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ARID PLATEAU-PLAINS AS FEATURES OF EOLIC EROSION.

By Charles Keyes.

Of all geographic features peculiar to arid areas plateau-plains have long remained explicable. They stand out prominently among the many geologic phenomena of deserts which have been either greatly misinterpreted or not interpreted at all. For such conspicuous and common objects of landscape they strangely enough have attracted small critical notice from travelers. Hill* is almost alone in giving them especial mention and a name.

Apparently typical water-graved forms of unusual size, they are set in plains where stream-corrosion is practically unknown. Mystic features of the desert landscape as they have always been, they at this time possess exceptional interest, since they appear to offer not only most conclusive proofs of their origin by wind erosion, but afford critical data on the eolic sculpture of all of the grander physiographic lineaments of excessively dry countries.

In the arid region plateau-plains appear as even surfaces well elevated above the general plains-level about. As broad, flat-topped hills they rise out of the vast expanse of level earth after the manner of bold-coast isles out of a glassy sea. Mesas, or "tables," the Spanish-speaking people aptly denominate them. The margin of a mesa forms the brow of a precipitous escarpment, which is one of its most characteristic features. Indeed, the upper part of the escarpment is not infrequently a vertical wall 100, 200 or even 500 feet in height. Mesa de Maya (armoured table) and Llano Estacado (walled plain) are Spanish descriptive terms referring especially to this feature. The talus-like slopes below are steep; and their meeting with the general plains-surface is sharp.

Some plateau-plains are so small in areal extent that they stand boldly out of the general plain as conspicuous cones or buttes. The Cameleon, in central, and Wagon Mound, in northeastern New Mexico, are illustrations. Others, as the Enchanted Mesa and the Covero, in western New Mexico, and the Sunset Tanks buttes, in Arizona, are only a few acres in extent. Toyalene is larger. From these to the great Chupadera Mesa and the Mesa Jumanes, which are a dozen miles across and a score of miles in length, or the vast Mesa de Maya, which extends along the southern border of Colorado a hundred miles, there is every size. Proportion is mainly a function of geologic substructure.

The foundation of the plateau-plain is generally some rock-layer more indurated than the rest. Structurally it may be made up of (1) remnants of former plains worn out upon the bevelled edges of folded strata, as in the cases of the Mesa Jumanes and the Chupadera Mesa; (2) slightly inclined strata of hard limestone or sandstone, which are intercalculated in extensive beds of less resistant materials, as in the Chaca Mesa and other platform-plains of the great Mesa Verde region; (3) nearly horizontally disposed hard beds from which the soft superimposed layers have been stripped, as the Toyalane and the Tucum-

*Final Rept. Artesian and Underflow Investigation, U. S. Dept. Agric., pt. 3, p. 54, 1892.

cari; (4) old lava-sheets which cover soft shales and sandstones, of which the Mesa de Maya and Mesa del Acoma are conspicuous examples; and (5) surface-wash locally hardened through the evaporation of lime-salts near the surface of the ground, well represented by the Galisteo Ceja south of Santa Fe.

A notable peculiarity of the fault-structures of the Great Basin region in particular, and of the arid region in general, is that they are, with some minor exceptions, very old, much older than is demanded to control the surface relief. When the so-called Basin-Range structure is critically examined, the frontal scarps of the tilted mountain blocks are found to have no relation whatever to the profounder fault-lines. No one seems as yet to have discovered such lines at the base of the present mountains. Whenever the fault-lines which seem to bound the range-blocks are met with, they are invariably several miles away, out on the plains. Notwithstanding the fact that many desert ranges are tiled mounain blocks, they are symmetrically developed. This would not be true were they recently uplifted or tilted.

Under conditions of a normally moist climate the existence of flat-topped hills is now commonly ascribed to circumdenudation effects on an upraised peneplain. All remnants of the old graded surface are on the same general level. Throughout the arid region the plateau-plains which rise above the surface of the general plains-surface also appear to be the direct result of circumdenudation; but, as will be seen later, of a somewhat different kind. In marked contrast to the humid-land effects the remnantal plains of the desert, whether their surfaces be on stratum-planes, beveled tables of flexed strata, lava-sheets, or cemented regolith, are of different elevations, even in the same district. In New Mexico, for example, these plains attain all altitudes above the general plains-surface, from a few feet, in the instance of the Malagro malpais in the Hueco bolson northeast of El Paso, to the broad Mesa de Maya, which is 3,500 feet above the general plains-surface, and 9,000 feet above the level of the sea. The Sierra del Datil, in western New Mexico, has a mignificent northward-facing escarpment 1,000 feet high; and in sight is the Acoma Mesa 500 feet above the plains.

