THE ANALYSIS OF LAND FORMS

WALTHER PENCK ON THE TOPOGRAPHIC CYCLE

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BETWEEN the crust of the earth and the forces of erosion there is an unequal interplay that has brought into being land forms of extremest variety. In the primitive view of earlier generations these were looked upon as the products of great convulsions of nature, but De Saussure in the first instance, and Hutton soon thereafter, began to explain them on the principle of uniformitarianism—that is that they are the product of the agencies that we see at work about us today. The discovery and application of this simple fact, first in the Swiss Alps and then in Scotland, marked what might be called the dawn of modern physiographic research. Even before this the old dread of mountains had generally disappeared, and in its place there arose an appreciation of scenery; but even with the advance of scientific interest the descriptions of the forms of the land were almost universally couched in picturesque or romantic terms. Physiography as the naturalistic basis of human affairs was not taken into consideration. "The still small voice of the level twilight on purple hills"—such was the romantic fashion in describing scenery in the vague phraseology of color and form.

American Studies and the Topographic Cycle

The analysis of land forms had no broadly scientific basis until "the refreshing juice of explanation" began to flow. It reached its climax in America in a period marked by four great names: Powell, Gilbert, Dutton, and Davis. While the principle of evolution had been applied to the crust of the earth through the work of De Saussure and Hutton half a century before the theory of biological evolution was launched by Darwin, yet it was a feebly developing idea at best until a period of robust manhood was expressed in the writings of these four men. Inspired by the scope and meaning of the great events so clearly recorded in the enormous sedimentary deposits of the Southwest and especially in the Grand Canyon region, there was begun a group of studies that may fairly be said to have become the foundation of modern geology and physiography. In this development Powell's work was noteworthy for the forceful ideas it conveyed of base-leveled land surfaces; Gilbert and Dutton excelled in their analyses of individual features; Davis systematized the sequence of forms through

an ideal cycle and provided a terminology. As early as 1885 Davis had gone far beyond the theoretical stages and made specific applications of his ideas in Montana[1] and later in much greater detail in the East.[2]

Before Davis had developed and extended the idea of the topographic cycle there had been no approach to full technical equipment for the exact description of landscapes. It was botany with the systematic terminology of the parts of plants left out. The widest acceptance was immediately given to three terms—youth, maturity, and old age—which he adapted from an earlier and somewhat different use of the terms young and old already employed by Chamberlin. Quick acceptance followed, partly because these terms seemed to be adapted to the most divergent forms made upon many types of rock almost everywhere in the world, partly because they fitted the evolutionary mode of thought that had pervaded the whole of science. It would surprise the non-physiographic reader to know how widely the fundamental ideas of physiography have spread. The accepted technique of description came to include a three-part analysis which expresses the evolutionary idea in the following terms: (1) What was this mountain (for example) before it was uplifted? (2) What agencies of erosion have acted upon it since and with what intensity and observable results? (3) What stage has it reached in terms of the whole sequence of stages from its initial to its ultimate form?

Criticism of the Topographic Cycle

During the past fifteen years increasing criticism of the idea of the topographic cycle has appeared in foreign literature. New methods of attack have been proposed in the avowed belief that the alleged simplicity of the topographic cycle was illusory. Too many facts were thought to be in disharmonious relation to the simple scheme of uplift and subsequent erosion through youth, maturity, and old age. The objections seem to spring in large part from an unwillingness to accept a terminology of foreign origin and in part from an inexplicably persistent misunderstanding of *stage* to mean *age*, a failure to see that the word stage is employed as a measure of development not of time. Of a piece with this is the refusal to describe two parts of a single valley as mature where excavated in weak rock and young where excavated in more resistant rock, again overlooking the distinction between *time* and *stage*.

One of the most extreme reactions against the idea of the topographical cycle is illustrated by Passarge.[3] He has sought to describe

[1] W. M. Davis: Relation of the Coal of Montana to the Older Rocks, Tenth Census of the United States, 1880, Vol. 15, 1886, pp. 697–757.

[2] *Idem:* The Rivers and Valleys of Pennsylvania, *Natl. Geogr. Mag.*, Vol. 1, 1889, pp. 183–253.

