning applied when he explained Deer Run barbed tributaries should have enabled Davis to recognize that multiple southwest-oriented barbed tributaries flow to east-oriented Neshaminy Creek and are evidence the east-oriented Neshaminy Creek valley (like the Deer Run valley) eroded headward in a west direction to capture multiple southwest-oriented streams. That recognition should have caused Davis to use map evidence to follow the southwest-oriented Neshaminy Creek tributary valleys headward so as to observe dry valleys crossing the Delaware River-Neshaminy Creek drainage divide and linking the southwest-oriented Neshaminy Creek tributary valleys with shorter northeast-oriented Delaware River barbed tributary valleys. Further, Davis should have noted in the small New Jersey region shown on the map that drainage is predominantly in a southwest direction. From this map information Davis should have used his deductive powers to determine that east-oriented Neshaminy Creek valley headward erosion captured multiple southwest-oriented streams and subsequent Delaware River valley headward erosion beheaded and reversed the northeast ends of those southwest-oriented streams to create the Delaware River-Neshaminy Creek drainage divide and short northeast-oriented Delaware River barbed tributaries. It is possible Davis saw what the map evidence says, but in his mind, he rejected the map information because it did not support his erosion cycle model.

3. The 1892 Ward Paper about the 1890 Doylestown Topographic Map

Robert DeCourcy Ward graduated from Harvard College in 1889 and one year later became an assistant to W. M. Davis before later becoming a Harvard College instructor in meteorology. In early 1892 Ward published an article in *Science* [6] titled "Another River-Pirate" with the following opening paragraph (p. 7): "In *Science*, vol. xiii, p. 108, under the title of 'A River-Pirate' Professor W. M. Davis described a recent case of river capture in southeastern Pennsylvania, brought about by the backward gnawing of one stream into the drainage area of another. In looking over with him the Doylestown sheet of the Pennsylvania Topographic Survey there were found numerous cases of similar capture, either already accomplished or about to take place, and at his suggestion the writer recently made a visit to the district in question, in the hope of being able to add something more to the history of the rivers of Pennsylvania."

Following this rather promising introduction Ward proceeds to describe his observations of the region which include noting the bedrock consists of hard and soft layers of Mesozoic sandstones and shales gently dipping in a northwest direction and "the surface of the country has been reduced by erosion of at least 1000 feet since the time when the beds were laid down." Then without describing any map evidence Ward (p. 8) says "The evidence from New Jersey and Pennsylvania goes to show that after the tilting of the sandstones there came an extensive period of denudation, which resulted in the production of a more or less prefect plain, the so-called Cretaceous base-level.… Following this came an elevation, giving the streams renewed energy, and resulting in the etching out of the softer rocks down to another peneplain, the Tertiary base-level. Finally, another elevation gave the streams another period of activity, and it is in this cycle that we find them today. The larger streams, like the Delaware, have already sunk their channels well into the Tertiary peneplain. It is with some of the smaller ones that we have now to deal."

On the 1890 Doylestown topographic map Tinicum Creek flows in a south-southeast direction before abruptly turning in a northeast direction to flow toward the south-oriented Delaware River as a barbed tributary, but just before reaching the Delaware River valley it turns in a southeast direction (see **Figure 4**). Tohickon Creek flows in a northeast direction (see **Figure 3**) from the Doylestown map western edge before turning in a southeast direction to flow into **Figure 4** area and near the Delaware Riverit turns in a south-southeast direction. Ward provides a sketch map showing the Tinicum and Tohickon Creek routes near the Delaware River and said "On examining the [Doylestown topographic] map, however, we find that many of them [smaller streams] show a tendency to deflect downstream as they run toward the Delaware." Yet, Ward fails to mention that with the exception of Tinicum and Tohickon Creeks almost all smaller streams shown on the Doylestown topographic map and which flow to the Delaware River (all of which are much shorter than Tinicum and Tohickon Creeks) do not show similar southward deflections and many flow in northeast directions to join the Delaware River as barbed tributaries.

