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THE CONVEXITY OF HILLTOPS[1]

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In a maturely developed topography, hilltops composed of unconsolidated materials are upwardly convex in profile. Their forms are thus contrasted with the longitudinal profiles of stream beds, which in mature development are concave upward. An explanation of the river profile offered by the writer more than thirty years ago[2] seems to have been generally accepted. Its fundamental principles are (1) that the transporting power of a stream per unit of volume increases with the volume, (2) that transporting power increases with the slope, and (3) that a stream automatically adjusts slope to volume in such way as to equalize its work of transportation in different parts.

In 1892, Davis proposed an explanation of the convexity of hilltops, ascribing it to creep.[3] His article occupied less than a page of *Science*, and may not have attracted the attention it merited. At any rate Fenneman, in a recent discussion of the same subject, makes no mention either of Davis or of creep; and it occurs to me that a restatement of Davis' explanation may be timely.

Fenneman ascribes the convex profile to running water, making a distinction between the behavior of water near hilltops and lower down. As I find it difficult to do justice to his analysis in an abstract, I refrain from a comparison of his hypothesis with that of Davis, but refer the reader, instead, to his article which is in the *Journal of Geology* for November-December, 1908.[4]

The subjoined presentation of the creep hypothesis, while essentially equivalent to Davis', is independent in respect to various details.

A layer of unconsolidated material resting on a gentle slope holds its position (1) because the particles are arranged so as to support one

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[2] *Geology of the Henry Mountains*, p. 116.

[3] W. M. Davis, "The Convex Profile of Bad-Land Divides," *Science*, XX, 245.

[4] N. M. Fenneman, "Some Features of Erosion by Unconcentrated Wash," *Journal of Geology*, XVI, 746–54.

another, and (2) because one particle cannot slide on another without developing friction. Spherical frictionless particles would flow on the faintest of slopes, and subangular frictionless particles would flow on a moderate slope. Whatever diminishes friction promotes flow. Whatever disturbs the arrangement of particles, permitting any motion among them, also promotes flow, because gravity is a factor in the rearrangement and its tendency is down the slope. Violent agitation by an earthquake suspends for the time the structural arrangement, surcharge by water greatly reduces friction, and each of these may cause flow, the flow phenomena being of the land-slide type.

In creep the chief disturbing agencies are expansion and contraction, and these are caused by freezing and thawing, heating and cooling, wetting and drying. If expansion were equal in all directions, and extended indefinitely downward, the arrangement of the particles —or the structure of the formation—would not be affected; but dilatation is resisted in all directions except outward, and expansion in a single direction modifies the structure. The structure is again modified during the ensuing contraction, and during both changes gravity enters as a constant factor tending downhill.

Prominent among other disturbing agencies are plant roots, which alike in growth and decay occasion soil movements; and roots also act on soils when trees are swayed by the wind. Animals promote creep in a more direct way, for as they walk either up or down a slope their feet push harder downhill than uphill.

Consider now the effect of creep on the law of slope. As we are speaking of mature topography only, we may assume the rate of degradation to be the same on all parts of the slope, so that the two lines in the diagrammatic section, Fig. 1, represent the surface of the ground at two epochs. In the interval between the epochs, there has been no transportation at the summit, *D*; but a volume of material equivalent to the prism enclosed by the lines between *D* and *A* has been carried past *A;* and a volume equivalent to the prism between

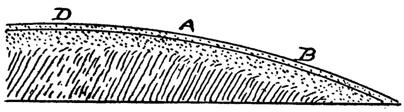

FIG. 1.—Diagrammatic section of a hilltop; indicating the zone of creep, and the position of the surface at two epochs.

D and *B* has been carried past *B*. The quantity passing each point of the slope has been proportional to the distance of the point from the summit. If the depth of the creeping layer has been uniform, the mean velocity of creep has been proportional to the distance from the summit. On the other hand the impelling force, gravity, depends for its effectiveness on slope, being able to cause more rapid flow where the slope is steeper. Therefore, on a mature or adjusted profile, the

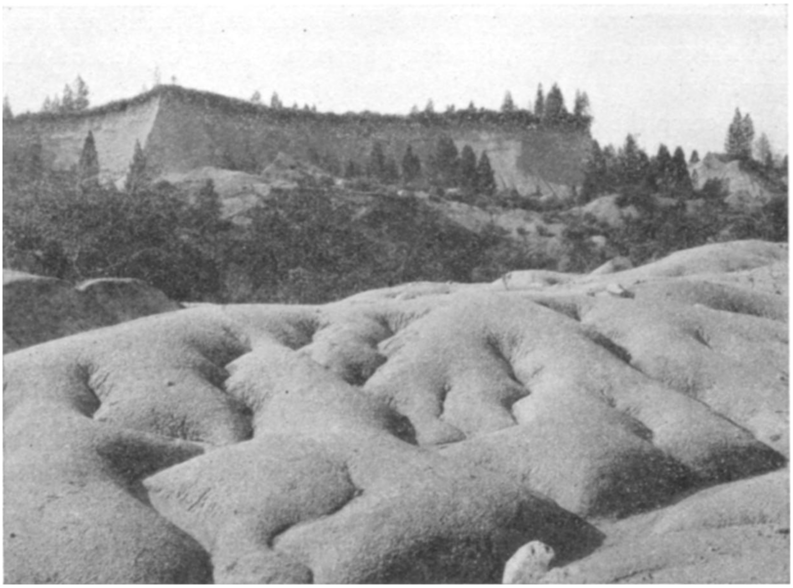

FIG. 2.—Miniature hills, illustrating the convexity of divides and interstream ridges.

slope is everywhere just sufficient to produce the proper velocity. It is greatest where the velocity is greatest, and therefore increases progressively with distance from the summit. In other words the normal product of degradation by creep is a profile convex outward.