[3] *Idem:* Passarge's Principles of Landscape Description, *Geogr. Rev.*, Vol. 8, 1919, pp. 266–273.

landscapes in non-explanatory terms, just as Sven Hedin in his journeys in Central Asia claimed to make only *observations*, leaving to "armchair theorists" the explanations of things. The most charitable opinion on such declarations is that the authors are unacquainted with the technique of logic, for in reality explanation everywhere creeps into their work, sometimes directly through inadvertence and sometimes by implication that can hardly be avoided. Even in drawing a simple cross section, inferences have to be made as to underground structures beyond the range of direct observation. To describe a landscape in empirical terms is to offer the reader an ideal of complete meaninglessness and deadly monotony. It is tilting at a man of straw to say that one chooses the empirical method in contrast to theoretical explanations not based upon direct observation. The attempt to study regional geography through a card catalogue of facts-to-be-observed is to guarantee complete sterility. Preoccupation with the filling in of the blank spaces of the outline shuts out discovery. Ideas run the world, not outlines or catalogues. Chamberlin thinks that one sees better if one goes out with an idea in his head to start with: the history of science corroborates the thought. After all, as Gilbert so wisely stated, it is the philosophy of science rather than its material that is of the greatest value to the human spirit.

Walther Penck's Study

One of the most important advances in physiographic study made during the past ten years is a book entitled "Die Morphologische Analyse" by Walther Penck, who died in 1923. The book was edited and published posthumously by his father, Professor Albrecht Penck of Berlin, in 1924. Excellently printed and bound, with illustrations of extraordinary fineness, it is to be commended for thorough reading to every American student of physiography. Fortunately, Penck has followed the explanatory method; it is the outstanding quality of his book. His ingenuity and genius in the analysis of land forms were first exhibited in a most important study entitled "Der Südrand der Puna de Atacama," published in 1920 and based upon field work carried out in 1912.[4] No such detailed and penetrating analysis of the physiography of a district has been made for any other part of South America.

As a result of his studies in northwestern Argentina and later in Anatolia and Central Europe, Penck essayed to rewrite systematic physiography and to place it upon a new foundation. It was not an expansion or adaptation of the subject as now developed but an entire revolution that he sought to bring about. Since his work is the clearest

[4] Reviewed by Alan G. Ogilvie: Argentine Physiographical Studies: A Review, *Geogr. Rev.*, Vol. 13, 1923, pp. 112–121. See also references in Isaiah Bowman: Desert Trails of Atacama, *Amer. Geogr. Soc. Special Publ. No. 5*, 1924.

and most profound of those who have criticized what might be called the American school of physiography, it deserves extended notice, for it is a book that cannot be lightly put aside. Eventually, and as it becomes better known, its arguments will have to be met paragraph by paragraph. For the present we can only indicate the more general features of the argument and point to the difficulties in which the author becomes involved in making his most conspicuous applications.

Penck believes what I think is not true, namely, that according to the current explanation of the cycle of erosion, progress in the cycle takes place *always in a definite sequence;* so that mature land forms follow on youthful, and old forms develop out of mature. This is an altogether elementary and rigid conception, and its only conceivable excuse is its exotic origin. Instead of the sequence—youth, maturity, old age—being an inexorable thing, the orderly progress of the cycle is conceived by Davis to be subject to interruption at any time, whereupon a new cycle or partial cycle (epicycle) may be begun, only to be interrupted in turn, and so on.[5] While Penck fully recognizes the value of the idea of the topographic cycle as a method of investigation, he puts it aside as something not to be accepted as a definite theory of broad application. He regards it as *a special case* in the general physiography of the lands. Well, the uninterrupted cycle, continued to its completion, is undoubtedly a special case; but there is nothing new in that.