The Ward paper (p. 8) next discussed the flood-plaining process and suggested Delaware River flood-plaining gave "side streams a superimposed course on a Tertiary peneplain, and as they cut down through the cover, …flowing across the outcropping edges of the underlying strata of sandstone and shale… It can be readily seen that if a side stream works back along the strike of one of these beds, it has, especially if the bed is soft, a much easier course than a stream which has to cross the edges of many hard and soft strata on its way to join the master." After describing the setting Ward observed that a Tinicum Creek segment flows along the strike of the strata while the nearby southeast-oriented Tohickon Creek segment flows across the strike of the strata which gives Tinicum Creek an advantage over Tohickon Creek and that a northeast-oriented Tinicum Creek tributary appears to be eroding headward across the Tinicum-Tohickon Creek drainage divide. Ward who may have visited the probable capture area also calculated distances to the Delaware River along the two different routes and concluded the Tinicum Creek tributary will succeed in capturing Tohickon Creek because it has a shorter route and a steeper gradient.

To conclude his paper Ward describes how headward erosion of the Tinicum Creek valley captured southeast-oriented Beaver Creek which prior to being captured had flowed in an abandoned valley that the map shows crossing the Tinicum-Tohickon Creek drainage divide. Ward's observations related to the Beaver Creek capture and to his predicted Tinicum Creek capture of Tohickon Creek demonstrate a good understanding of the stream capture process and a careful study of the pertinent map evidence and probably also of the field evidence. However, the Ward paper [6] only discusses map evidence located in the Tinicum Creek drainage basin area seen on the 1890 Doylestown topographic map and like the earlier 1889 Davis article [5] makes no mention of the other stream capture evidence in other regions shown on the Doylestown map. Ward like Davis should have been able to have applied the same type reasoning to argue that an east-oriented Neshaminy Creek valley had zig-zagged its way headward across alternating hard and soft strata to capture what the map shows as southwest-oriented Neshaminy Creek tributaries which include Cook's Run, Pine Run, and the North Branch Neshaminy Creek. And the same type of reasoning could have been used to argue that the Delaware River valley had eroded headward across multiple southwest-oriented streams. It is possible that Ward wanted to interpret more of the stream capture evidence shown on the map, but was unable to do so in a way that did not challenge the Davis erosion cycle model or that Davis himself would permit.

The Davis and Ward papers [5] [6] combined describe only a small fraction of the Doylestown map drainage system evidence, yet demonstrate a good understanding of that map evidence which suggests that much more of the map evidence could have been interpreted. Probably the most important not-mentioned map evidence is located in the Neshaminy Creek drainage basin and the Delaware River valley areas and is also related to the map's major drainage divides which are determinable from the map evidence. Reasons why Davis and Ward chose not to comment on the majority of the map's drainage system and erosional landform evidence are unknown. However, it is possible Davis (and/or Ward) could not find ways to interpret the not-mentioned evidence that would be supportive of hypotheses which Davis presented in his "Rivers and Valleys of Pennsylvania" paper [4]. Those hypotheses suggested Pennsylvania river valleys during Tertiary time eroded downward from a possible Cretaceous sediment cover and through flood-plaining produced peneplains on which smaller streams developed. Had Davis (or Ward) trusted what the 1890 Doylestown topographic map evidence said and used that map evidence to disprove what at that time was the still developing Davis erosion cycle model it is possible today's unrecognized geology paradigm problem would not exist.

4. Subsequent Interpretations of Doylestown Topographic Map Drainage System Evidence

For unknown reasons Davis when interpreting the 1890 Doylestown topographic map evidence apparently did not trust what the well-mapped topographic map drainage system and erosional landform evidence told him and as a result, said nothing about most of the map's drainage system and erosional landform evidence. Davis does refer to his "River-Pirate" paper in his much longer "Rivers and Valleys of Pennsylvania" paper (which was published later in the 1889 year), so he must have studied the 1890 Doylestown topographic map advance copy prior to submitting a final copy of what became his authoritative work on Pennsylvania drainage history and which according to Davis [9] in a comment written much later in his life "suggested the Appalachians had, after their folding, experienced a succession of erosional reductions to low relief, during which a progressive modification of an initially consequent drainage system had led to the gradual evolution of the adjusted drainage system which, with many long subsequent and short obsequent and resequent members is seen in the rivers and valleys of Pennsylvania today.

