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THE CONVEX PROFILE OF BAD-LAND DIVIDES.

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IN Mr. Gilbert's analysis of land sculpture, constituting chapter V. of his "Geology of the Henry Mountains," he explains why the surface of an eroded region possesses slopes that are concave upwards and steepest near the divides, and shows that it is for the reasons there stated that mountains — that is, mature and well-sculptured mountains, such as are of ordinary occurrence — are steepest at their crests (p. 116). The *arêtes* of the Alps illustrate this perfectly. Gilbert calls this generalization the "law of divides."

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But in discussing the forms assumed by eroded bad-lands, or arid regions of weak structure with insignificant variety of texture, he finds an exception to the law of divides. The two lateral concave slopes of a bad-land ridge do not unite upwards at an angle, forming a sharp divide, but are joined in a curve that is convex instead of concave upwards. "Thus in the sculpture of the bad lands there is revealed an exception to the law of divides, — an exception which cannot be referred to accidents of structure, and which is as persistent in its recurrence as are the features which conform to the law, — an exception which in some unexplained way is part of the law. Our analysis of the agencies and conditions of erosion, on the one hand, has led to the conclusion that (where structure does not prevent) the declivities of a continuous drainage-slope increase as the quantities of water flowing over them decrease; and that they are great in proportion as they are near divides. Our observation, on the other hand, shows that the declivities increase as the quantities of water diminish, up to a certain point where the quantity is very small, and then decrease: and that declivities are great in proportion as they are near divides, unless they are *very* near divides. Evidently some factor has been overlooked in the analysis, — a factor which in the main is less important than the flow of water, but which asserts its existence at those points where the flow of water is exceedingly small, and is there supreme" (pp. 122, 123).

downward sloping

It has for some time seemed to me that the overlooked factor is the creeping of the surface soil; and, as I have not seen mention of this process as bearing on the form of the crest-lines of divides, a brief note on the subject is here offered.

The superficial parts of rock-masses are slowly reduced to rock-waste or soil by the various processes included under the term, *weathering*. Unconsolidated materials are in the same way reduced to finer texture near their surface. The loose and often fine material thus provided at the surface is carried away by various processes, of which the chief are moving water, moving air, and occasionally moving ice; but there is an additional process of importance, involving dilatation and contraction of the soil, and in consequence of which not only the loose particles on the surface are transported, but a considerable thickness of loose material is caused to creep slowly down-hill.

Dilatation is caused by increase of temperature, by increase of moisture, and by freezing. Vegetable growth may probably be added to this list. The movements are minute and slow. They are directed outwards, about normally to the surface. Contraction follows dilatation, when the soil cools or dries, or when its frost melts. The movement of the parts is then not inward at a normal to the surface, but vertically downwards, or even downwards along the slope. As the two motions do not counterbalance each other, a slow down-hill resultant remains. This is greatest near the surface, where the dilatations and contractions are greatest; but it does not cease even at a depth of several feet, perhaps of many feet. Hence the down-hill dragging of old-weathered rock, often well shown in fresh railroad cuttings in non-glaciated regions. I presume all this is familiar to most readers; although from the frequent inquiry concerning the means by which valleys are widened it is evident that the creeping process is not so generally borne in mind as that by which running water washes loose material down-hill.

The form assumed by the surface of the land depends largely on the ratio between the processes of washing and creeping. Wherever the concentration of drainage makes transportation by streams effective, the loose material is so generally carried away (except on flood-plains) that the action of creeping is relatively insignificant. But on divides, where drainage is not concentrated but dispersed, the ratio of creeping to washing is large, even though the value of creeping is still small. This is especially the case in regions of loose texture and of moderate rainfall; that is, in typical bad-lands, where the supply of loose surface-material ready to creep is large, and where the loose material is slowly taken away by washing. On the divides of such regions, the surface form is controlled by the creeping process. The sharp-edged divides, that should certainly appear if washing alone were in action, are nicely rounded off by the dilatations and contractions of the soil along the ridge-line. The result thus determined by the slow outward and downward movements of the particle might be imitated in a short time by a succession of light earthquake shocks.