While Penck believes that the introduction by Davis of the time factor in the evolution of topographic relief was a very great step forward, he considers it an equally progressive step to bring into consideration the relative rapidity of the three processes of uplift, erosion, and denudation. He thinks that "the Davis cycle" does not take into consideration the constant movement of the earth's crust from the beginning. In his view the *mobility of the crust of the earth* should be an integral part of the cycle theory. Once this principle is accepted, the partial cycle of Davis, that is the epicycle, would not be needed to explain the forms in a given case. It is of the utmost importance that anyone who wishes to understand Penck should fasten his attention upon this *factor of crustal mobility*, or, as he would put it, the *principle* of mobility, for it is upon that principle and its corollaries that he would found the whole of geomorphology or physiography. While granting the pedagogical value of the simpler statement of the theory that Davis is supposed to have given, Penck believes in a new and entirely different formulation of the cycle theory. What his formulation really amounts to is only a more explicit and detailed consideration of the *complications* of the cycle that Davis treats more briefly.

[5] W. M. Davis: Complications of the Geographical Cycle, *Rept. Eighth Internatl. Geographical Congress*, 1904, Washington, D. C., 1905, pp. 150–163.

In order to obtain a clearer notion of Walther Penck's views, I exchanged letters with his father, Professor Albrecht Penck, for the purpose of making the matter clearer. With his permission I quote a statement which holds that it is not a modification of Davis' theory of the topographic cycle or an expansion of it that Walther Penck has in mind, but a step far in advance of Davis, an advance toward a deeper physiographic understanding of the processes of erosion on the surface of the earth. In discussing this point Professor Penck writes as follows:

> Let a comparison make the matter clearer. According to the Ptolemaic system of the universe, the planets move in cyclic orbits. To explain their retrograde motion epicycles are brought in. According to this method all planetary motions can be explained, but they only become comprehensible when we place ourselves with Copernicus—when we say that our standpoint, the earth, moves in a cyclic orbit just as do the planets. Their motions can only be calculated when we, with Kepler, conceive their orbits to be elliptical and apply his three laws to their motions. Certainly, each of the three great astronomers stands on the shoulders of his predecessors. But, for this reason, one will not, after all, call the Copernican system of the universe an expanded Ptolemaic system. In just the same way, the cycle theory, as my son develops it in his posthumous work on physiographic analysis, is not to be designated an expanded theory of Davis.

Four Bases of Criticism

There are at least four main lines of argument to be advanced in testing Penck's morphological analysis: (1) Except for the case of the so-called Mittelgebirge of Germany to which abundant reference is made, the chief illustrations are from front ranges or border ranges of far more extensive cordilleran highlands *within* which quite different conditions obtain. (2) The mobility of the earth's crust is one of the most striking features in Davis' development of the cycle idea, for it is constantly emphasized that the earth's crust is uneasy and that a vital part of a demonstration or explanation of land forms in a given region is the determination of the forms the landscape had in a prior state at a different level or in subyouthful stages during uplift. (3) There is a very curious lapse in Penck's bibliography in that the examples are very largely taken from German sources. A wholly inadequate reference is made to American literature in which the idea and applications of the cycle have been most thoroughly weighed and described. It is not merely that adequate reference is wanting. It is the far-reaching importance of the illustrations afforded by them that Penck does not take into account. (4) The fourth basis of criticism lies on the outermost fringe of the science of physiography today. It is that the relationship between isostasy and topographic form has not been determined with a degree of accuracy that enables one to put so fine an edge to an argument as Penck develops in his new study of topographic forms.

Types of Slopes and Their Origin

To support his main conclusions Penck begins by making a most elaborate analysis of the manner in which different types of slopes may come into being. Certainly in this respect his work is a contribution of the first order, and I can think of nothing comparable to it in this country except the analytical work done by the late Professor Joseph Barrell of Yale University. Everyone who has made extensive field studies in physiography must have become aware of the fact that our analytical equipment at the present time is not sufficiently well rounded. It is easy, as a rule, to explain the more picturesque and striking elements of a landscape. The direct relation between certain rock types and their corresponding slopes is not difficult to determine in many of the great mountains and canyons of the world. But when we analyze the old erosion surfaces now found in many parts of the world and in almost every important mountain system, we are confronted with difficulties of the first order. Adjacent fragments of old erosion surface are relatively easy of correlation, especially if such surfaces have been preserved from subsequent dissection by a capping of lava, as, for instance, in many of the mesas and fault-block mountains of the Southwest. On the other hand, if these surfaces be widely separated and without a protecting cap of resistant rock, they will be found in various stages of destruction (owing to different rock resistances, climatic conditions, elevation, etc.); and the fragmentary nature of an old erosion surface may leave doubt as to the correctness of any explanation based on former continuity.

