# ROCK PLANES OF ARID REGIONS

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# ROCK PLANES OF ARID REGIONS

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AMONG the most characteristic elements of the arid landscape are far-spreading lowland plains which incline gently away from the larger mountain masses. In 1897 McGee[1] demonstrated that such surfaces in the southwestern United States and northern Mexico consisted in part of remarkably smooth rock planes. He attributed them to the erosive action of "sheet floods," vast expanses of moving water formed when a flooded canyon discharged upon the lowland, or when very heavy rains fell directly upon its nearly level surface. To a typical example he applied the term "pediment." American writers have often followed McGee in speaking of these rock planes as "pediments," although few have accepted his theory of their origin.

Other investigators, both in America and abroad, have sought to explain these rock planes as a product of wind erosion or deflation.[2] Lawson[3] advanced the theory that such a plane could be produced by progressive retreat of the adjacent mountain front due to weathering processes alone, especially rock disintegration under the influence of insolation. Bryan,[4] Davis,[5] and others have to a large extent followed Lawson, although both attribute minor rôles to lateral planation by streams.

## THE THEORY OF STREAM PLANATION

For some years the writer has been developing and testing a theory of pediment formation, based on an early suggestion by Gilbert.[6] The essence of this theory is that rock planes of arid regions are not the product of sheet-flood erosion, nor of wind erosion, nor of mountain-front retreat by weathering, *but of normal stream erosion.* A peculiarity of the stream erosion theory is the relative importance attached to lateral corrasion. This results from the fact that heavily

[1] W J McGee: Sheetflood Erosion, *Bull. Geol. Soc. of America,* Vol. 8, 1897, pp. 87–112.

[2] See for example a long list of titles by Charles R. Keyes.

[3] Andrew C. Lawson: The Epigene Profiles of the Desert, *Univ. of California Publs. in Geol.,* Vol. 9, 1915–1916, pp. 23–48.

[4] Kirk Bryan: Erosion and Sedimentation in the Papago Country, Arizona, *U. S. Geol. Survey Bull. 730,* 1922, pp. 19–90.

[5] W. M. Davis: Rock Floors in Arid and in Humid Climates, *Journ. of Geol.,* Vol. 38, 1930, pp. 1–27 and 136–158.

[6] G. K. Gilbert: Report on the Geology of the Henry Mountains (U. S. Geogr. and Geol. Survey of the Rocky Mountain Region), Washington, 1880.

laden streams of arid regions are not able to cut vertically downward to the same extent as are the relatively less burdened streams of humid areas. Hence the consequences of lateral migration, always taking place in every stream of running water, are more conspicuously in evidence. For this reason one may properly speak of this conception of pediment origin as the theory of lateral corrasion, or lateral planation; although it should not be forgotten that the essence of

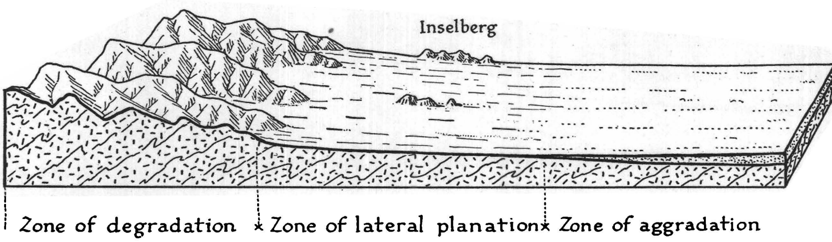


FIG. 1—Zonal arrangement of stream action in arid regions.

the theory lies in the broader conception that rock planes of arid regions are the product of stream erosion rather than in any particular belief as to the relative proportions of lateral and vertical corrasion.

In 1931 the writer outlined his theory of the origin of rock planes.[7] The substance of the theory may briefly be re-stated as follows:

Every stream is, in all its parts, engaged in the three processes of (a) vertical downcutting or degrading, (b) upbuilding or aggrading, and (c) lateral cutting or planation. Under different conditions one or another of these processes may become more important, and the other two operate less vigorously or intermittently. If we imagine an isolated mountain mass in an arid region (Fig. 1), it will be evident that the gathering ground of streams in the mountains, where greater precipitation occurs, will normally be the region where vertical cutting is at its maximum. Aggradation will be intermittent, local, and temporary. Lateral cutting will be vigorous, and for every hundred feet of downcutting two or more hundred feet of lateral movement of the stream may take place. But even so the deepening process keeps the valleys youthful in character, with narrow bottoms and relatively steep sides. Valley deepening appears dominant, even if it be actually subordinate to lateral corrasion.

