Origin of Steps on Loess-Mantled Slopes

By JAMES C. BRICE

CONTRIBUTIONS TO GENERAL GEOLOGY

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By James C. Brice

ABSTRACT

Steps that consist of bare scarps and sod-covered treads have developed in many places on steep loess-mantled slopes in southern Nebraska, western Iowa, and northwestern Missouri. The steps are retreating upslope as the sod-capped scarps are undercut by sheetwash. Sediment production appears to be much greater from stepped slopes than from smooth slopes, and understanding of the origin of steps should be useful in planning measures for the control of slope erosion. Several hypotheses of origin are examined, and evidence is presented to show that the steps originate as low sod scarps which rim bare patches in the sod cover; these scarps increase in height by upslope retreat.

INTRODUCTION

Stepped slopes in Kansas have been described by Frye and Leonard (1949); Hadley and Rolfe (1955) and Weaver and Albertson (1944) have described such slopes in eastern Colorado, as have Kay and Apfel (1929) in western Iowa. Sharpe (1938), who discusses stepped slopes in connection with slumping, lists references in which stepped slopes in England, Scandinavia, and elsewhere are described. Steps on the Great Plains are commonly called "catsteps," but elsewhere many names, both common and technical, have been applied, of which Sharpe prefers the name "terracettes." Stepped slopes of both tropical and middle latitudes appear to be stable relative to the more transitory stepped slopes associated with solifluction in cold climates. In general, most stepped slopes appear to be rather steep, and the steps are developed on unconsolidated mantle that has a connected cover of vegetal growth. Steps on slopes ordinarily have a superficial resemblance to the paths of grazing animals, but most authors have concluded that some type of slumping, perhaps aided in some localities by animals, has been mainly responsible for step development. The steps discussed here were first observed by the writer in 1953 during an investigation of gully erosion in the Medicine Creek drainage basin, Nebraska (fig. 5). Observation of steps was continued, in connection with other work, in the Medicine Creek area during the summers of 1955 and 1956; and steps in the loess hills bordering the Missouri River in western Iowa and northwestern Missouri were studied for several days in the spring of 1956. Evidence is presented to show that, in the region studied, most steps begin as low sod scarps which rim bare patches in the sod cover and which increase in height by upslope retreat.

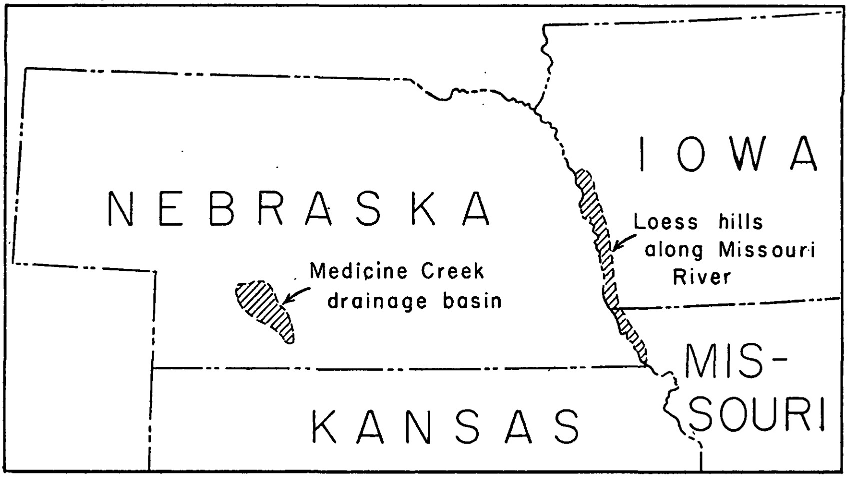


FIGURE 5.—Location map. Areas described in this report are shaded.

STEPPED SLOPES IN SOUTHERN NEBRASKA, WESTERN IOWA, AND NORTHWESTERN MISSOURI

Most steps in the Medicine Creek basin are developed on steep side slopes of minor tributaries or on the steep slopes that appear more rarely along major tributaries. The dendritic drainage pattern is incised into a mantle of loess that has an average thickness of about 75 feet, so that nearly all the valley sides are underlain by loess to a depth of several tens of feet. The steps consist of bare scarps and nearly horizontal or downhill-sloping treads covered with sod (pls. 2*A* and 3*A* and fig. 6). The scarps show a general conformity to slope contours, although some slant at a low angle and the courses of most are marked by minor irregular bends that curve either up or downslope. In general, scarps higher than about one foot have distinctly more regular trends than do lower scarps. The length of individual scarps along the slope is generally limited to a few feet or tens of feet, although some scarps extend for about a hundred feet. The scarp height for different steps ranges from a few inches to about 10 feet, and most steps do not end abruptly but taper out at either end by a gradual decrease in height. Where low sod scarps