It is precisely because there are so many unexplained physiographic features in existence that physiography continues to have the vigor of youth. I know of no adequate explanation, for instance, of the quite abrupt change in slope which one finds near many of the hilltops about the border of the White Mountains. The same abrupt break may be found at the foot of many residual masses in the central and less dissected portions of former all but base-leveled surfaces. Various elementary explanations have been offered for the marked difference in the character of slopes whether convex or concave to the sky—whether it is the variable rainfall, the varying resistance of the rocks, or the unequal depths of erosion that may be responsible, or what the effect is of changing combinations of all these and other factors. Intensive research upon such questions is needed in order to extend the area of explanation and to put a large portion of weakly descriptive physiography upon a rational basis.

Such an analysis Penck essays to make through the intensive study of selected examples and through a consideration of the manner in which stream profiles and valley-slope profiles change from stage to stage in the steady advance of erosion upon a given mass of rock. He believes that the orderly progression of forms through youth to matu-

rity and old age is the exception, not the rule. He concludes that uplift cannot be taken as a process in and by itself and erosion described as an event subsequent thereto. A very large part of his book deals with the relation of uplift to erosion. It seems to be his idea that Davis and other modern physiographers have assumed the movement of the land to be completed before significant erosion takes place. He would recalculate the rapidity of uplift and the rapidity of erosion of mountains in which old or mature forms are displayed. In the examples upon which his arguments are chiefly based (the front ranges of the Andean cordillera in northwestern Argentina) he accounts for the gentler slopes of the crest and upper flanks of the range not by erosion during a prolonged stillstand of the land and subsequent elevation to present mountainous height but, on the contrary, by that erosion which produced the very sediments that now flank the mountains and form the floors of the adjacent basins.

Penck claims to find through his detailed analysis of the mode of retrogression of the slopes of the land an explanation for the forms of old age independent of the idea of the cycle. Certainly he has brought into the literature a number of useful terms and has challenged prevailing explanations at a number of quite critical points. His recognition of the piedmont step; the brow of the uplifted block upon which an old erosion surface may be identified; the sharp topographic unconformity that exists between the old erosion surface and the residuals that rise above it and the remarkable localization of this last feature on a line almost as definite as a strand line; the importance of studying the effects of piedmont stripping upon an upland border where accumulation of sediments was made before an old erosion surface was developed upon the adjacent uplifted mass; the agencies which effect a change in the form of a landscape from concave to convex or from convex to concave; the constant challenge with which he meets a new grouping of forms—these are among the most important contributions of his book. A far-reaching influence is attributed to *intensity and degree of uplift* (as opposed to climate) in the modeling of slopes. If convex, the slopes are a response to rapid uplift; if concave, they bespeak a slower rate. Obviously the full test of the idea must come with the inspection of a far larger number of examples under the most divergent conditions.

There is no doubt that he has thrown out a most inviting challenge on page 238, where he questions the correlation of widely separated erosion remnants without the close analysis of their border phenomena which give a clue to their former position and also to their mode of origin. Such a challenge has often been made before but in most cases upon weak grounds. By organizing his detailed analysis in excellent form Penck greatly strengthens his position when he reaches the point where the larger conclusions and the larger physiographic interpreta-

tions are brought into consideration. Were his book translated and put into the hands of American students it would certainly lead to a profound stimulation in physiographic field work. Such stimulation is needed, for the detailed field studies now being made in the United States have reached the point where challenging questions are thrown out in ever increasing number.

Front-Range Physiography a Specialized Chapter

Having said this much, one may now return to the first of the four main criticisms of Penck's work as noted above. Front-range physiography is certainly a highly specialized chapter. It is unsafe to argue a revision of the whole science on the basis of the specialized phenomena there displayed. In this narrow belt are concentrated effects of change of level and of changes of climate whether these take place upon the plain or valley crustal block on the one side or the mountain block on the other. Moreover, there is here an overemphasis of the purely lateral attack of the streams. From the examples which he has studied in detail Penck concludes that a youthful stage of erosion may be initiated by uplift while the inner or more distant part of the mountain may continue to progress from an old stage to a still older stage. This is eminently possible if the inner part is uplifted without tilting, but it is startling to have such a statement put forward as a new discovery!