Far out from the mountain mass conditions are reversed. Each stream must distribute its water and its load over an ever-widening sector of country. The water disappears, whether by evaporation or by sinking into the accumulating alluvium. Aggradation is at its maximum, and vertical downcutting is intermittent in character and both local and limited in extent. Lateral corrasion may be dominant in fact, the streams shifting hundreds or thousands of feet laterally

[7] Douglas Johnson: Planes of Lateral Corrasion, *Science*, Vol. 73, 1931, pp. 174–177.

for every hundred feet of upbuilding. But the observer is impressed by the ever-thickening mantle of alluvium: aggradation appears dominant, even if it be actually subordinate to lateral corrasion.

Between the mountainous region of apparently dominant degradation and the distant region of apparently dominant aggradation there must be a belt or zone where the streams are essentially at grade.

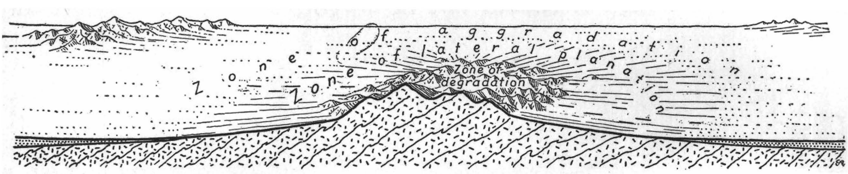


FIG. 2—Concentric zones of the ideal desert range.

Both downcutting and upbuilding are at a minimum, while lateral corrasion is again dominant not only in fact but also in appearance. Since the dominant lateral cutting takes place essentially at a constant level, its results are strikingly obvious. Interstream areas are consumed, and the valley bottoms coalesce to give a single rock plane sloping in all directions away from the central mountain mass. On this plane the thin veneer of alluvium left by the shifting streams will remain until weathering, sheet floods, and wind have disintegrated and removed everything down to bed rock.

About each desert range there should then normally be found three concentric zones (Fig. 2) in all of which lateral corrasion is actually dominant but in each of which the three processes of degradation, corrasion, and aggradation assume such strikingly different relations that each zone in turn appears to be dominated by a different process. Thus from the center outward are (1) the *zone of degradation*, (2) the *zone of lateral corrasion*, (3) the *zone of aggradation*. Heavily laden streams issuing from the mountainous zone of degradation are from time to time deflected against the mountain front. This action, combined with the removal of peripheral portions of interstream divides by lateral corrasion just within the valley mouths, insures a gradual recession of the face or faces of the range. Such recession will be aided by weathering as well as by rain and rill wash; but it must occur even were these processes of negligible importance. The three zones thus progressively contract, providing a beautifully adjusted mechanism which insures that at every point within the initial mountain mass streams will ultimately be maintained at a given level in the balanced or graded condition until the work of planation is complete.

## Rock Fans

While the writer was engaged in deducing the reasonable consequences of the foregoing theory of pediment origin, he came upon a wholly unanticipated result. On purely theoretical grounds it appeared that, if the pediment be a product of stream erosion and the mountain front retreats mainly through trimming of its frontal spurs as the shifting streams from time to time impinge against them, the zone where plane and mountain meet should exhibit a series of relatively flat semi-cones, or less than semi-cones. Each partial cone would appear to be an ordinary alluvial fan where deposition of débris was plentiful; but in the absence of such débris it should be a bed-rock surface having the form of a typical fan and apexing like the alluvial fan at the mouth of the canyon from which issued the sculpturing stream (Fig. 3). That this must be the case will be evident to anyone who will visualize the geometric form described by an inclined stream relatively (but not rigidly) fixed in position at the point of issuance from the canyon mouth and shifting more and more widely below that point. The alluvial fan is the expression of that form where deposition alone has occurred or where considerable deposition has accompanied erosion of bed rock. The "rock fan," as I have called it, is the same form where retreat of a mountain front has let streams operate on the solid mass of the range and where erosion has exceeded deposition.