Mr. Gilbert has himself given several beautiful illustrations o the close dependence of sharp or rounded divides on rainfall structure remaining constant. If the rainfall should increase i bad-land regions, would not all their divides become sharper and if the rainfall were continuous, so as to carry away every loo particle as soon as it is loosened, would not the divides assume the sharp ridge-line expected from Mr. Gilbert's analysis but no found in the actual arid bad-land climate? In the eastern an well-watered part of our country, I have often seen clay-bank much more sharply cut than the equally barren surface of th western bad lands; but even on clay-banks, the minute divide between the innumerable little valleys are not knife-edge sharp they are rounded when closely looked at. Perhaps they ar sharper in wet weather and duller in dry spells.

If rainfall remain constant and structure vary, then the harde the structure, the less the supply of soil for creeping and th sharper the divides; the weaker the structure, the more plentifu the supply of soil for creeping and the duller the divides. Numerous examples of this variation might be given.

Key?

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THE CONVEXITY OF HILLTOPS[1]

G. K. GILBERT

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.

Henry Mts *

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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[1] Published by permission of the Director of the U. S. Geological Survey.

[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

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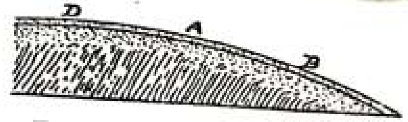

FIG. 1.—Diagrammatic section of a hilltop, indicating the zone of creep, and the position of the surface at two epochs.

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 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.

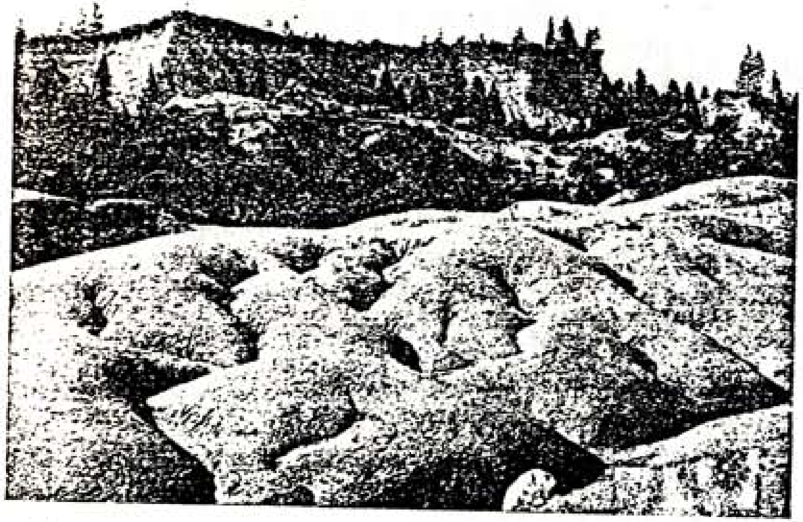

FIG. 2.—Miniature hills, illustrating the convexity of divides and interstream ridges.

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.

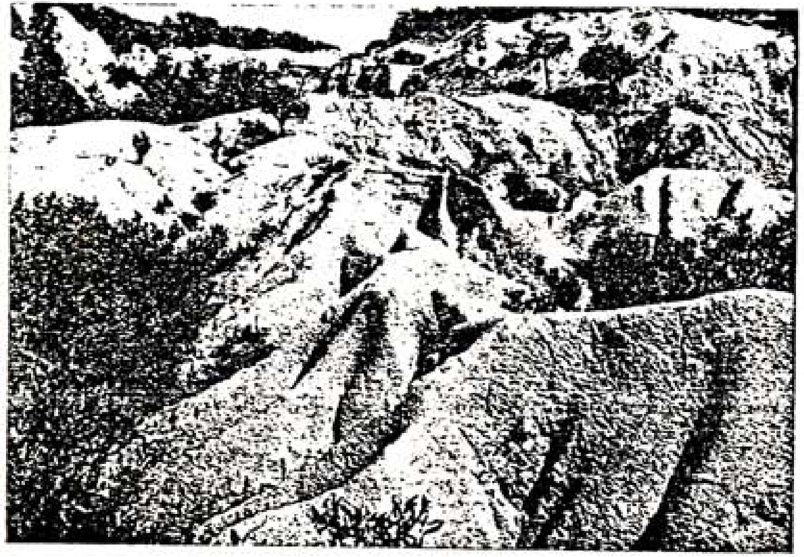

Fig. 4.—Miniature hills, illustrating the convexity of divides.

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 representative. 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.—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.

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.