If soil creep and carriage by water are the only important processes of transportation operative in a region of maturely sculptured hills, the above analysis seems adequate. On the upper slopes, where water currents are weak, soil creep dominates and the profiles are convex. On lower slopes water flow dominates and profiles are concave. Other factors may be mentioned, but it is probable that they acquire prominence only in special cases.

One of the mentionable factors is wind, which is no respecter of slopes, working as readily uphill as down. Another is rain beat. The two have this in common: that for each locality they have a dominant direction, so that any direct influence they may have on topographic expression tends toward asymmetry.

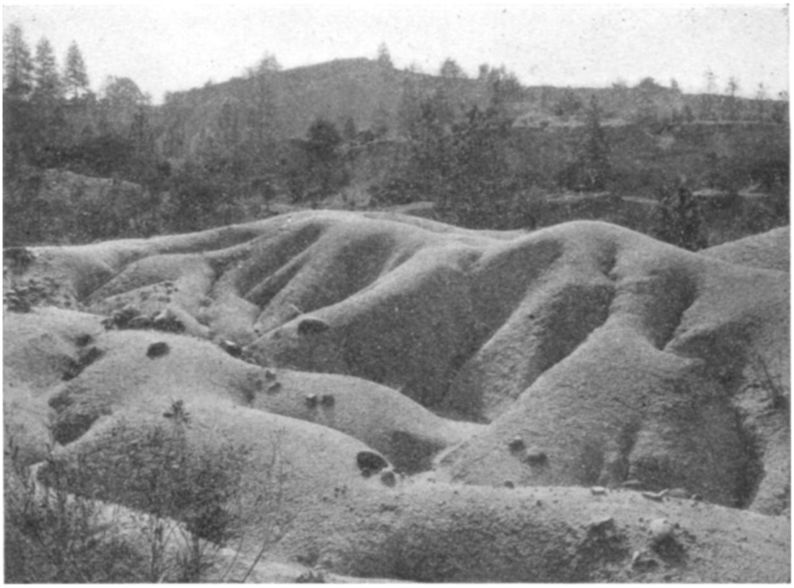

FIG. 3.—Miniature hills, illustrating the convexity of divides.

There is an indirect effect of rain beat due to its combination with water flow and this follows the direction of water flow. When raindrops beat heavily on the upper slopes there is usually also a diffused flow of water. Particles disturbed by the drops are momentarily suspended by the flowing water and drifted down the slope. Near the summit such transportation is favored by the shallowness of the water sheet but restricted by the slowness of the current. Lower down it is favored by more rapid current but restricted by depth of water, which lessens the effect of impact. Whether the ordinary result is greater transportation near the divides, tending to produce a convex profile, or greater transportation on lower slopes, tending to produce a concave profile, is not easy to see.

As wind and rain beat are effective only on bare surfaces and surfaces imperfectly clothed by vegetation, while convex hilltops are found alike in forested regions, prairies and deserts, it is evident that their work is not of prime importance in this connection. Soil creep is omnipresent and appears to be competent.

FIG. 4.—Miniature hills, illustrating the convexity of divides.

The development of gullies on convex slopes when vegetal protection is removed, does not import a transformation to concave slopes and acute water partings, but merely a change in what Fenneman aptly calls the texture of the topography—a reduction of the scale of the drainage pattern and hill pattern. The removal of vegetation gives water flow greater velocity, thereby enlarging the domain of stream sculpture, with associated concave profiles, and reducing the domain of creep and convexity.

Figs. 2, 3, and 4 show mature hill forms developed in homogeneous material. They occur on the floors of hydraulic gold mines at

Nevada City, California. The washing away of the auriferous gravels laid bare tracts of decomposed granite in which the feldspars are largely changed to kaolin, and for about twenty years these have been exposed to the elements. There can be little question that here the convexities are due to creep; and the miniature topography illustrates strikingly the contrast between creep and stream work; but the conditions are not so near to normal as to make the forms fully repre-

FIG. 5.—Erosion and sculpture by the beating of raindrops. The material is regolith, exposed in a road cutting. The rain was driven by a strong wind so as to strike the ground in an obliquely ascending direction, from right to left.

sentative. The kaolin is so cohesive when wet as to tolerate slopes far above the "angle of repose," and this leads to an exaggerated expression of the convex profile, shown especially in Fig. 2; and in the other examples there is reason to believe that the positions of gullies were largely determined by shrinkage cracks.

Fig. 5 illustrates the power of raindrop impact to attack unprotected surfaces of waste. In ordinary examples of rain sculpture the lesson is conveyed by the presence of pillars of earth each capped by a pebble or other protective particle, but it is not easy to determine whether the work of sculpture consumed little or much time. In this particular case the raindrops were driven by so violent a wind as to be swept *up* a slope. The wind in question blew for but a fraction of an hour, but in that brief time the rain beat developed on the earthbank (of regolith) a complete system of furrows and ridges parallel to the direction of the wind.