There is insufficient analysis of the fact that in the uplift of a broad cordillera or of a broad plateau there is never equality of uplift from district to district in a great region but a most involved and complicated result such as is shown in the Central Andes and in the Sierra Nevada. Faults and warps throw the older surface into new attitudes, and, however impressive the concentrated erosion of the main mountain borders may appear to be, no less impressive is the deep dissection of streams clear to their headwaters within the region, thus leaving undisturbed broad surfaces of erosion of earlier origin.

Basal sapping at the border, upon which Penck places such strong emphasis, has a special geographical position; it has no relation to that vastly larger number of cases where streams are invigorated throughout their entire length by a pronounced change in gradient as in the drainage systems of southern New England. A restoration of the older surface here shows a greater uplift in the more northerly sections, as, for instance, in northern Connecticut and more particularly in western Massachusetts. Basal sapping is a minor and almost negligible feature in the coastal belt. The successive profiles which Penck presents as the normal condition of changing stream profiles are inapplicable here. It is not near the southern border but in the

northern sections of the peneplain of southern New England that erosion has been most vigorous. The Deerfield gorge and related features are of a much higher order of importance than basal sapping on the margins of the peneplain. However complicated the physiography of southern New England may prove to be upon further analysis, and certainly it is much more complicated than the earlier and simpler statements would lead one to suppose, it is still true that the main episodes in that history are not difficult to understand, lengthy as the detailed explanations may be. In his attempt to harmonize the topographic cycle of mountain areas such as the Sierra de Fiambalá and the corresponding cycle of sedimentation in the adjacent basin floor, Penck has found a key not to systematic physiography as a whole but to that special chapter of it which might be called front-range physiography.

It is significant that there is no reference in Penck's bibliography to two papers by Louderback and Emmons.[6] Louderback has shown, by a most detailed study of the Humboldt Range in western Nevada, that the present mountain ranges and broad intermontane basins were produced by the differential movement of large crust blocks which rose or sank as units though not as absolutely rigid masses, since there are evidences of internal deformations of both faulting and warping on a moderate scale. Now it appears that, preceding the period of faulting and warping, there were great explosive eruptions from a number of volcanic centers and rhyolite outpourings covered large tracts of land. These lava beds followed the slopes of their time which were developed upon a complicated structure of anticlines and synclines formed in an early period of mountain making. The low relief which the region had in the period immediately preceding the period of faulting is not a matter of inference, of theory, or of guesswork. There the surface stands under the lava beds, preserved as it was when sealed up by the lava. Its low relief is no less in doubt than the low relief of the land surfaces exposed in the fifteen-mile section both at the top and the bottom of the Algonquin wedge in the Grand Canyon section.[7]

The next step in the argument may be briefly summarized. The lava beds are in many instances but little dissected, showing that uplift was sufficiently rapid to put them in their new position before significant erosion could take place. The resistant lava has limited

[6] G. D. Louderback: Basin Range Structure of the Humboldt Region, *Bull. Geol. Soc. of America*, Vol. 15, 1904, pp. 289–346; reference on p. 336.

W. H. Emmons: A Reconnaissance of Some Mining Camps in Elko, Lander, and Eureka Counties, Nevada, *U. S. Geol. Survey Bull. No. 408*, 1910, pp. 76–81 *et al.*

[7] Powell in the first instance described and explained the section, and Dutton elaborated the explanation. For a more analytical confirmation see W. M. Davis: An Excursion to the Grand Canyon of the Colorado, *Bull. Museum of Comp. Zoöl. at Harvard College*, Vol. 38 (Geol. Ser., Vol. 5), 1901, pp. 108–201. For a detailed study of later date see: L. F. Noble: Contributions to the Geology of the Grand Canyon, Arizona: The Geology of the Shinumo Area, *Amer. Journ. of Sci.*, Vol. 29, 1910, pp. 374–380.