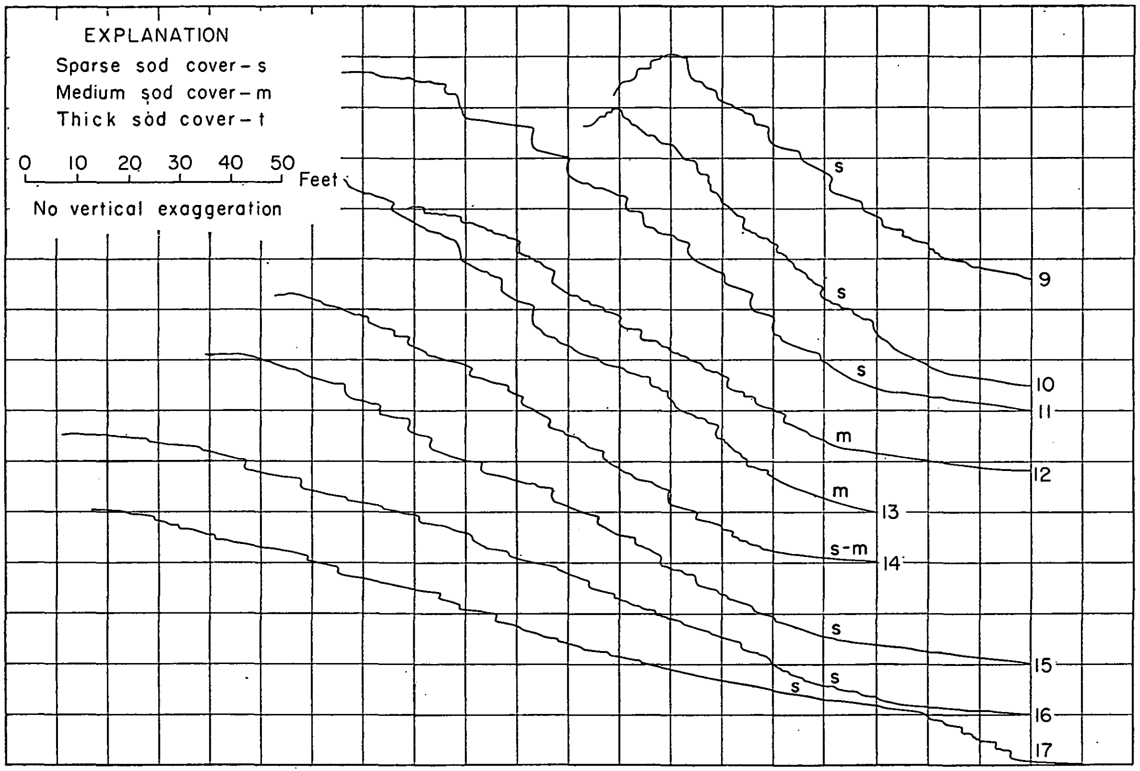


FIGURE 6.—Measured profiles of stepped slopes in the Medicine Creek drainage basin, Nebraska. 9–16, slopes at upper end of Dry Creek, Lincoln County, Nebr.; 17, valley-side slope of Dry Creek at Nebr. Hwy. 23 bridge, Frontier County, Nebr.

face inward around the periphery of a nearly circular break in the sod cover, the downslope-facing scarp is distinctly higher than the upslope-facing scarp; the difference in height is attributed to the flow of sheetwash over the sod cap of the downslope-facing scarp and to the consequent undercutting of the base of the scarp.

Along the Missouri River and its tributaries in western Iowa and northwestern Missouri (fig. 5), steps are developed on many of the steeper slopes, but in general the steps of this region are subdued and are a less conspicuous element of the topography than in western Nebraska. The valley sides are underlain by a thick mantle of loess that is essentially similar to the loess of western Nebraska. Steps are not present on the loess hills at St. Joseph, Mo., nor were they observed at any place along the Missouri River between St. Joseph and St. Louis, Mo.

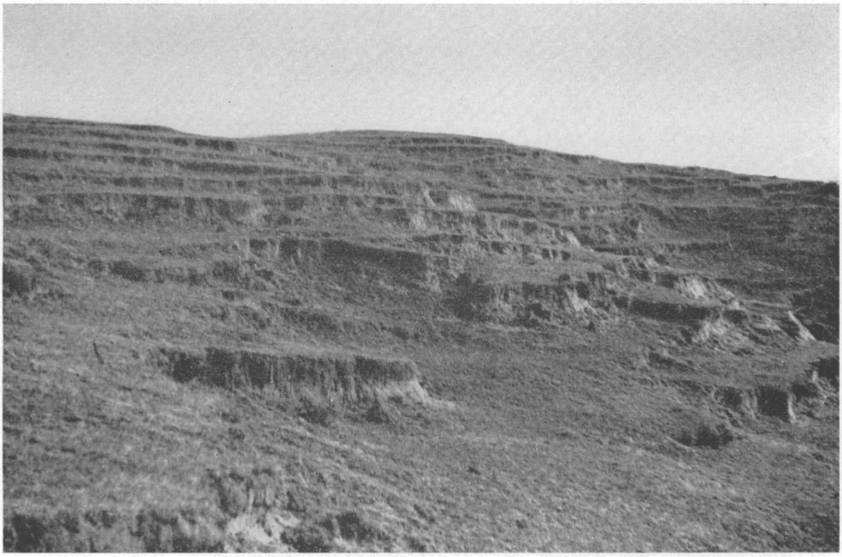
Inasmuch as stepped slopes were observed only on grasslands, the nature of the grasses should be considered. The Medicine Creek basin lies on the broad transitional boundary between the short grass region to the west (plains grassland) and the tall grass region to the east (prairie grassland). In eastern Nebraska and western Iowa, tall grasses form the climax community both on upland and on valley sides. In the Medicine Creek basin, the climax community evidently consists predominantly of midgrasses (with an understory of short grasses) on the uplands and of tall grasses on the valley bottoms. Big bluestem (*Andropogon furcatus*) is a prominent tall grass in both Nebraska and Iowa, little bluestem (*Andropogon scoparius*) and side-oats grama (*Bouteloua curtipendula*) are among the abundant midgrasses, and buffalograss (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*) are abundant short grasses. Drought and overgrazing lead to an increase of short grasses relative to long grasses and midgrasses. Each of the abundant native species of grass may form a dense, thick, and continuous sod, although the bluestems and blue grama have, under some conditions, a tendency to form separate bunches. Maximum height of big bluestem is about 6 feet; little bluestem, about 3 feet; and buffalograss, about 6 inches. Maximum depth of the root system is about 8 feet for big bluestem and about 5 feet for buffalograss and blue grama. Grass height and depth of root system depend on the vigor of the grasses, which is in turn influenced by available moisture and by degree of grazing.