The Davis "Rivers and Valleys of Pennsylvania" paper [4] became the authoritative work when conducting research related to Pennsylvania and adjacent state drainage system and erosional history. Geologists such as Bascom *et al.* [10] and Barrell [11] used Davis ideas as models when describing drainage system and erosional histories of areas they mapped. For example, Bascom *et al.* [12], who mapped the Doylestown topographic map area geology, state in reference to the Schuylkill-Delaware River drainage divide (which crosses the Doylestown topographic map area where Davis interpreted topographic map evidence to suggest that Deer Run in the Delaware River drainage basin had captured drainage area from the East Branch Perkiomen Creek in the Schuylkill River drainage basin): "The divide is very closely contested by the eastern tributaries of the Schuylkill and the western tributaries of the Delaware. The Delaware has apparently been rejuvenated by an inconsiderable uplift which did not affect the Schuylkill, to the south, and which has given the advantage of gradient to the tributaries of the Delaware working under conditions otherwise common to the two basins. In many places only a small fraction of a mile separates rival streams, and in other places the tributaries of the two river systems interfinger." However, Bascom *et al.* were primarily concerned with geologic mapping and they did not use the Doylestown topographic map evidence to interpret the regional drainage history.

Not satisfied with the Davis proposed model Douglas W. Johnson [13] tried to improve upon the Davis model (without mentioning any the use of topographic map drainage system evidence) by proposing a marine incursion had deposited Cretaceous sediments which buried the Appalachian Mountain region (Davis and other geologists had proposed a more limited similar concept). Johnson then suggested rivers and streams developed their courses on his hypothesized Cretaceous sedimentary cover and as the Cretaceous sediments were removed the rivers and streams maintained their courses as they cut down into underlying geologic structures. Johnson was convinced this improvement explained Appalachian Mountain region water and wind gaps, but no evidence of the Cretaceous sedimentary cover could be found and some years later Strahler [14] concluded that while the Johnson hypothesis could not be disproved no supporting evidence could be found.

Doylestown area topographic map drainage system evidence was used in at least two other 20th-century studies, neither of which used topographic map evidence to determine the regional drainage history. In a paper which introduced the stream order concept Horton [15] used data from many different drainage basins and included a graph comparing Neshaminy, Perkiomen, and Tohickon Creek drainage basin stream length with stream order and a map of those three drainage basins which for unknown reasons shows the entire East Branch Perkiomen Creek drainage basin as a blank space. Mock [16] used topographic map evidence to determine Tohickon Creek had a moderate to well-developed trellis drainage pattern that was best developed "where the [Triassic] Lockatong and Brunswick lithofacies interfinger, such as in the eastern part of the Tohickon drainage basin. Streams have preferentially developed in the direction of regional strike on the less resistant shales of the Brunswick lithofacies." Mock's study, which makes no mention of asymmetric drainage divides, barbed tributaries, dry valleys crossing drainage divides, or southwest-oriented flow concluded "that even a stream network with strong geologic controls...shows only subtle departures from topological randomness."

Clausen [17] used the 1890 Doylestown topographic map drainage system evidence and map interpretation techniques similar to those that Davis and Ward had used to reconstruct Doylestown topographic map area drainage history. Everywhere on the map northeast-southwest oriented dry valleys were observed to cross all major drainage divides and link northeast-oriented valleys with southwest-oriented valleys. **Figure 5** illustrates some northeast-southwest oriented dry valleys crossing the Delaware River-Neshaminy Creek drainage divide and linking short northeast-oriented Delaware River barbed tributary valleys with longer southwest-oriented Neshaminy Creek tributary valleys and **Figure 3** illustrates the dry valley crossing the Deer Creek-East Branch Perkiomen Creek drainage divide that Davis must have observed. Clausen interpreted the northeast-southwest oriented dry valleys to be evidence the Delaware River and Tohickon Creek valleys had eroded headward across southwest-oriented streams probably flowing in diverging and converging channels and the northeast-oriented Delaware River tributaries originated when headward erosion of the deep Delaware River valley beheaded and reversed southwest-oriented streams that had been flowing into the Neshaminy Creek drainage basin and the northeast-oriented Deer Run valley originated when Tohickon Creek valley headward erosion beheaded and reversed a southwest-oriented stream that had been flowing into the present-day East Branch Perkiomen Creek drainage basin.