Field search revealed the existence of such "rock fans" in a number of localities, and the finding of these forms, following the purely deductive conclusion that they ought to exist, inevitably inspired an added measure of confidence in the theory that rock pediments, or suballuvial benches, owe their development chiefly to the corrading action of heavily laden, frequently shifting streams. A full discussion of these highly interesting forms, and of their relation to the problem of desert rock planes, was recently published.[8]

## Braided and Swinging Streams

There are certain considerations implicit in the theory of planation by stream erosion which should perhaps be specified to avoid misunderstanding, especially since the oversimple statements of my earlier papers have led to some misconception as to what the theory involves. It must be realized, for example, that the drainage conditions of arid regions described in the text and pictured in Figures 1 and 2 imply extensive braiding, or anastomosing, of streams. It should not be inferred that master streams issuing from mountain canyons continue across either alluvial fans or rock fans and pediments with their integrity unimpaired. Heavily laden streams in arid regions, losing water by evaporation and by infiltration into alluvium, behave quite differently. They divide and subdivide

[8] Douglas Johnson: Rock Fans of Arid Regions, *Amer. Journ. of Sci.*, Ser. 4, Vol. 23, 1932, pp. 389–416.

indefinitely (Fig. 4), the minor channels reuniting and interlacing and frequently shifting both their positions and their connections.

Rarely is the observer fortunate enough to see the stream at work. Ordinarily he beholds only a network of dry, broad, shallow channels, each filled with sand, gravel, or boulders. These may lie

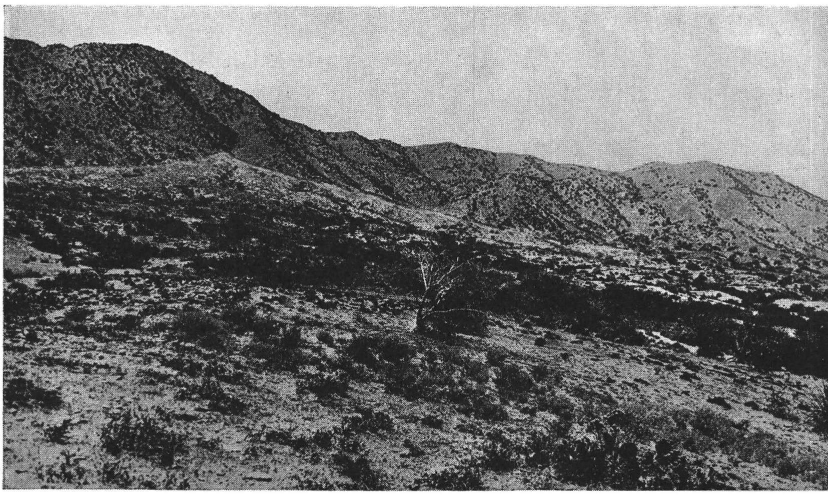

FIG. 3—Rock fan, eroded on granite at eastern base of Sierrita Mountains, Arizona. The negative was retouched to emphasize outline of the fan, but the view correctly represents the essential relations.

near the surface of the rock plane, and offer so little evidence of stream erosion that the observer discounts their importance. Only when seen from some neighboring height or from an airplane, does the vast network of interlacing stream lines appear impressive.

The irregular "swinging" of heavily laden streams in arid regions should not be confused with the systematic lateral and down-valley migration of meanders. Both processes involve lateral planation; but a stream embarrassed by a heavy load is not free to swing in symmetrical serpentine curves. Accumulation of débris tends to block the channel, the stream spreads, cross currents are set up, and braiding develops rather than meandering. The heavy load favors lateral planation at a given horizon not only by preventing vertical incision of the stream but also by favoring its lateral displacement through accumulation of débris along and within the channel. Since there are a multitude of interlacing channels, no one of them need shift very far in order that lateral planation should take place over the entire surface of fan or pediment.