Climax vegetal communities have not prevailed continuously during the erosional history of the region studied, but instead the uplands and valley sides have been periodically covered with short grasses that formed a sod whose depth and continuity varied with degree of deficiency in precipitation. Some evidence as to the condi-

A. STEPPED SLOPES IN THE MEDICINE CREEK DRAINAGE BASIN, LINCOLN COUNTY, NEBR.

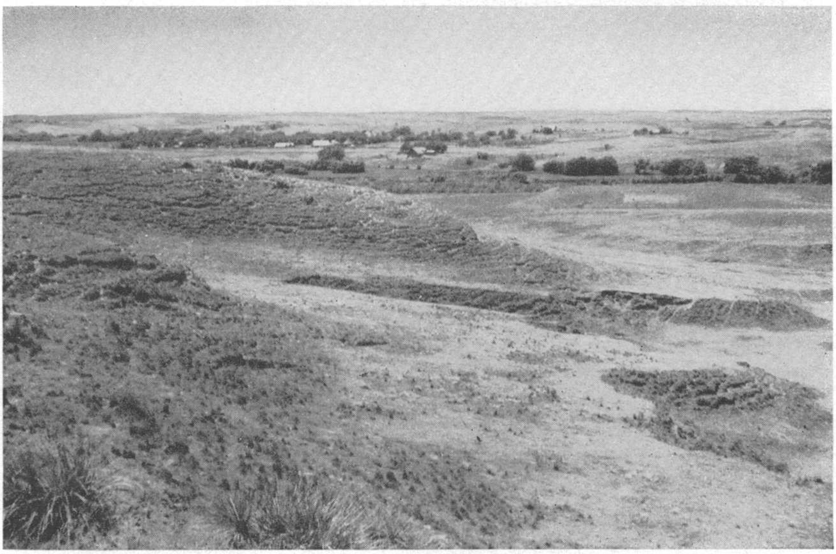
B. VALLEY-SIDE SLOPE OF MEDICINE CREEK AT STOCKVILLE

Steps are developed both above and below the smooth 12-degree slope, which is the surface of a Wisconsin terrace.



A. STEPS ON MISSOURI RIVER BLUFFS AT CRAIG, MO.

Note sod clumps fallen from scarps near center of photograph.



B. LOW SOD SCARPS ON 10-DEGREE SLOPE

These represent an initial stage in development of steps. Scarp in foreground is about 5 inches high. Medicine Creek drainage basin, Nebraska.

tion of grasslands in the Medicine Creek basin immediately before white settlement, which took place mainly after 1872, was found in notes made during the period 1869–72 by surveyors for the General Land Office.[1] During this period, the uplands and valley sides were covered with a sparse growth of short grasses, and the valley bottoms were covered with a thick growth of tall grasses. Such conditions also prevailed during the moisture deficient period of 1953–56, when field notes for the present report were made. Since 1872, upland grasslands in the Medicine Creek basin have been almost wholly converted to cultivated fields, and valleys sides and bottoms have been either moderately or excessively grazed.

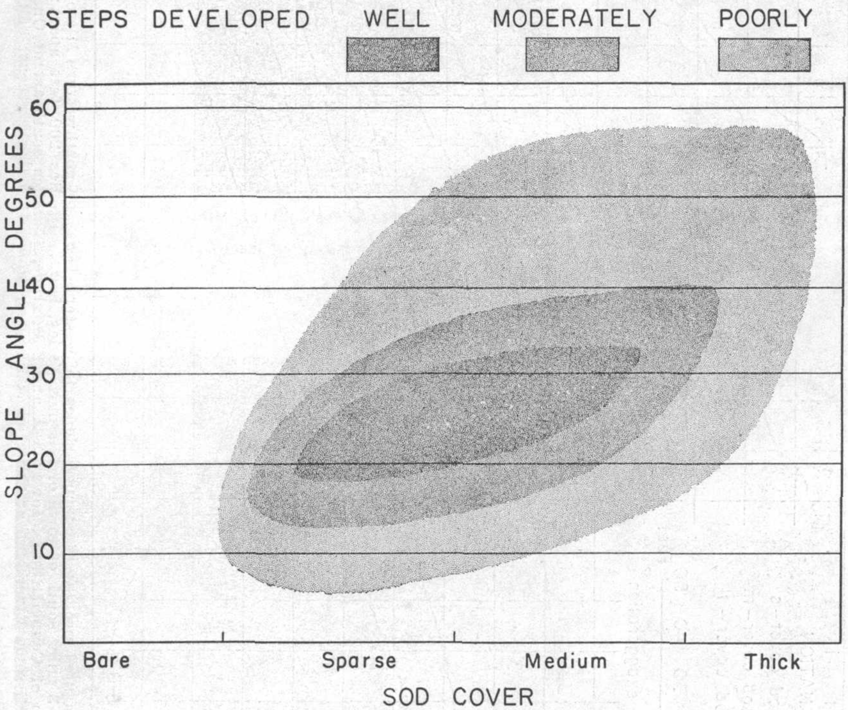


FIGURE 7.—Relation of step development to slope angle and sod cover.

The relation of step development to slope angle and condition of sod cover is illustrated diagramatically in figure 7, and plate 2B shows the relation between slope angle and step development as seen in the field. The sod is classified as thick if the ground surface is less than 25 percent bare and if the grass is mostly higher than 6

[1] Field notes of survey, on file at the Dept. of Educ. Lands and Funds, State Capitol, Lincoln, Nebr.