Clausen noted the southwest-oriented Neshaminy Creek tributaries drain much of the Doylestown topographic map southern half (neither Davis or Ward commented on any Neshaminy Creek drainage basin evidence) and join a meandering east-oriented Neshaminy Creek as barbed tributaries, which suggested headward erosion of the Neshaminy Creek valley (probably zig-zagging as it eroded headward in a west direction across the tilted edges of alternating sandstone and shale strata) had captured closely-spaced streams of southwest-oriented water. Recognizing that the Doylestown topographic map evidence showed how the headward erosion of deep valleys across what had probably been massive and prolonged southwest-oriented floods (perhaps from a continental ice sheet) enabled Clausen to explain how the asymmetric Delaware River-Neshaminy Creek, Tohickon Creek-Perkiomen Creek, and Perkiomen Creek-Neshaminy Creek drainage divides and most of the barbed tributaries seen on the map had originated.

5. Discussion

Davis must have carefully studied his advance copy of the 1890 Doylestown topographic map, yet for unknown reasons his 1889 *Science* paper [5] only discusses limited evidence found in just one relatively small region of the map. Ward in his 1892 *Science* paper [6] notes that he and Davis had observed and discussed evidence for numerous past and future stream capture events that the Doylestown topographic map evidence showed, but again for unknown reasons he only discusses evidence found in one relatively small region of the map (that overlapped to some extent with the region Davis had previously discussed). The 1890 Doylestown topographic map as Ward strongly implies shows evidence for many more stream capture events than the few discussed in the Davis and Ward papers. It is puzzling why Ward chose to limit his comments to the Tinicum Creek area and to omit all mention of the Neshaminy Creek capture evidence, especially since Ward claims to have visited the Doylestown topographic map area. Ward, who at the time was an assistant working under the supervision of Professor W. M. Davis, may have wanted to discuss more of the Doylestown topographic map stream capture evidence, but felt that by doing so he might be questioning Davis interpretations of the map evidence.

Both Davis in his 1889 paper and Ward in his 1892 paper assume the Delaware River and its tributary streams were eroding down into an uplifted erosion surface and argued that streams with steeper gradients had captured or were about to capture other streams. While the evidence they discussed in their 1889 and 1892 papers did not challenge the Davis erosion cycle interpretation, trying to explain how Neshaminy Creek captured southwest-oriented streams (as seen in this paper's **Figure 6**) or that would have explained the northeast-oriented Delaware River barbed tributaries (seen in this paper's **Figure 5**) probably would have challenged the Davis interpretations. In any case Davis said nothing about evidence on the newly available 1890 Doylestown topographic map that did not fit his interpretations even though most of the Doylestown topographic drainage system and erosional landform evidence did not support the regional drainage history interpretations that he presented in his subsequently published 1889 "Rivers and Valleys of Pennsylvania" paper [4] and in his 1890 "Rivers of Northern New Jersey" paper [18], both of which were submitted for publication after his 1889 "River-Pirate" paper had been published.

By receiving an advance copy of the 1890 Doylestown topographic map (and probably copies of other newly available topographic maps) Davis had an opportunity to use his map interpretation skills to interpret newly available topographic map drainage system and erosional landform evidence to test what at that time were his still developing regional erosion history interpretations. Davis certainly knew enough that he could have used the 1890 Doylestown topographic map evidence to notice that headward erosion of the east-oriented Neshaminy Creek valley had captured multiple and closely-spaced southwest-oriented streams and that headward erosion of the deeper Delaware River valley had probably beheaded and reversed the northeast ends of those closely-spaced southwest-oriented streams to form what are now northeast-oriented Delaware River tributaries.