## Piedmont Depressions

A master stream debouching from a canyon mouth upon its alluvial fan may descend first one radius of the fan, then another, and so on; or it may split and descend several radii simultaneously. It has been observed that a favorite location is along the inner borders of the fan, where the latter makes contact with the mountain wall. Streams very commonly occupy these marginal positions, even when the master stream from the canyon descends the central portion of

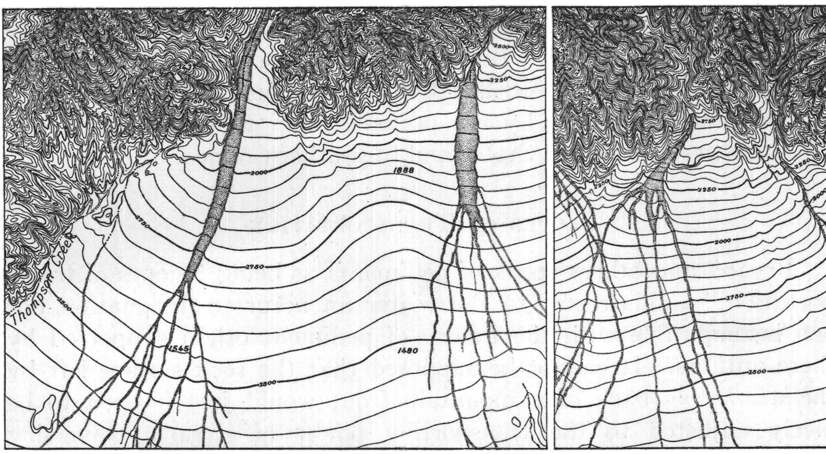


**FIG. 4—Alluvial fans of the Cucamonga region, California, showing braided channels. Note on the left the depression followed by Thompson Creek. Scale approximately 2 miles to the inch. (From U. S. G. S. topographic sheet, Cucamonga Quadrangle.)**

the fan. If the reader will examine portions of the Cucamonga (California) topographic quadrangle (Fig. 4), he may better appreciate both the fact and its explanation. Streams from minor canyons and still smaller ravines, debouching upon the sides of the fan, encounter the pronounced slope graded by the master stream. They turn abruptly along the mountain base and follow down this slope. There is thus assured a marginal channel, into which the master stream may itself debouch at times. Thompson Creek (Fig. 4, left) occupies such a depression on a fan where the master stream descends one of the more central radii; the master stream from Day Canyon (Fig. 4, right) itself descends a marginal depression. It should be noted that these marginal streams are forced into a position where trimming back of the mountain front by their lateral swinging must be peculiarly effective.

Analysis shows that the relations just observed on alluvial fans should likewise exist on rock fans carved by lateral planation of heavily laden streams. Field investigations demonstrate that marginal channels are a characteristic feature of rock fans.[9] Both the northern and southern inner margins of the rock fan shown in Figure 3 are trenched by ravines, that shown on the south (left of view) being particularly effective in trimming back the mountain spurs. Where

[9] *Ibid.*

rock fans at the inner borders of pediments are deeply eroded, the marginal streams along the mountain base play an important rôle in the process of dissection and often give rise to major "piedmont depressions" separating the mountain wall from undestroyed remnants of former rock fans and pediment. Whether this is the same feature as the piedmont depression described by Passarge[10] from Africa, the writer cannot say, as he is not familiar with the regions studied by that author. But in general it appears that the rock planes and inselberge described by Passarge and others are similar to the forms attributed by the present writer to stream erosion in the southwestern United States and in southern Africa.

## Slopes of Transportation

Bryan[11] and others speak of pediments as being "slopes of transportation." This seems to the writer an accurate designation but one incompatible with the theory of pediment origin supported by these authors. It cannot be supposed that the rock surface left by the *weathering* back of a mountain front would just happen to be nicely adjusted to the transporting power of streams traversing that surface. Even were such supposition possible, the pediment slope close to the mountain front, if there adjusted to stream transport, could not be adjusted to the very different conditions of stream transport that must exist after further mountain retreat has left that part of the pediment far out in front of the range.