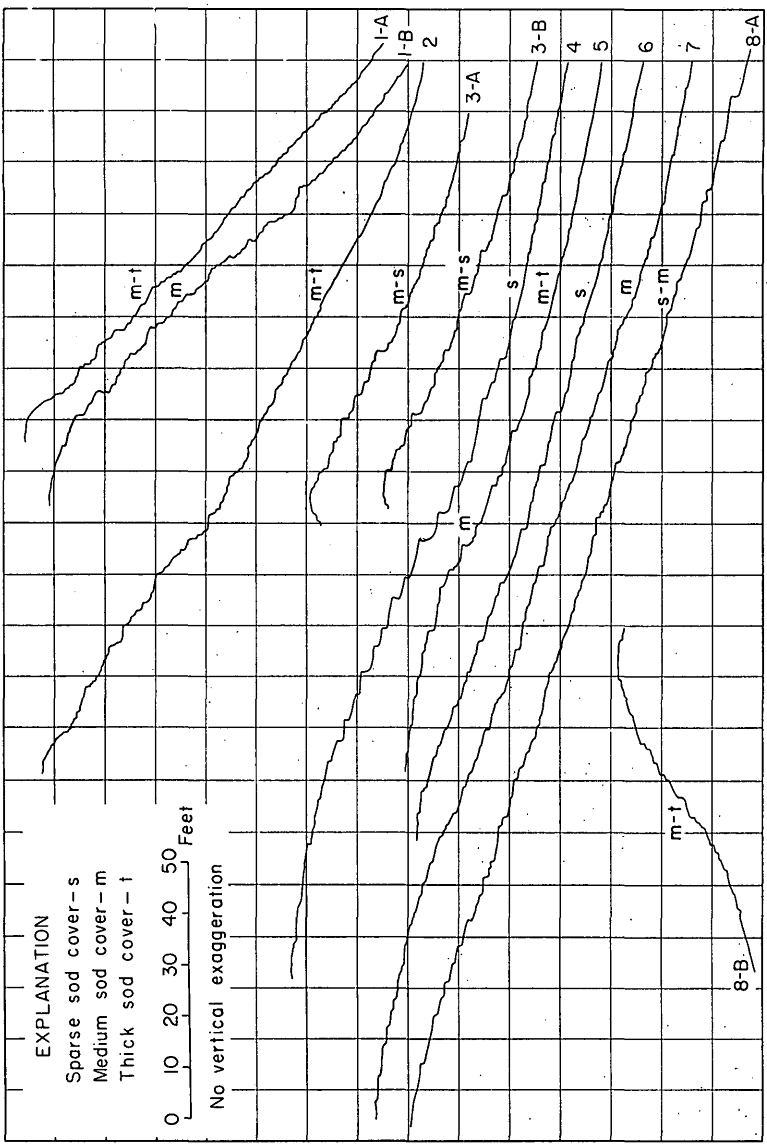


FIGURE 8.—Measured profiles of stepped slopes in western Iowa and northwestern Missouri. 1–A and 1–B, Missouri River bluff 3 miles south of town of Missouri Valley, Iowa. Profiles 200 feet apart; 2, Missouri River bluff 5 miles south of Council Bluffs, Iowa; 3–A and 3–B, slope, 15 miles southeast of Onawa, Iowa. Profiles 20 feet apart; 4, Missouri River bluff at Craig, Mo.; 5 and 6, slopes 12 miles southeast of Onawa, Iowa; 8–A and 8–B, slope at Moorhead, Iowa.

inches, as medium if the ground surface is 25 to 50 percent bare and if taller slumps of grass are scattered about, and as sparse if the ground surface is more than 50 percent bare and if no tall clumps of grass are present. Steps are considered to be well developed where the scarps average a foot or more in height, are nearly vertical, are continuous for several tens of feet along the slope, and are present over most of the slope (pls. 2*A* and 3*A*). On thickly sodded slopes, scarps are neither high nor continuous and tend to have overhanging clumps of sod that may reach nearly to the tread below. On steep and sparsely sodded slopes, scarps have sloping and irregular profiles and most of the treads are sloping. As shown by figures 5–7, steps are best developed on 18- to 33-degree slopes that have a sparse to medium sod cover. The detailed profiles of stepped slopes in Nebraska, Iowa, and Missouri were measured with a stadia rod and with a hand level that was equipped with stadia hairs and mounted at eye height on a staff. The stadia rod was read to the nearest tenth of a foot, and horizontal distances were measured with a tape or read to the nearest foot by means of the stadia hairs.

HYPOTHESES OF ORIGIN

SLUMPING

According to Sharpe (1938, p. 74) the most common general cause for the development of steps appears to be typical slumping that results from slippage along deep-seated curved surfaces. Steps on the slopes of western Iowa, in the same area as the slopes of figure 8, are attributed by Sharpe to slumping and by Kay and Apfel (1929) to slippage of individual blocks along vertical joint planes in the loess. Sharpe's evidence for origin by slumping is the association of steps on the steeper slopes with larger land-slide movements and with crescentic scarps that show the characteristics of slump.