Davis and Ward in their published papers also demonstrate sufficient knowledge of stream capture events that they should have been able to use the map evidence to reconstruct a drainage system history for the entire Doylestown topographic map area. That drainage history should have begun with closely-spaced southwest-oriented streams eroding southwest-oriented valleys along the strike of easier to erode strata with headward erosion of the east-oriented Neshaminy Creek valley next capturing the closely-spaced southwest-oriented streams. Headward erosion of the Delaware River valley and its southeast-oriented Tohickon Creek valley would have next beheaded and reversed the northeast ends of the closely-spaced southwest-oriented streams while headward erosion of the south-oriented Delaware River valley next beheaded and reversed the northeast ends of southwest-oriented streams which were then flowing to the newly eroded Tohickon Creek valley so as to create northeast-oriented barbed tributaries including the northeast-oriented Tinicum Creek segment which captured a southeast-oriented stream which had probably been eroding headward (in the region located to the north of the Doylestown map) across what might have been additional closely-spaced southwest-oriented streams.

Davis might have had a difficult time conceiving of a water source for the closely-spaced southwest-oriented streams that must have eroded the Doylestown topographic map surface area and that would have also been large enough to enable the Neshaminy Creek and the deeper Delaware River valleys to erode headward across the region, although he was definitely aware of evidence for a nearby continental ice sheet. In 1883 Davis had published a short paper in *Science* describing northeastern Pennsylvania continental ice sheet evidence [19] in which he describes the presence of glacial drift in the Delaware and Lehigh River valleys (in areas which are located upstream in the Delaware River drainage basin from the Doylestown topographic map area). Further, Chorley *et al.* ([1], pp. 139-141) describe how in 1884 Davis began part time work with the Glacial Division of the United States Geological Survey and include the text of a personal letter to T. C. Chamberlain (who was then directing the Glacial Division) in which Davis describes several upstate New York glacial features which included a comment about two gorges in the Mohawk Valley area in which Davis says "I conclude therefore that the gorges were begun as subglacial channels, or that they are survivals of streams on the surface of the melting and stagnant ice sheet." Davis was aware of the continental ice sheet approximate margin location which was just a short distance to the north of the Doylestown topographic map area and that the ice sheet at times must have produced significant melt water flow.

6. Conclusions

Davis played a key role in establishing a scientific interest in the development of erosional landforms and was an influential teacher and a prolific writer who according to Chorley *et al.* [1] published more than 500 substantial scientific papers and books. He also worked at a time when topographic maps were just beginning to become available. In spite of having access to an advance copy of the 1890 Doylestown, Pennsylvania topographic map and of having a good knowledge of how to recognize (on the maps) stream capture evidence and of having published about nearby continental ice sheet evidence Davis in his 1889 "River-Pirate" paper did not use most of the map's drainage system evidence to reconstruct a drainage history for the Doylestown topographic map area, but instead interpreted most of the map's landscape features from the perspective of his previously developed erosion cycle model and described just one of many stream capture events the map evidence shows. In the subsequent 1892 "Another River-Pirate" paper Ward, who had discussed the Doylestown topographic map evidence with Davis and who had visited the area, also interpreted the regional landscape from the Davis erosion cycle model perspective and described one different impending stream capture event and again did not use the topographic map drainage system evidence to reconstruct a drainage history for the larger map area.

The advance copy of the 1890 Doylestown topographic map that Davis probably received at some time during the 1888 calendar year provided an opportunity for Davis to demonstrate how the newly available topographic map drainage system and erosional landform evidence could be used to reconstruct a drainage history for the area shown on a topographic map. Instead of doing so Davis interpreted the topographic map evidence from the perspective of his previously developed erosion cycle model while describing just one of the many stream capture events the map evidence shows and then proceeded to write (or finish writing) and submit for publication his lengthy "Rivers and Valleys of Pennsylvania" paper. Near the end of his 1889 "Rivers and Valleys of Pennsylvania" paper, which was written before topographic maps of most Pennsylvania regions were available and which describes a very complex Pennsylvania drainage history, Davis notes "It follows that any one river as it now exists is of so complicated an origin that its development cannot become a matter of general study and must unhappily remain only a subject for special investigation for some time to come." And he continues "The history of the Susquehanna, the Juniata, or the Schuylkill is too involved with complex changes, if not enshrouded in mystery, to become intelligible to any but advanced students." And with those actions and words, Davis pointed the geology research community toward a future in which most of the now available topographic map drainage system and erosional landform evidence has yet to be explained and to a future where the geology research community still does not know what most of the well-mapped topographic map drainage system and erosional landform evidence is silently waiting to say.

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Conflicts of Interest

The author declares no conflicts of interest regarding this paper.

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