That the arid plateau-plains, small as some of them are, in reality are remnants of former plains-surfaces of great extent cannot be questioned. Whether these old remnantal areas are preserved by lava-flows, indurated strata, or cement-beds, it is certain that their surfaces represent essentially the horizon of the general plains-surface of the region when it stood at a higher level than at present, while since that time general erosion has proceded vigorously until the present lower general plains-surface has been reached. The fact that the surfaces of the plateau-plains have a vertical range of more than 4,000 feet above the present general plains-surface seems to afford incontestible proof of the continuity of erosional activities through a very considerable period of time. There has been general-leveling wholly independent of normal base-leveling. The total amount of erosion accomplished is roughly measurable by the distance between the general plains-surface and the crests of the present desert ranges that, significantly enough, present remarkable uniformity in height. The elevation of the main mountain ranges is about a mile above the general plains-surface; below the latter, the canyons of the four through-flowing rivers extend more than half of this distance.

The utter inadequacy of water-action as an erosive agent in an arid climate is made manifest by a number of well-known phenomena. In the desert regions of the West that which strikes the scientific traveler with greatest wonderment is the prodigious amount of erosion which is plainly evidenced on every side. At first thought, all is readily ascribable to the action of running water just as it naturally would be in the more familiar moist quarters of the globe. However, soon the impression is gained that the process of water-sculpture must be excessively slow. After a considerable sojourn in the region there may be encountered one of those sporadic heavy downpours of rain called "cloud-bursts," and it is at once surmised that the real secret of the vast erosion displayed by the desert is disclosed. Should the sojourner actually live for a few years in the dry country, he finds that notwithstanding the numerous evidences of fresh, extensive, and vigorous erosion, the "cloud-burst" is too infrequent, too local, too ephemeral in its effects, to be seriously considered as an important agent of general erosion. By inquiry among the older dwellers of the country, and by marshalling together the deductions from his own observations, the geographer reaches finally the conclusion that in the desert there is at best far too insufficient water to account for even a small fraction of the erosional effects. Ample evidences of great erosion there surely are; but as surely no water to produce it.

The verity of the utter impotency of water-erosion to accomplish the prodigious erosional effects everywhere displayed throughout the dry region is deeply impressed upon the mind of every desert dweller. After falling below about 10 inches annually, rain-waters quickly lose their general corrading powers. In the arid region of Western America most of the precipitation takes place in the form of light showers which immediately are absorbed by a loose and thirsty soil. Only once or twice a year, perhaps, is the rain-fall abundant enough in a locality to form any run-off at all.

Sharply contrasted are whatever erosive effects there are on desert mountain and desert plain. Should rain-fall on the former be so much as 10 inches each year it is often less than half as much on the latter. Desert mountains are usually made up of very hard rocks almost devoid of soil; the desert plains of non-resistant materials, with deep, porous soils. On the mountains, the effects of torrential stream-action is seemingly often as marked as it is in the highlands of moist countries. On the plains evidences of stream-corrasion are in reality almost entirely wanting. In its effects and in its vigor even the sheet-flood is quite local, sporadic and relatively unimportant.* Unless the itme element be made excessively long, water as a corrasive agent is utterly inadequate to produce the tremendous amount of sculpturing which, throughout the desert region, is on every hand so apparent.

The extent, rapidity and vigor of wind-erosion under the favorable climatic conditions of aridity have not been, until quite lately, appreciated as fully as they seem to merit. Recently in the writing of Passarge*, Walther‡, Penck§, and others, the great importance of this geologic agent in desert regions is urged. In

*Bull. Geol. Soc. America, Vol. XIX, p. 81, 1908.
†Zeitschrift d. deutschen geol. Gesellschaft, lvi Bd., Protokol, p. 108, 1904.
‡Das Gesetz der Wustenbildung, Berlin, 1900.
§American Jour. Sci., (4), Vol. XIX, p. 165, 1905.

our own country Spurr*, Cross†, and Blackwelder‡ have also called attention to certain phases of wind-work in general erosion.