Field evidence of external conditions necessary for slumping were rarely observed on stepped slopes by the writer, nor do the slopes ordinarily show any internal or external evidence of mass movement. An important external cause of slumping is removal of support downslope from the slumped block. The lower parts of most stepped slopes are not undercut by streams or any other agent, but instead they grade smoothly into the adjoining valley floor. Slumping is ordinarily manifested by a crescentic scarp, by a backward rotation of the top of the slump block, and by a bulge in the slope profile downslope from the scarp. Such evidence of slumping was observed on some of the steeper slopes in Nebraska and Iowa, but not on slopes where steps are best developed. Treads on stepped slopes generally show no backward rotation, and no bulges appear on the profile either downslope from the scarps or beyond the toe of the slope. If mass movement of any sort is involved in the development of steps, fence lines placed normal to the steps should reveal some dislocation. Three such fence lines on stepped slopes were found and examined closely. Although farmers are vague about the age of fence lines, weathering of fence posts indicated an age of at least 10 years. No evidence of horizontal dislocation or of tilting was found. As for internal evidence of slumping, deep sections cut across stepped slopes by gullying revealed no evidence of internal movement. It is possible that slip planes are present but not visible because the loess is not stratified.

If the steps originate by slumping, instability of the slope prior to slumping should be indicated by the methods of soil mechanics; and, therefore, a slope-stability analysis was made, based on measured physical properties of loess and on assumed weather conditions that should be most favorable for slumping. Values of density, cohesion, friction angle, and permeability have been measured for the loess of this region by the Denver Earth Laboratory of the Bureau of Reclamation in connection with construction projects in Kansas and Nebraska (Holtz and Gibbs, 1952; Clevenger, 1956). Some of the loess samples on which Bureau of Reclamation measurements were made are from the Medicine Creek basin at the site of Medicine Creek Dam. To insure further that the Bureau of Reclamation samples were representative of loess in the Medicine Creek basin, density measurements and size analyses of loess samples collected from different parts of the basin were made by the writer for comparison. All physical properties of loess described here apply to unweathered loess. Influence of the surface zone of weathering is considered to be insignificant because this zone is weakly developed on stepped slopes that were studied. Only the top 2 or 3 inches is darkened by organic matter, and depth of carbonate leaching is less than 4 inches.

Densities of Medicine Creek loess samples, as determined by the writer, and of western Iowa loess samples, as determined by D. T. Davidson and associates at Iowa State College, are available for comparison with Bureau of Reclamation samples. The writer collected six trimmed blocks of Peorian loess in areas where steps are developed and determined in-place density by coating the blocks in paraffin and weighing in water and in air. Mean density of these blocks was 88 lb per cu ft (pounds per cubic foot), and the range was 81.5 to 93 lb per cu ft. Determinations of in-place densities of 63 samples of valley-fill silt from Dry Creek, collected by means of cylindrical metal samplers and measured by the Geological Survey in Lincoln, showed a mean dry density of 77 lb per cu ft and a range of 61.2 to 97.3 lb per cut ft. Properties of western Iowa loess, in the region where stepped slopes are well developed, have been thoroughly investigated by D. T. Davidson and associates. In-place density (on an oven-dry basis) of western Iowa loess ranges from about 70 lb per cu ft near the surface to about 90 lb per cu ft at depth (Davidson, Handy, and Chu, 1953). Mean in-place densities of loess samples of comparable size distribution, as measured by the Bureau of Reclamation, was about 85 lb per cu ft. For the slope-stability analysis, a mean density of 77 lb per cu ft was assumed because a determination of the minimum safety factor was desired; the shearing strength of loess decreases with decreasing density.

Size distribution of Medicine Creek loess was determined for comparison with Bureau of Reclamation samples, although variations of particle size within the fine sand and silt range are evidently not critical factors in development of stepped slopes. Stepped slopes were observed on sand at the border of the sandhills, where median diameter of the sand is 100 microns, and also observed on loess in all parts of the basin. Median diameter of loess is about 40 microns near the Platte River and decreases to about 30 microns in the southern part of the basin. Size analyses on 36 samples collected from all parts of the basin were made by using a combination of sieve method and pipette method. Sodium metaphosphate was used as a dispersant. Means of the 36 size analyses are: fine sand (125 to 62 microns), 16 percent; silt (62 to 5 microns), 70 percent; and clay (less than 5 microns), 13 percent. Most loess samples showed only a trace of sand coarser than 125 microns. X-ray diffractometer analyses were made, under the direction of W. D. Johns at Washington University, on the <2-micron fraction of 2 loess samples, which was found to consist mainly of montmorillonite and small amounts of illite, chlorite (or kaolinite), quartz, and calcite. The median diameter of western Iowa loess is about 30 microns, and the clay fraction constitutes about 16 percent of the loess (Davidson, Handy, and Chu, 1953; Davidson and Handy, 1952). The grain-size distribution of Medicine Creek loess and of western Iowa loess is similar to that of loess samples on which Bureau of Reclamation measurements were made.

The following physical properties of Missouri River basin loess, based on data published by Holtz and Gibbs (1952) and by Clevenger (1956), are used in the slope-stability analysis:

Density in place of dry loess	lb per cu ft	77
Of loess at 10-percent moisture	lb per cu ft	85
Of loess at 25-percent moisture	lb per cu ft	96

Cohesion of loess in place at 10-percent moisture	psf	1, 728
Of loess at 25-percent moisture	psf	432
Of highly wetted loess		no cohesion
Friction angle (coefficient of friction 0.62)		32 degrees
Permeability of undisturbed dry loess	ft per day	.8

The slope-stability analysis was made by the Swedish method of slices, in which the assumption is made that the surface of failure beneath a slump on a slope is represented in cross section by the arc of a circle and that the slumped segment rotates about point 0, the center of the circle (fig. 9). The segment was divided into vertical slices of equal width, and the forces acting on each slice were determined graphically. The loess is assumed to be homogeneous, and the factor of neutral pressures was not taken into account because field studies in the Medicine Creek basin show that the ground-water table is well below the base of the slopes being considered. Stability of a slope, or possibility of failure along an arc, may be expressed by a factor of safety, f. s.:

$$\text{f.s.} = \frac{\text{shearing resistance}}{\text{shearing force}} = \frac{cl + \Sigma N \tan \phi}{\Sigma T}$$

where

c = cohesion
l = length of arc
N = normal component of the weight of a slice
T = tangential component of the weight of a slice
ϕ = angle of internal friction

If shearing resistance is equal to shearing force, the factor of safety for a particular arc is equal to 1, and failure should not occur. Where the factor of safety is less than 1, failure is considered to be probable. For engineering purposes, a factor of safety of 1.5 is considered to be ample.