In most cases a pediment left by simple weathering back of the mountain front will presumably be either too gently sloping or too steep to be in perfect equilibrium with stream transport of débris. In the former case streams will deposit until equilibrium is established, and we shall have an alluvial plain, not a pediment. In the latter case streams will entrench themselves until equilibrium is reached, then open out a new plane; and we shall have a pediment determined by stream erosion at the lower level, not a pediment due to retreat of the mountain front by weathering.

## Regraded Rock Planes

According to the theory of pediment origin here advanced, the pediment when first formed is truly a "slope of transportation," in perfect equilibrium with the heavily laden streams traversing it because carved by those streams. If conditions of transport vary gradually, the rock plane is slowly regraded to maintain the necessary equilibrium. This is the normal case and explains the fact observed by Bryan, that pediments in the southwestern United States com-

[10] Siegfried Passarge: Panoramen Afrikanischer Inselberglandschaften, Berlin, 1928, pp. 6–9.
[11] Bryan, *op. cit.*

monly have a slope of 200 feet to the mile close to the mountain front but only 50 feet to the mile farther out. Regrading of the rock plane A′ A″ in Figure 5, to give the rock plane B′ B″ at a lower level, is the only manner known to the writer by which the relation of pediment slopes described by Bryan can be maintained as the mountain front retreats from A to B. The slope of 200 feet per mile at A′, close to the mountain scarp, must be changed to 50 feet per mile in the

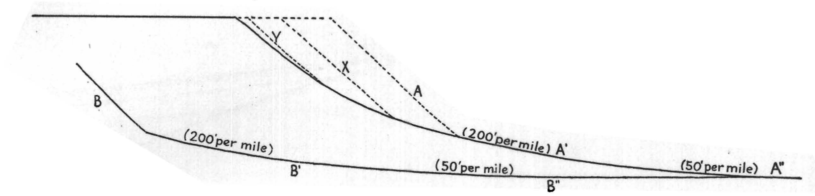


FIG. 5—Mountain-front retreat and pediment formation by weathering (AA′A″) and by stream erosion (BB′B″).

same locality (B″) by the time the mountain front has reached B. As both slopes must be bed-rock surfaces, and both must be adjusted to stream transport under the different conditions existing at A′ and B″, stream erosion appears to be the only agent competent to effect the change.

## COMPARISON OF THEORIES

Such regrading by stream erosion disposes of a difficulty that seemingly confronts the theory of mountain-front retreat by weathering. If we accept as normal the slope relations described by Bryan, viz., a rock surface growing progressively steeper toward the mountain base; and if we imagine the mountain front to retreat in such manner as to let the residual rock surface grow ever steeper (as we must do if we are to maintain the prescribed relation without regrading), then we encounter the difficulty that mountain-front retreat is limited to a relatively narrow zone. For, as the front retreats from A to X (Fig. 5), the steepening pediment slope must more closely approach the angle of slope of the mountain front. This latter, according to the theory of weathering, is a relatively fixed quantity determined by size of spalls detached by insolation and other weathering agents. At Y the mountain-front slope and the pediment slope nearly coincide, and further appreciable retreat is precluded. Thus the retreat of a mountain front into the center of a broad range would appear to be impossible, and pediment slopes far steeper than those described by Bryan should commonly be reported. Neither of these deduced consequences of the weathering hypothesis corresponds with the facts noted in the field.

Lawson inferred mountain-front retreat by weathering under conditions that would leave a pediment, or "suballuvial bench" as he called it, with surface convex upward (Fig. 6). Here we encounter the difficulty that mountain-front retreat would carry the pediment to the top of a broad mountain mass or plateau, a possibility specifically envisaged by Lawson but not represented by any case in nature so far as known to the writer. Nor does the convex surface appear nearly so characteristic of pediments as the concave form. Furthermore, Lawson's theory calls for an alluvial embankment

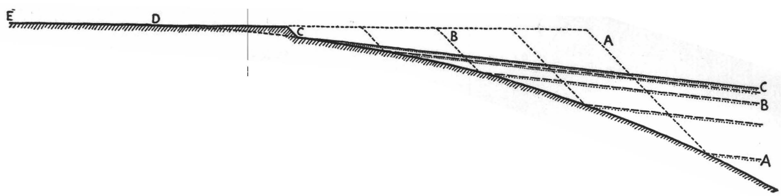


FIG. 6—Mountain-front retreat by weathering to give a pediment convex upward (after Lawson).