In the western arid country recent observations seem to point strongly to the fact that the wind is to be regarded as the chief erosive agent§; water-action playing distinctly only a very secondary role. According to the conclusions thus reached, the wind must be considered in a dry climate fully as effective in general erosion and leveling as is water in a normal wet region. In the arid country wind appears not only the most potent of the gradational agencies, but its efficiency as an erosive force is probably greater than that of all other erosive processes combined. Within the confines of the desert itself its main activities are severely degradational in character; its constructive effects are local and relatively inconsequential.

Under favorable conditions wind-action is, in its broader effects of reducing a country to a lower plains-level, not so very unlike water-action. The areas occupied by the less resistant rock-belts are removed faster than the areas of more indurated rock-masses, dividing the region into belts of lowland and belts of highland. The former unite in the general plains-surface; the latter constitute the mountain ranges which, owing to ancient deformation, now have the aspect of tilted or upthrusted blocks.

Physiographically the ultimate goal of general erosion is the plain. Whether accomplished by marine denudation, stream-corrasion, or deflation, a general plains-surface is the final product of a completed geographic cycle. Between general leveling in moist climates and in dry ones the chief difference is that in the one case the greater part of each geographic cycle is spent in attaining the general plains-surface, or peneplain; while, from the very beginning, in the other the plains-surface is the dominant relief-form. In the case of the latter, as Passarge‖ has pointed out in the instance of the South African desert lands, and as has been urged for the arid regions of western America**, there is, without base-leveling, leveling more complete than that of peneplanation. The intermont plains and the general plains-surface of the desert are smoother than any known pepeplain.

It may be here observed that eolian activities under the favorable conditions of an arid climate are pre-eminently plains-forming. In a region of alternating belts of non-resistant and hard rocks the materials of the first are much more rapidly removed than in the case of the second. As general lowering of the country goes on the plains character is constantly extended. This seems to be largely accomplished by the air-currents heavily charged at the bottom with sands which cut most vigorously at the line where plain and mountain meet††, much in the same way as the sea works in, carving out of its shore a submarine shelf. In comparing the effects of a large stream in time of flood, and a gale of wind, it was recently estimated that in the cases of the river, and of the lower 20 feet of a desert air-stream, there are equal amounts of fine rock-waste moving in like areas of cross-section; but the air-stream moves 40 miles

*U. S. Geol. Surv., Prof. Pap. No. 42, p. 110, 1905.
†Bull. Geol. Soc. America, Vol. XIX, p. 53, 1908.
‡Journal of Geology, Vol. XVII, p. 443, 1909.
§Journal of Geology, Vol. XVII, p. 31, 1909.
‖Zeitsch. d. deut. geol. Gesellschaft, LVI Bd., Protokol, pp. 193-209, 1904.
**Bull. Geol. Soc. America, Vol. XIX, p. 86, 1908.
††Science, N. S., Vol. XXIX, p. 753, 1909.

an hour instead of four, and in place of being perhaps only a mile wide, is frequently several hundreds of miles in width.

The role of the plain in the general scheme of the arid cycle is especially instructive; since, as Davis* with great acumen has lately noted, the latter is in one respect at least even better supported than that of the normal wet cycle, "for while the arid African plains are examples of old desert plains now growing older, it is difficult to point out any large peneplain that still stands close to the baselevel with respect to which it was worn down."

That some of the low, lava-capped mesas located in the largest and dryest of the intermont plains represent the levels of the general plains-surface at the time when the lava-stream was out-poured, is an inference which cannot well be disputed. Some of the greater successive plains-levels, as the Mesa de Maya, the Ocate Mesa, the Las Vegas plateau and the Canadian valley have been recently fully described†. Between these great levels are many minor ones.

On the hypothesis of normal water gradation the remarkable smoothness of the intermont plains is very plausibly accounted for by considering them floored with debris brought down from the neighboring mountains. It is customary to regard these basin-plains as deeply filled with rock-waste from the peripheral highlands. In the physiographically older districts, as Russell puts it, the mountains appear to be buried up to their shoulders.

In a recent discussion it is pointed out‡ that in many cases at least the floors of these intermont plains are only thinly covered by soils and that these plains are actually worn out on the bevelled edges of the underlying strata. Even around "lost mountains" as those of the Mojave desert, the tilted bed-rocks of the piedmont about reach the surface of the inclined plains§.