If steps result from failure by slumping, their positions on the slope indicate that either "slope" failures, represented by *A* and *C* in figure 9, or "toe" failures, represented by *B* and *D*, are responsible. Slopes of 25 and 45 degrees were chosen for analysis because the 25-degree slopes exhibit well-developed steps but no field evidence of slumping; whereas the 45-degree slopes exhibit poorly developed steps and, in places, crescentic scarps and profile bulges diagnostic of slumping. Positions of circular arcs representing possible failure surfaces on the slopes are determined by location of steps, by observations of actual slumps on steeper slopes, and by trial-and-error determination of the arc having the lowest factor of safety.

On the 45-degree slope (fig. 9, *A* and *B*), both slope and toe arcs have high factors of safety at 10-percent moisture and at 25-percent

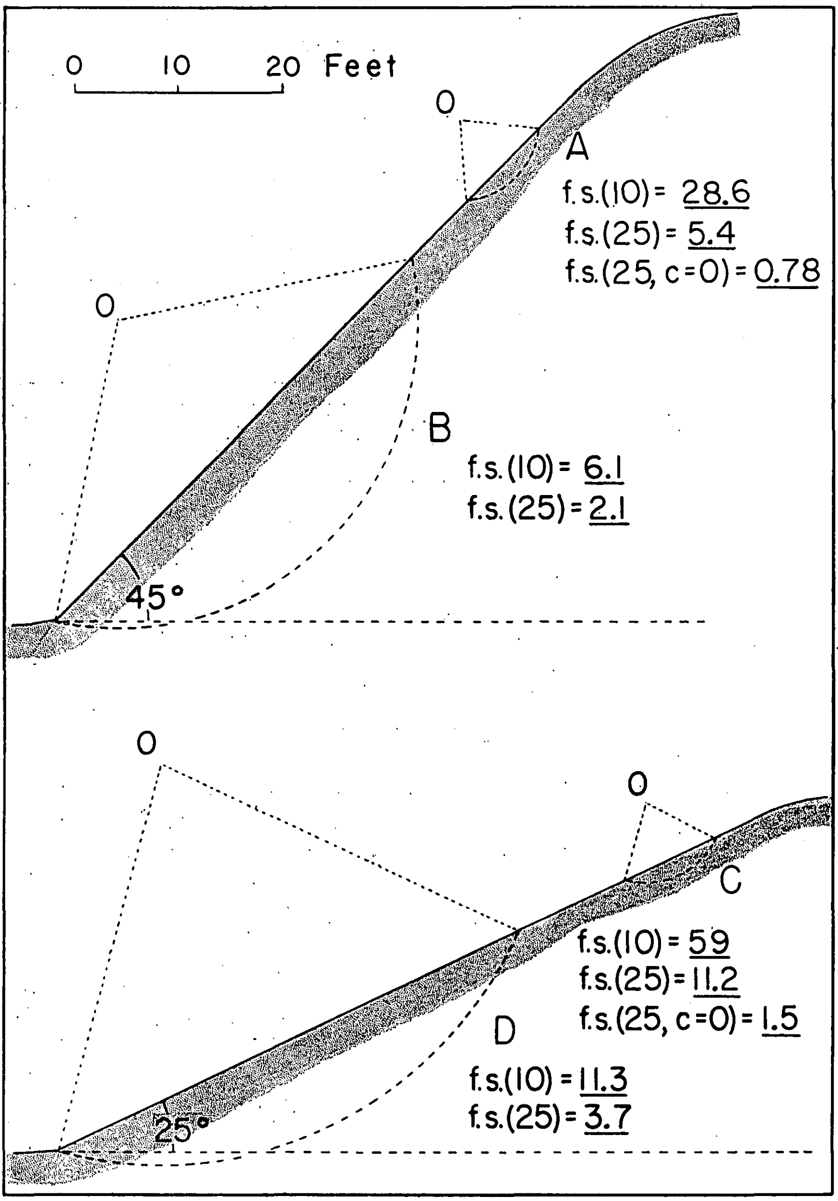


FIGURE 9.—Safety factors, computed by Swedish method of slices, of failure arcs on slopes underlain by loess. Numbers in parentheses are moisture content expressed in percent of dry weight; c represents cohesion.

moisture. However, the arc of *A* is only 3 feet below the surface, and loess could become saturated to that depth under unusual weather conditions. Such saturation would reduce the cohesion to zero and the factor of safety to 0.78, and failure by slumping would be probable. Shallow-slope failures such as *A* were observed on 45-degree slopes, and such failures probably develop when the loess becomes so saturated that its cohesion is greatly reduced. Graded slopes of 45 degrees probably develop under a thick sod cover that has sufficient binding properties to inhibit shallow slumping. Root systems of vigorous native grasses extend to depths of 5 to 8 feet. When the sod cover is weakened, shallow slumps may occur. Such slumps might be expected on slopes having angles as low as 35 degrees, but only under unusual weather conditions that would cause the loess to become completely saturated to a depth of several feet. Depth of zone of carbonate accumulation may be taken as a long-term index of depth of the periodically moist layer of surface soil; in the Medicine Creek basin the upper part of the zone lies at an average depth of about 30 inches where the soil is well developed.