overlapping the rock surface to meet the base of the mountain scarp, unless the rock be laid bare by certain abnormal conditions specified by him. According to the writer's observations, the existence of a zone several miles broad, in which bed rock is abundantly exposed at the surface and the alluvium is restricted to a thin and discontinuous veneer of recent stream deposits, is quite as normal a feature as the more deeply buried pediment. Lawson recognized that under certain conditions of weathering the resulting rock plane might be concave upward or a straight slope; but he does not fully analyze these possibilities. We have already seen what difficulties the weathering theory encounters in the case of concave surfaces (Fig. 5). If we assume such retreat as would give a straight or uniform slope, we may either imagine the encroaching alluvial cover to lag behind

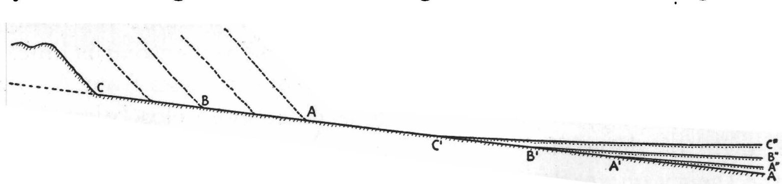


FIG. 7—Mountain-front retreat by weathering to give a pediment of uniform slope.

the retreating scarp, leaving a zone of pediment exposed as shown in Figure 7; or we may imagine the alluvial embankment to reach to the mountain base, as in Figure 6. In either case the possible extent of mountain-front retreat is limited, and the assumed relations of pediment slope to mountain front and to alluvial slope are not those most commonly observed in the field.

If the writer correctly visualizes the problem, it is not possible to represent successive profiles of mountain-front retreat in combination with *a single lengthening but unaltered profile* of the associated pediment, as is done in Figures 6 and 7 and in the upper part of Figure 5. As the mountain front retreats the pediment is progressively regraded and hence must be represented by *a succession of profiles*, as in Figure 8. The rock plane of the pediment grades imperceptibly into the alluvial plain farther out from the mountain, and both are normally in nice adjustment with the streams traversing them. Regrading can,

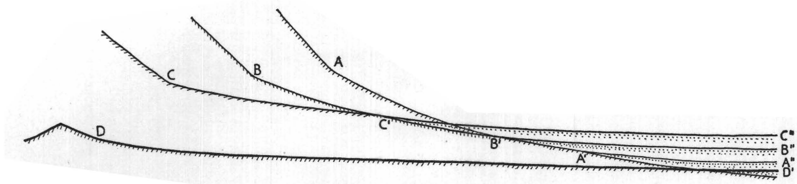


FIG. 8—Successive profiles of regraded pediments.

as shown in Figure 8, result in a certain convexity of the bed-rock surface (CC′ B′ A′) which may explain the well records accepted by Bryan as confirmation of the Lawsonian hypothesis (Fig. 6).

Regrading not only permits mountain-front retreat into the heart of broad ranges but permits lowering of both mountain front and pediment deep within the original mass, as shown at D, Figure 8. It may also involve, as revealed by profile DD′, broadening of the pediment zone in both directions, away from the mountain front as well as toward it, and the planation of older alluvium to give what is really a "pediment" erosion surface beveling the sands and gravels at a slight angle with their bedding planes. Finally, where regrading takes place suddenly, as a result of faulting, warping, change of base level, change of climate, or other competent cause, rapid stream incision followed by the development of new rock planes at successively lower levels will explain the existence of remnants of higher and intermediate rock fans and pediments that are so characteristic a feature of many arid regions.[12]

The theory of planation through erosion by heavily laden streams of arid regions satisfactorily explains so many complex relations observed about the borders of desert ranges that it seems to deserve recognition as a working hypothesis by those engaged in the study of desert morphology. Where weather and wind apparently rule today, it may prove that throughout the recent past, and perhaps even to the present time, water really has held sovereign sway.

[12] Johnson, Rock Fans of Arid Regions, pp. 394–399.