erosion pretty much to the border of the range. From a study of the cliffed spurs that terminate on the straight line of the bounding fault one can even make out successive steps in the uplift of the tilted block.[8] When one passes to other fault-block ranges near by and discovers the same old topography not preserved by a lava cover yet readily identifiable though now deeply dissected, one is led to conclude that there is ample justification for treating the mountain range in just the simple manner that Penck supposes Davis uses on all occasions, that is, rapid uplift into its present position is a thing of greater importance than the amount of erosion that has occurred during uplift. In addition, there is here no question of warping because the topographic features have a demonstrated relation to faulting. While the argument at first depended upon a purely physiographic analysis of the blunt spur ends intermittently renewed, the broken alluvial fans across the valley mouths where they were crossed by the fault, and the slicken-sided rock surfaces on the edge of the upthrown block, we have long ago passed the point of inference and reached the stage of direct observation. This is the point in Emmons' paper, as will be seen by reference to his cross sections as actually observed in mines in the Bullfrog district, Nevada. It is a point made with equal force by Knopf in his studies of Inyo Range and the bordering Sierra Nevada.[9]

It seems impossible to escape the conclusion that Penck has overlooked the recognition of varying rates of uplift in the scheme of the cycle and has emphasized precisely the wrong things in his exposition. To take the case of the German Mittelgebirge again. He sees upon the rounded slopes and smoother surfaces of that region a progress toward a still more advanced stage of topographic development in which forms become gentler and flatter. But he sees at the same time the continued growth of youthful forms on the border of the area. Finally, he sees these youthful forms gradually replace the older forms of the interior. Thus he believes he has found a reversal of the normal sequence of erosion that takes place under conditions of uninterrupted activity. I cannot see why he considers this to be a discovery that requires the revision of physiographic science. Penck would have it that the Mittelgebirge are advancing to old age and then to youth, and Davis would merely put it that (having been in a stage of old age the surface is becoming older, to be sure, here and there) the significant thing is that the present elevation of the Mittelgebirge above sea level and its present relation to the bordering drainage lines will surely impose upon it in time a youthful condition such as Penck recognizes on the border and which he admits will extend its characteristics into

[8] W. M. Davis: The Basin Range Problem, *Proc. Natl. Acad. of Sci.*, Washington, D. C., Vol. 11, 1925, pp. 387–392.

[9] Alfred Knopf: A Geologic Reconnaissance of the Inyo Range and the Eastern Slope of the Southern Sierra Nevada, California, *U. S. Geol. Survey Professional Paper 110*, 1918.

the whole mass until finally the entire surface has again become youthful.

In such renewed dissection in headwater streams "youth" does not necessarily mean sharp ravines, since they deepen slowly and the valleys widen as they deepen. The result is to elide youth, as Davis has shown in his "Erklärende Beschreibung der Landformen." Typical young valleys, gorgelike, are characteristic of middle-course streams, where they have good height to cut down and good volume to cut down with.

If we take the case of the border ranges at the southern end of the Puna de Atacama as Penck has described them (pp. 212 to 216) one finds the significant statement on page 216 that the upper slopes are not fragments of a now all-but-dissected earlier relief nor that they have been elevated to their present position by some extraordinary uplift, but that their position depends upon the depth of dissection of the neighboring valleys and the resistance of the rock. But such an argument is altogether inadequate when applied to other regions even if we grant full competence to it in the front ranges of the southern border of the Puna de Atacama.

The next great steps in physiography may well be the application of Penck's argument to landscapes in critical or classical topographic regions and its use in the fuller discussion of cases of variable rates of upheaval which have been only briefly treated in earlier studies. When this is done it seems fairly clear that the idea of the topographic cycle as developed by Davis will still be the most important part of interpretative generalization. Combined with these in the ultimate analysis of the physiography will be the fundamentals of isostasy now just yielding to scientific treatment. Even then it will no doubt be found that topographic relations exist for which no satisfactory explanation may be found because they require too fine an edge of correlation. When that time comes it will be even clearer than now that a really scientific study of physiography is as much geological as it is geographical: as in Penck's subtitle, "a chapter in physical geology." It is not, however, a field that the geographer can neglect; for he must handle its elements with facility and real understanding if the feet of his "humans" are to remain on the earth.