For the 25-degree slope (fig. 9, *C* and *D*), the arcs have such high factors of safety that slumping seems very improbable. Even if the loess above arc *C* is so highly wetted that its cohesion is reduced to zero, the safety factor of the arc is still 1.5, and failure by slumping seems improbable under any weather conditions. Furthermore, slumping is still less probable for slopes less than 25 degrees, and steps may be well developed on such slopes.

SUBSIDENCE

If a layer of loess underlying a slope were reduced in volume by compaction owing to wetting or by selective removal of fine particles, subsidence might result and give rise to steps. Slippage of blocks of loess along individual joint planes, as proposed by Kay and Apfel (1929) for the origin of steps, would evidently require subsidence. Rubey (1928) has described slumping and steps caused by subsidence near Amarillo, Tex., on well-sodded slopes underlain by Tertiary and Triassic sand and shale. Rubey attributes this slumping to the selective removal of clay and silt particles from bedrock, but the properties of loess are such that the selective removal of fine material from it at the water table seems most unlikely. Moreover, the occasional closed depressions that result from subsidence were not observed on the loess slopes.

Regarding subsidence resulting from wetting and consequent compaction of the loess at depth, available evidence indicates that wetting of loess in the Medicine Creek area does not lead to compaction and subsidence. In the construction of Medicine Creek Dam, moisture content of loess in one area was raised from 12 to 28 percent by construction of artificial ponds in order to induce consolidation. No subsidence was induced in this manner (Clevenger, 1956).

SCARP RETREAT

Field study indicates that low sod scarps represent an initial stage in the development of step scarps and that the low sod scarps are formed by breaks in the sod cover (pl. 3*B*). Such breaks may be caused by drought, by overgrazing, by burrowing of rodents, or by the hoofs of grazing animals that follow paths along the slope contour. Although step scarps of regular trend may originate from irregular breaks in the sod cover (fig. 10), most of the longer and more regular step scarps probably originated from animal paths. Moreover, the steps of some localities conform so nearly to present cowpaths that they appear to have originated from cowpaths since white settlement.

The sod formed by prairie grasses is interrupted by irregular but continuous patches of bare ground where the grass is weakened by drought or by overgrazing. These irregular patches or breaks were observed by the writer in the Medicine Creek basin during the moisture-deficient period of 1953–56; and a detailed description is given by Weaver and Albertson (1944) in connection with studies of effect of the drought of 1933–40 on grasslands in Kansas and Nebraska. The continuous, though irregular, character of the bare patches is considered by the writer to be of great importance in slope erosion because erosion scarps commonly develop at the downslope-facing edges of such patches. Weaver and Albertson also show a photograph (p. 469) of a stepped slope, but make no comment on the steps except for the caption under the photograph, which is as follows:

> Typical broken sod on a steep hillside near Last Chance, Colorado. The slope is irregular and contains many small nearly level depressions into which the water infiltrates. Often they appear as miniature terraces. On this "catstep" type of land, of which there are many thousands of acres, side-oats grama is often common.

Low sod scarps surrounding breaks in the sod cover may be oriented in any direction, but the scarps facing downslope are heightened by sheetwash that flows over the protecting sod cap and removes the more loosely held silt at the base of the cap (pl. 3*B*). At the base of scarps facing upslope, sediment is not removed but instead accumulates. Separate scarps that face downslope and lie at about the same elevation may be joined together to form a continuous low scarp of irregular trend. After erosion by sheetwash has so increased the height of the scarp that the sod cover is undercut, overhanging clumps of sod are detached, and the scarp retreats up and into the slope (pl. 3*A* and fig. 10). As the scarp retreats upslope, the segments more nearly parallel to contour lines retreat more rapidly because these segments receive a greater amount of sheetwash