In other piedmont districts where great thicknesses of "wash deposits" are reported, the unconsolidated deposits have been found, upon more critical inspection, to be made up largely of Tertiary beds. This is notably the case in the Rio Grande valley, in some of the intermont "valleys" of Arizona, and in Death valley in California. In the light of these observations the general statements that all of the intermont plains of the Great Basin and other parts of the arid region are deeply filled with "wash" must be held in abeyance and the data upon which they rest examined anew.

The evolution of the plateau-plain thus presents some novel features. The governing factors in an arid cycle are discussed by Davis‖; and other phases of the subject I have also pointed out**. The initiation of an arid cycle may be considered in connection with either one of two antithetical types of relief. One is a mountainous type; this is the one discussed by Davis. The other is the plains type, which is believed to be the type upon which the Great Basin is based. Beginning with an upraised peneplain the degradational processes, whatever might be their nature, would be expected to start to reduce the country towards ultimate base-level, just the same as under conditions of a moist climate. Assuming for the moment wind-scour to be the chief erosive factor instead of water-action, the broader relief features need not be very unlike the general topographic effects produced by stream-systems. In fancy,

*Journal of Geology, Vol. XIII, p. 395, 1905.
†Journal of Geology, Vol. XVII, p. 31, 1909.
‡Bull. Geol. Soc. America, Vol. XIX, p. 63, 1908.
§Trans. American Inst. Mining Eng., Vol. XL, p. 890, 1910.
‖Journal of Geology, Vol. XIII, p. 382, 1905.
**Bull. Geol. Soc. America, Vol. XIX, p. 86, 1908.

the immediate valleys of the rivers only need be regarded as filled up. As deflation progresses the belts of hard and soft rocks would be, perhaps, brought into somewhat sharper contrast than they commonly are at corresponding stages in a wet climate. The geologic structures would also be more accentuated. The rock-floor would be cleaner swept. The areas of weak rocks would be removed somewhat faster. At all times the plains aspect would be more strikingly dominant.

The country upon which an arid climate is imposed might be in the beginning either of plain or mountainous relief. Whether the one or the other, there would be a tendency for the different surfaces to become soon very much alike. Crustal uprising in an arid climate does not initiate a new and distinct cycle of down-cutting; it merely allows greater or longer erosion. In this respect the soil is different from that of the erosion cycle in a moist climate.

In general, four fundamental factors have to be considered: (1) Whether in the introduction of an arid climate the general relief was mountainous or of the plains type; (2) whether the epeirogenic movement was slight or great; (3) whether before the epeirogenic movement there was much or little folding and faulting; and (4) whether subsequent to the epeirogenic movement there was extensive deformation.

Applying these tests to a specific region, as arid United States, for example, I recently suggested* that in the high-lying plain of the Mesa de Maya there is strong reason for believing that it is the last remnantal representative of a great pepeplain upraised in Mid or Late Tertiary time. It has been long universally conceded that the epeirogenic movement was great.

In the arid country it seems that all four mutations or combinations above mentioned are well represented. The Great Basin appears to be an area which both prior and subsequent to the last epeirogenic movement suffered severe folding and faulting. There was much early, but little late deformation in the northern part of the Mexican tableland. The Colorado plateau appears to have been little effected by either ancient or modern faulting and folding; which is also true of the South African region. In southern California there is little to indicate very extensive pre-epeirogenic deformation but much evidence of great and wide-spread post-epeirogenic orogeny.

In the existence of plateau-plains at many different levels in the broad belts of the less resistant rocks there thus appears to be furnished one of the strongest proofs of the eolic character of the general erosive activities; since in situations of this kind not only are rain-fall and water-action very deficient and wholly inadequate to produce the relief effects presented, without the time-element be vastly and unreasonably prolonged, but conditions are such in many cases as absolutely to preclude the intervention of stream-work.

The summit plains of the continent in New Mexico is a region of continual high winds and constant sand-storm. Nowhere else in the desert of the Southwest is windscour in active operation so advantageously viewed. Nowhere else in this country are defiative effects and desert-leveling so well displayed. Nowhere else in all the world is general lowering of a country by the wind so strikingly presented. Few places there are on this continent where stream-action as a general erosional power is so manifestly utterly impotent.

*Bull. Geol. Soc. America, Vol. XIX, p. 76, 1908; also, Proc. Iowa Acad. Sci., Vol. XIII, p. 221, 1908.