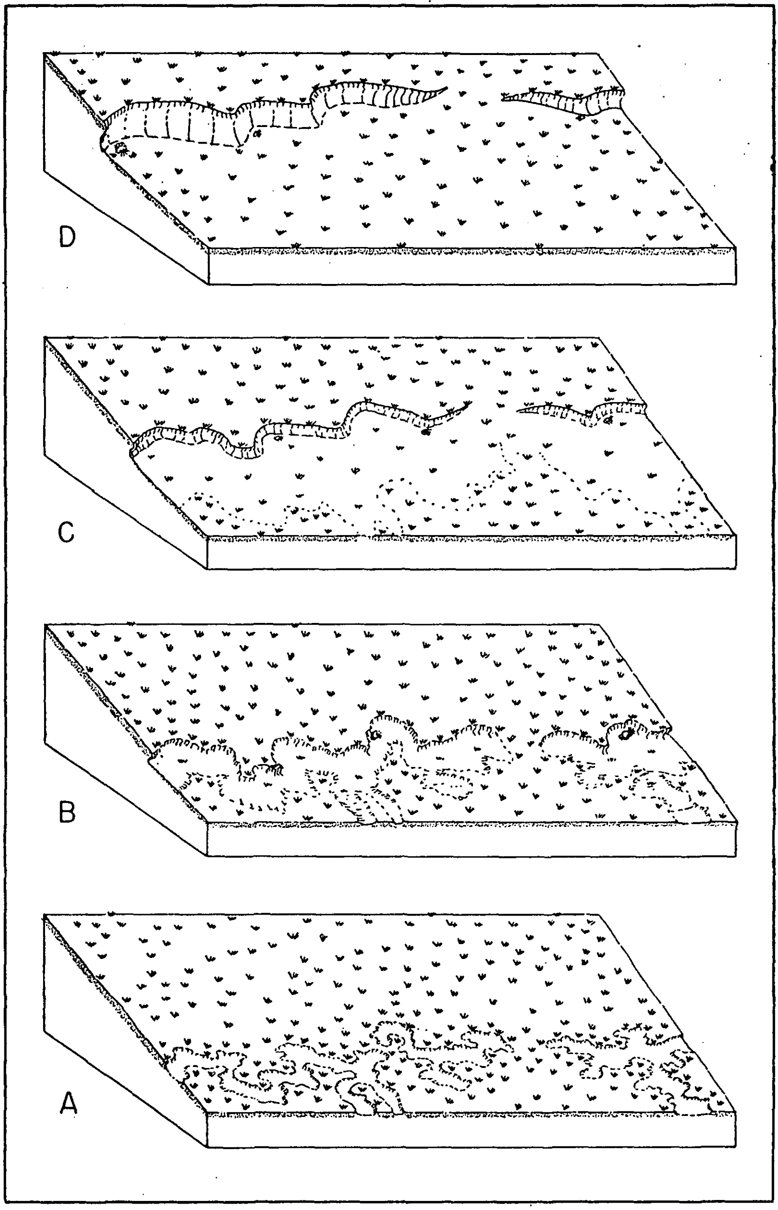


FIGURE 10.—Stages in the development of steps from bare patches in sod cover. *A*, initial stage, low sod scarps rim typical bare patches in sod cover, which has been weakened by drought. *B*, downslope-facing scarp is undercut as sheetwash spills over resistant sod cap and removes loose silt beneath; sod clumps are thereby detached, scarp retreats upslope and is straightened by reduction of salients. Scarps facing in other directions are subdued by accumulation of silt. *C* and *D*, scarp continues to increase in height as it retreats upslope. Detachment of sod clumps is facilitated as base of scarp extends well below sod cap.

per unit of length, and hence the scarp is straightened; moreover, salients are reduced and finally eliminated by scarp retreat from both sides of the salient. Scarps at nearly a common level coalesce further to form longer, more continuous scarps. When the scarps farthest upslope approach the top of the slope, their advance is slowed because of the smaller available quantity of sheetwash. Scarps farther downslope continue to advance up and into the slope, and some may merge with upslope scarps.

In origin and development, the step scarp is considered to be the slope counterpart of the channel scarp or headcut. Both types of scarp originate from breaks in the sod cover. Sheetwash is responsible for the development and retreat of the step scarp, whereas concentrated channel flow is responsible for the development and retreat of the channel scarp. Both channel scarps and step scarps may develop into upland gully scarps that encroach onto the flat upland.

The relations of step development to slope angle and thickness of sod (fig. 7) are explained as follows: Steps are poorly developed on heavily sodded slopes because the sod cover reduces the amount of sheetwash and inhibits the initial development of low scarps. Steps are not well developed on slopes steeper than about 33 degrees because scarp retreat into such steep slopes is very slow and because slumping along shallow curved surfaces may begin at about this angle of slope. On slopes more gentle than about 6 degrees, steps are not developed because of the decreasing effectiveness of sheetwash at this angle of slope and because incipient scarps grow very little by retreating into such gentle slopes.

OTHER HYPOTHESES

Thorpe (1945, p. 276) has proposed that steps on loess-mantled slopes may originate by upslope recession of successive waves of gully walls from intermittent drainageways, but this mechanism is not generally applicable to the steps described here. Slopes of the Medicine Creek basin are graded to a late Wisconsin valley fill that appears as the highest paired terraces along most streams of the region, and the walls of the later channels or gullies have not generally advanced beyond the fronts of these terraces. Also, most of the stepped slopes that were measured have no intermittent gullies in their adjoining drainageways.

Hadley and Rolfe (1955) described steplike features in Wyoming, which they termed "seepage steps" and attributed to seepage at the contact between surficial mantle and weathered bedrock. These seepage steps migrate upslope nearly on contour. This mechanism is not applicable to steps on loess, because the loess is homogeneous and no seepage occurs at the base of the steps.

ROLE OF STEPS IN EROSION AND SEDIMENT YIELD

That a significant quantity of sediment is dislodged by retreat of step scarps is apparent from the clumps of sod that are observed at the base of the scarps and from freshly deposited sediment below slopes on which steps are well developed. Although no means was devised for making reliable measurements of the average rate of retreat of all step scarps, measurements were made of the retreat of small segments of some scarps at the upper end of Dry Creek. During the period 1953–56, the amount of retreat was as much as 3 inches along some narrow segments of scarps, whereas along other segments the amount of retreat was negligible. The maximum rate of retreat is estimated to be about an inch per year. Scarps several feet in height retreat at a slower rate than do low scarps.

An estimate may be made of the sediment eroded annually from step scarps in the Dry Creek basin, which is tributary to the Medicine Creek basin. Stepped slopes occupy about 1.5 square miles of the basin, which has an area of 23 square miles. If the scarps occupy 25 percent of the vertical height of these stepped slopes and retreat at the rate of 1 inch per year, the amount of sediment eroded from the scarps would amount to 9.3 acre-feet per year. Part of this eroded sediment is deposited on the step treads, and part is deposited in the valley bottoms; an undetermined amount is carried out of the basin. This estimate may be compared with the estimated average sediment load of Dry Creek, which is 103 arce-feet per year. The amount of sediment eroded by upland gullies in Dry Creek basin during the period 1937–52, as determined from measurements on air photographs, was 4.5 acre-feet per year.

Erosion by step scarps can be prevented by protection and restoration of the sod cover on slopes. The presence of steps on the slopes of narrow interstream ridges is evidence that sufficient runoff originates on the slope itself for the development of steps; hence, reduction of runoff from cultivated uplands would not prevent erosion by step scarps.

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